CAIE AS Level Chemistry

Paper 2

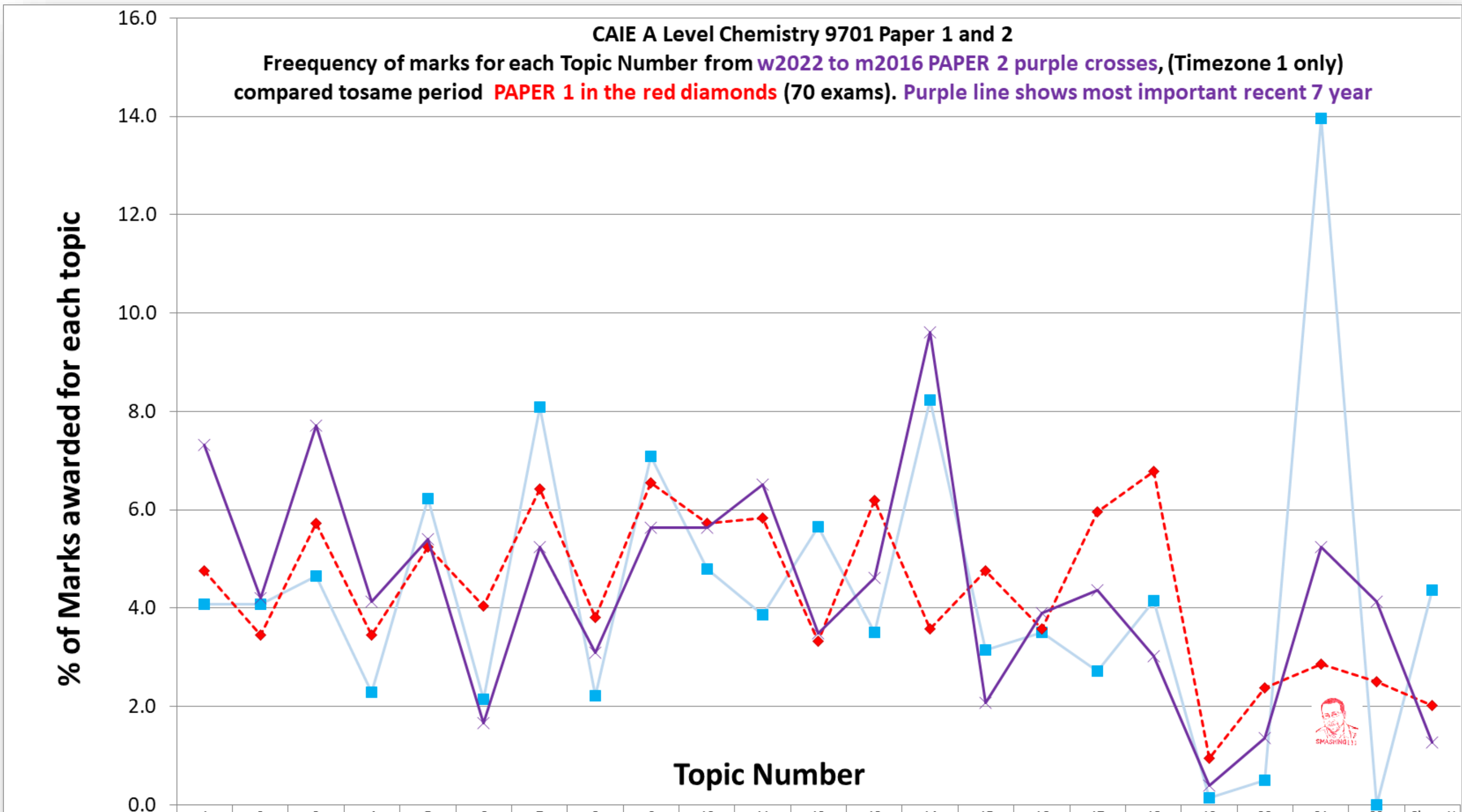
Past Exam Questions

Organised by Topic Number

Summer 2009 to Winter 2022 (35 Papers)

Name: ____________________________

Class: ____________



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Chem X
09w-15w P1+2	4.1	4.1	4.6	2.3	6.2	2.1	8.1	2.2	7.1	4.8	3.9	5.7	3.5	8.2	3.1	3.5	2.7	4.1	0.1	0.5	13.9	0.0	4.4
P1 16m-22w	4.8	3.5	5.7	3.5	5.2	4.0	6.4	3.8	6.5	5.7	5.8	3.3	6.2	3.6	4.8	3.6	6.0	6.8	1.0	2.4	2.9	2.5	2.0
P2 16m-22w	7.3	4.2	7.7	4.1	5.4	1.7	5.2	3.1	5.6	5.6	6.5	3.5	4.6	9.6	2.1	3.9	4.4	3.0	0.4	1.4	5.2	4.1	1.3

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Patrick Brannac

For and electronic version of this Work Book

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Contents

Organising your months in 2024

January						
S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

February						
S	M	T	W	T	F	S
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29		

March						
S	M	T	W	T	F	S
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

April						
S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

May						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

June						
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

CAMBRIDGE
International Education

Cambridge IGCSE™
Cambridge O Level
Cambridge International AS & A Level

Cambridge Final Exam Timetable June 2024

Administrative zone 5

CAIE Chemistry 9701 A Level Chemistry Exam Timetable for *Administrative Zone 5 (Time Zone 2)*:

Paper 1 – AS Chemistry

Tuesday 04 June

	Syllabus/Component	Code	Duration	Session
IG	Drama	0411/13	2h 30m	AM
IG	Design & Technology	0445/33	1h	AM
IG	Design & Technology	0445/43	1h	AM
IG	Design & Technology	0445/53	1h	AM
AS	Accounting (Multiple Choice)	9706/13	1h	AM

	Syllabus/Component	Code	Duration	Session
AS	Chemistry (Multiple Choice)	9701/12	1h 15m	PM

Paper 2 - AS Chemistry

Wednesday 15 May

	Syllabus/Component	Code	Duration	Session
IG	Literature in English	0475/23	1h 30m	AM
IG	Literature in English	0475/33	45m	AM
IG	Literature in English	0475/43	1h 15m	AM
OL	Literature in English	2010/23	1h 30m	AM
AL	Mathematics (Pure Mathematics 3)	9709/33	1h 50m	AM

	Syllabus/Component	Code	Duration	Session
IG	Computer Science	0478/12	1h 45m	PM
IG	French	0520/22	1h	PM
OL	Computer Science	2210/12	1h 45m	PM
OL	French	3015/02	1h	PM
AS	Chemistry	9701/22	1h 15m	PM
AL	Chemistry	9701/52	1h 15m	PM

Paper 3 - AS Chemistry

Thursday 02 May

	Syllabus/Component	Code	Duration	Session
IG	Geography	0460/13	1h 45m	AM

	Syllabus/Component	Code	Duration	Session
IG	Sanskrit	0499/22	1h 30m	PM
IG	Biology (Core)	0610/32	1h 15m	PM
IG	Biology (Extended)	0610/42	1h 15m	PM
IG	Combined Science (Core)	0653/32	1h 15m	PM
IG	Combined Science (Extended)	0653/42	1h 15m	PM
IG	Co-ordinated Sciences (Double Award) (Core)	0654/32	2h	PM
IG	Co-ordinated Sciences (Double Award) (Extended)	0654/42	2h	PM
OL	Biology	5090/22	1h 45m	PM
OL	Combined Science	5129/22	1h 45m	PM
AS	Global Perspectives & Research	9239/12	1h 30m	PM
AS	Chemistry (Practical - Advanced)	9701/33	2h	PM

Thursday 30 May

	Syllabus/Component	Code	Duration	Session
OL	Commerce	7100/23	2h	AM
AL	Sociology	9699/43	1h 45m	AM

	Syllabus/Component	Code	Duration	Session
IG	Accounting (Multiple Choice)	0452/12	1h 15m	PM
OL	Accounting (Multiple Choice)	7707/12	1h 15m	PM
AS	Law	9084/22	1h 30m	PM
AS	Chemistry (Practical - Advanced)	9701/34	2h	PM

Paper 4 (A2 Chemistry)

Wednesday 08 May

	Syllabus/Component	Code	Duration	Session
IG	Information & Communication Technology	0417/13	1h 30m	AM
IG	Global Perspectives	0457/13	1h 15m	AM
AS	Computer Science	9618/13	1h 30m	AM
AS	Information Technology	9626/13	1h 45m	AM

	Syllabus/Component	Code	Duration	Session
IG	English (as an Additional Language)	0472/22	1h	PM
IG	English (as an Additional Language)	0472/42	1h	PM
IG	First Language English (Oral Endorsement)	0500/12	2h	PM
IG	English as a Second Language (Speaking Endorsement)	0510/12	2h	PM
IG	English as a Second Language (Count-in Speaking)	0511/12	2h	PM
OL	English Language	1123/12	2h	PM
AL	Chemistry	9701/42	2h	PM
IG	Latin	0480/13	1h 30m	EV
AS	Thinking Skills	9694/23	1h 45m	EV

Paper 5 (A2 Chemistry)

Wednesday 15 May

	Syllabus/Component	Code	Duration	Session
IG	Literature in English	0475/23	1h 30m	AM
IG	Literature in English	0475/33	45m	AM
IG	Literature in English	0475/43	1h 15m	AM
OL	Literature in English	2010/23	1h 30m	AM
AL	Mathematics (Pure Mathematics 3)	9709/33	1h 50m	AM

	Syllabus/Component	Code	Duration	Session
IG	Computer Science	0478/12	1h 45m	PM
IG	French	0520/22	1h	PM
OL	Computer Science	2210/12	1h 45m	PM
OL	French	3015/02	1h	PM
AS	Chemistry	9701/22	1h 15m	PM
AL	Chemistry	9701/52	1h 15m	PM

Syllabus view (A–Z)

CAMBRIDGE International Education

Cambridge International AS Level

Syllabus/Component	Code	Duration	Date	Session
A				
Accounting (Multiple Choice)	9706/13	1h	Tuesday 04 June 2024	AM
Accounting	9706/23	1h 45m	Thursday 09 May 2024	AM
B				
Biology (Multiple Choice)	9700/12	1h 15m	Tuesday 11 June 2024	PM
Biology	9700/22	1h 15m	Tuesday 14 May 2024	PM
Biology (Practical - Advanced)	9700/33	2h	Thursday 09 May 2024	PM
Biology (Practical - Advanced)	9700/34	2h	Tuesday 28 May 2024	PM
Business	9609/13	1h 15m	Monday 06 May 2024	AM
Business	9609/23	1h 30m	Friday 10 May 2024	AM
C				
Chemistry (Multiple Choice)	9701/12	1h 15m	Tuesday 04 June 2024	PM
Chemistry	9701/22	1h 15m	Wednesday 15 May 2024	PM
Chemistry (Practical - Advanced)	9701/33	2h	Thursday 02 May 2024	PM
Chemistry (Practical - Advanced)	9701/34	2h	Thursday 30 May 2024	PM
Chinese Language (Listening - Multiple Choice)	8238/12	1h	Monday 27 May 2024	PM
Chinese Language (Multiple Choice)	8238/22	1h 30m	Wednesday 29 May 2024	PM
Chinese Language	8238/32	1h 30m	Friday 26 April 2024	PM
Computer Science	9618/13	1h 30m	Wednesday 08 May 2024	AM
Computer Science	9618/23	2h	Friday 17 May 2024	AM
D				
Drama	9482/13	2h	Friday 24 May 2024	AM
E				
Economics (Multiple Choice)	9708/12	1h	Friday 07 June 2024	PM
Economics	9708/22	2h	Friday 10 May 2024	PM
English General Paper	8021/12	1h 15m	Thursday 25 April 2024	PM
English General Paper	8021/22	1h 45m	Monday 29 April 2024	PM
English Language	9093/12	2h 15m	Friday 03 May 2024	PM
English Language	9093/22	2h	Monday 06 May 2024	PM
Environmental Management	8291/13	1h 45m	Friday 26 April 2024	EV
Environmental Management	8291/23	1h 45m	Wednesday 01 May 2024	EV
F				
French Language	8682/23	1h 45m	Wednesday 01 May 2024	AM
French Language	8682/33	1h 30m	Wednesday 29 May 2024	AM
Further Mathematics	9231/13	2h	Monday 06 May 2024	AM
Further Mathematics	9231/33	1h 30m	Friday 24 May 2024	AM
Further Mathematics	9231/43	1h 30m	Wednesday 29 May 2024	AM
G				
Geography (Core)	9696/12	1h 30m	Friday 03 May 2024	PM
Geography (Core)	9696/22	1h 30m	Friday 17 May 2024	PM
Global Perspectives & Research	9239/12	1h 30m	Thursday 02 May 2024	PM
H				
History	9489/13	1h 15m	Friday 03 May 2024	AM
History	9489/23	1h 45m	Friday 10 May 2024	AM

Syllabus/Component	Code	Duration	Date	Session
I				
Information Technology	9626/13	1h 45m	Wednesday 08 May 2024	AM
L				
Language & Literature in English	8695/12	2h	Monday 06 May 2024	PM
Language & Literature in English	8695/22	2h	Wednesday 01 May 2024	PM
Law	9084/12	1h 30m	Tuesday 28 May 2024	PM
Law	9084/22	1h 30m	Thursday 30 May 2024	PM
Literature in English	9695/12	2h	Wednesday 01 May 2024	PM
Literature in English	9695/22	2h	Monday 13 May 2024	PM
M				
Marine Science	9693/13	1h 45m	Friday 26 April 2024	EV
Marine Science	9693/23	1h 45m	Wednesday 01 May 2024	AM
Mathematics (Pure Mathematics 1)	9709/13	1h 50m	Monday 29 April 2024	AM
Mathematics (Pure Mathematics 2)	9709/23	1h 15m	Tuesday 07 May 2024	EV
Mathematics (Mechanics)	9709/43	1h 15m	Tuesday 07 May 2024	AM
Mathematics (Probability & Statistics 1)	9709/53	1h 15m	Monday 13 May 2024	AM
Media Studies	9607/22	2h	Tuesday 07 May 2024	PM
Music (Listening)	9483/13	2h	Monday 20 May 2024	AM
P				
Physics (Multiple Choice)	9702/12	1h 15m	Thursday 06 June 2024	PM
Physics	9702/22	1h 15m	Thursday 16 May 2024	PM
Physics (Practical - Advanced)	9702/33	2h	Tuesday 30 April 2024	PM
Physics (Practical - Advanced)	9702/34	2h	Thursday 23 May 2024	PM
Portuguese Language	8684/02	1h 45m	Tuesday 30 April 2024	EV
Portuguese Language	8684/03	1h 30m	Monday 20 May 2024	EV
Psychology	9990/12	1h 30m	Thursday 25 April 2024	PM
Psychology	9990/22	1h 30m	Tuesday 30 April 2024	PM
S				
Sociology	9699/13	1h 30m	Thursday 09 May 2024	AM
Sociology	9699/23	1h 30m	Friday 17 May 2024	AM
Spanish Language (Listening - Multiple Choice)	8022/13	1h	Monday 13 May 2024	AM
Spanish Language (Multiple Choice)	8022/23	1h 30m	Wednesday 22 May 2024	EV
Spanish Language	8022/33	1h 30m	Monday 06 May 2024	EV
Sport & Physical Education	8386/13	1h 45m	Friday 24 May 2024	AM
T				
Thinking Skills	9694/13	1h 30m	Monday 29 April 2024	EV
Thinking Skills	9694/23	1h 45m	Wednesday 08 May 2024	EV
Travel & Tourism	9395/13	2h	Tuesday 30 April 2024	AM
U				
Urdu Language	8686/02	1h 45m	Monday 29 April 2024	EV
Urdu Language	8686/03	1h 30m	Wednesday 22 May 2024	EV

Cambridge Final Exam Timetable June 2024

Syllabus view (A–Z)

CAMBRIDGE International Education

Cambridge International A Level

Syllabus/Component	Code	Duration	Date	Session
A				
Accounting	9706/33	1h 30m	Tuesday 14 May 2024	AM
Accounting	9706/43	1h	Tuesday 21 May 2024	AM
B				
Biology	9700/42	2h	Tuesday 07 May 2024	PM
Biology	9700/52	1h 15m	Tuesday 14 May 2024	PM
Business	9609/33	1h 45m	Thursday 16 May 2024	AM
Business	9609/43	1h 15m	Monday 20 May 2024	AM
C				
Chemistry	9701/42	2h	Wednesday 08 May 2024	PM
Chemistry	9701/52	1h 15m	Wednesday 15 May 2024	PM
Chinese Language & Literature (Multiple Choice)	9868/12	1h 30m	Monday 27 May 2024	PM
Chinese Language & Literature	9868/22	2h	Friday 26 April 2024	PM
Chinese Language & Literature	9868/32	2h	Monday 29 April 2024	PM

Syllabus/Component	Code	Duration	Date	Session
L				
Law	9084/32	1h 30m	Monday 03 June 2024	PM
Law	9084/42	1h 30m	Wednesday 05 June 2024	PM
Literature in English	9695/32	2h	Tuesday 21 May 2024	PM
Literature in English	9695/42	2h	Thursday 23 May 2024	PM
M				
Marine Science	9693/33	1h 45m	Monday 06 May 2024	AM
Marine Science	9693/43	1h 45m	Friday 24 May 2024	EV
Mathematics (Pure Mathematics 3)	9709/33	1h 50m	Wednesday 15 May 2024	AM
Mathematics (Probability & Statistics 2)	9709/63	1h 15m	Tuesday 07 May 2024	AM
Media Studies	9607/42	2h	Wednesday 22 May 2024	PM
P				
Physics	9702/42	2h	Monday 13 May 2024	PM
Physics	9702/52	1h 15m	Thursday 16 May 2024	PM

Organising your weeks

Week Starting	Wk #	Events	Topic Focus
25-Mar	11		
1-Apr	12		
8-Apr	13	MOCK EXAM(?)	
15-Apr	14		
22-Apr	15		
29-Apr	16	Thur 2nd PM Paper 33 (TZ2)	
6-May	17	Wed 8th PM Paper 4 (TZ2)	
13-May	18	Wed 15th PM Paper 2 (TZ2) Wed 15th PM Paper 5 (TZ2)	
20-May	11		
27-May	12	Thur 30th PM Paper 34 (TZ2)	
3-Jun	13	Tues 4th PM Paper 1 (TZ2)	
10-Jun	14		
17-Jun	15		
24-Jun	16		

V1.0 – Continue to refine these to find and RECORD times you study best (and when you never study)

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
	7:00 pm							
	7:30 pm							
	8:00 pm							
	8:30 pm							
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							

Planning your days – v2.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
	7:00 pm							
	7:30 pm							
	8:00 pm							
	8:30 pm							
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							

Planning your days – v3.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
	7:00 pm							
	7:30 pm							
	8:00 pm							
	8:30 pm							
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							

Planning your days – v4.0

Period	Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
	5:00 am							
	5:30 am							
	6:00 am							
	6:30 am							
	7:00 am							
Regstn	7:25 am							
1	7:50 am							
2	8:40 am							
3	9:30 am							
4	10:20 am							
5	11:00 am							
Lunch	11:50 pm							
6	1:10 pm							
7	2:00pm							
8	2:50 pm							
9	3:40 pm							
	4:20 pm							
	5:00 pm							
	5:30 pm							
	6:00 pm							
	6:30 pm							
	7:00 pm							
	7:30 pm							
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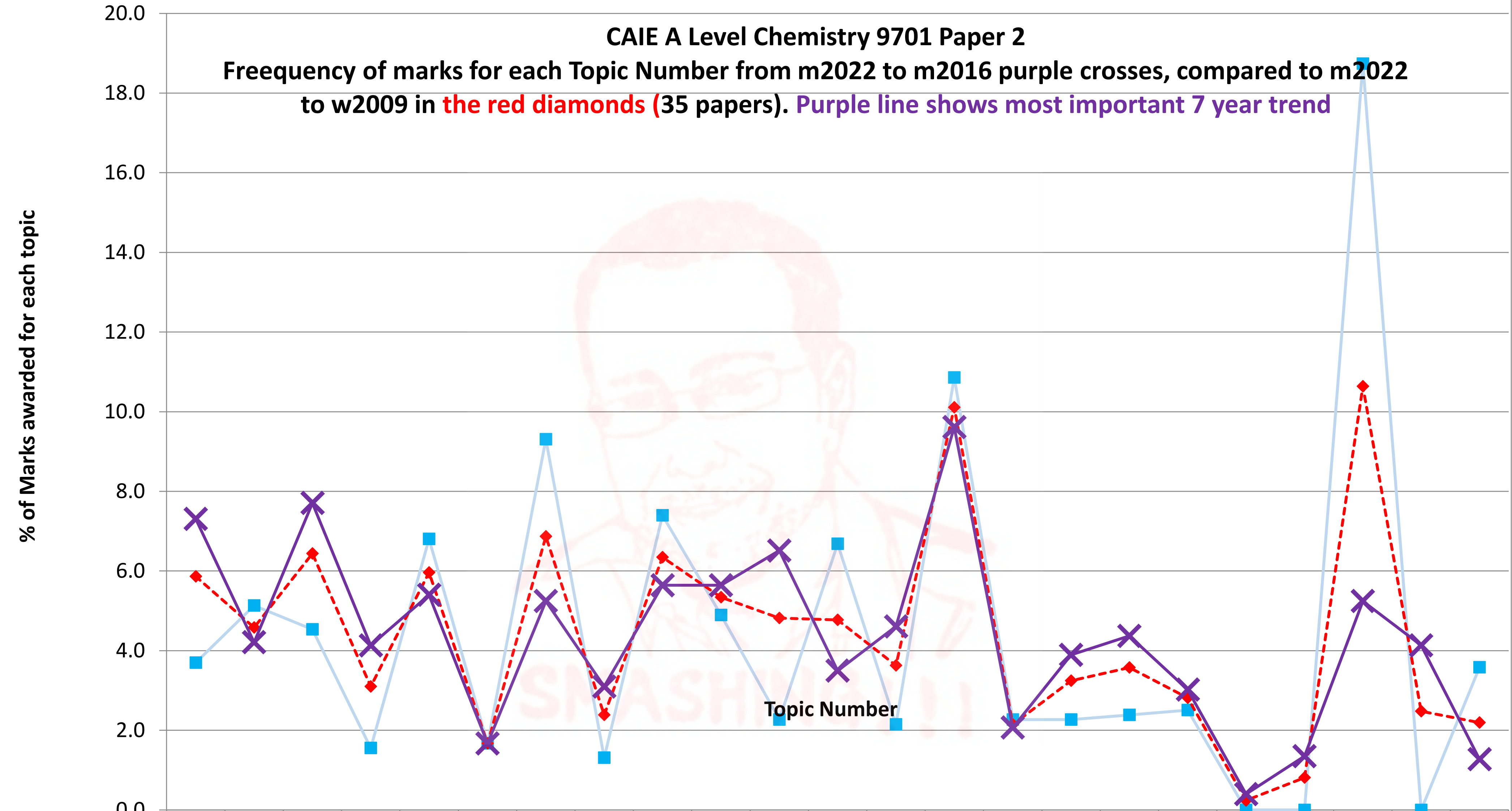
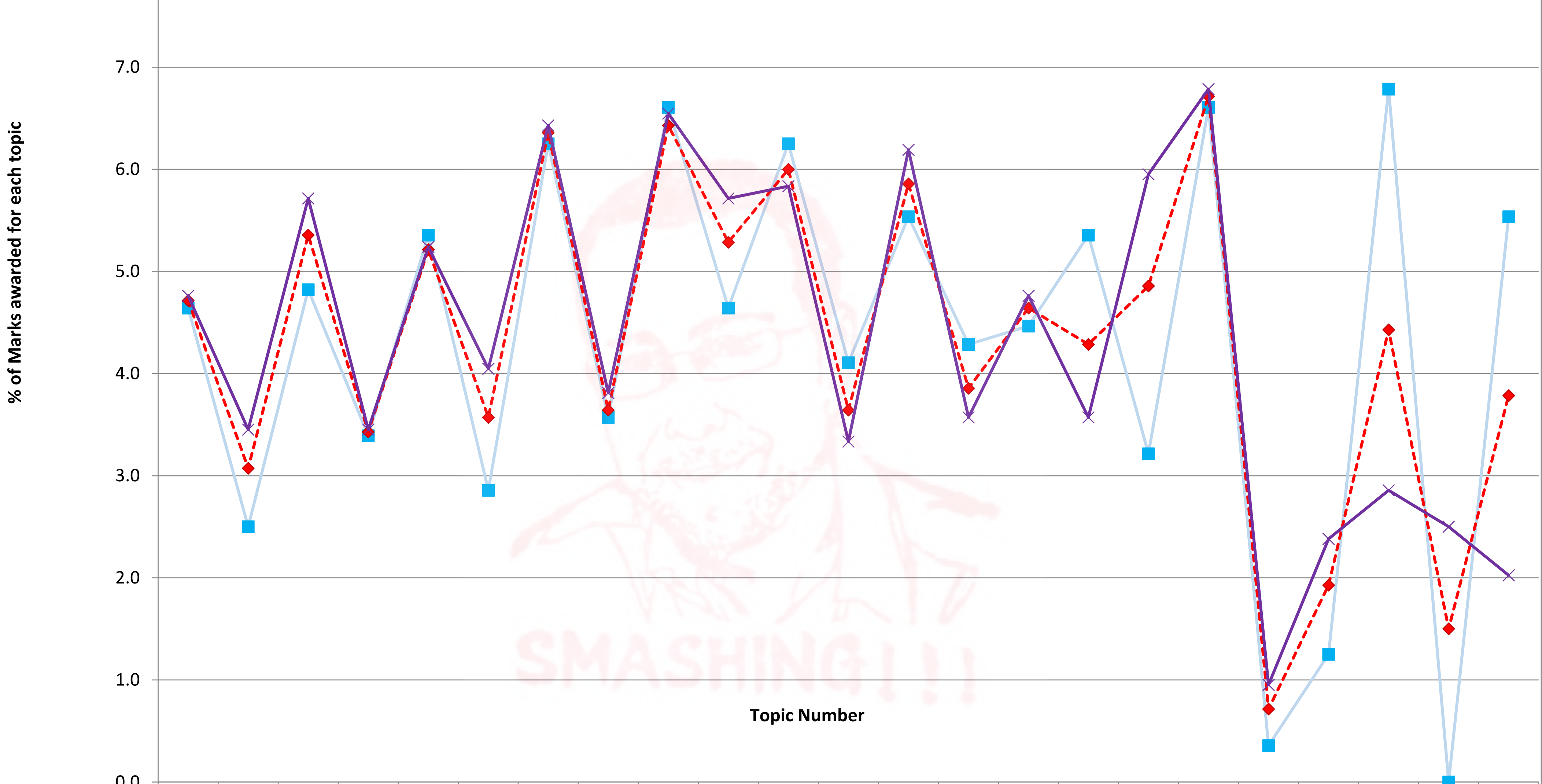
	9:00 pm							
	9:30 pm							
	10:00 pm							
	10:30 pm							



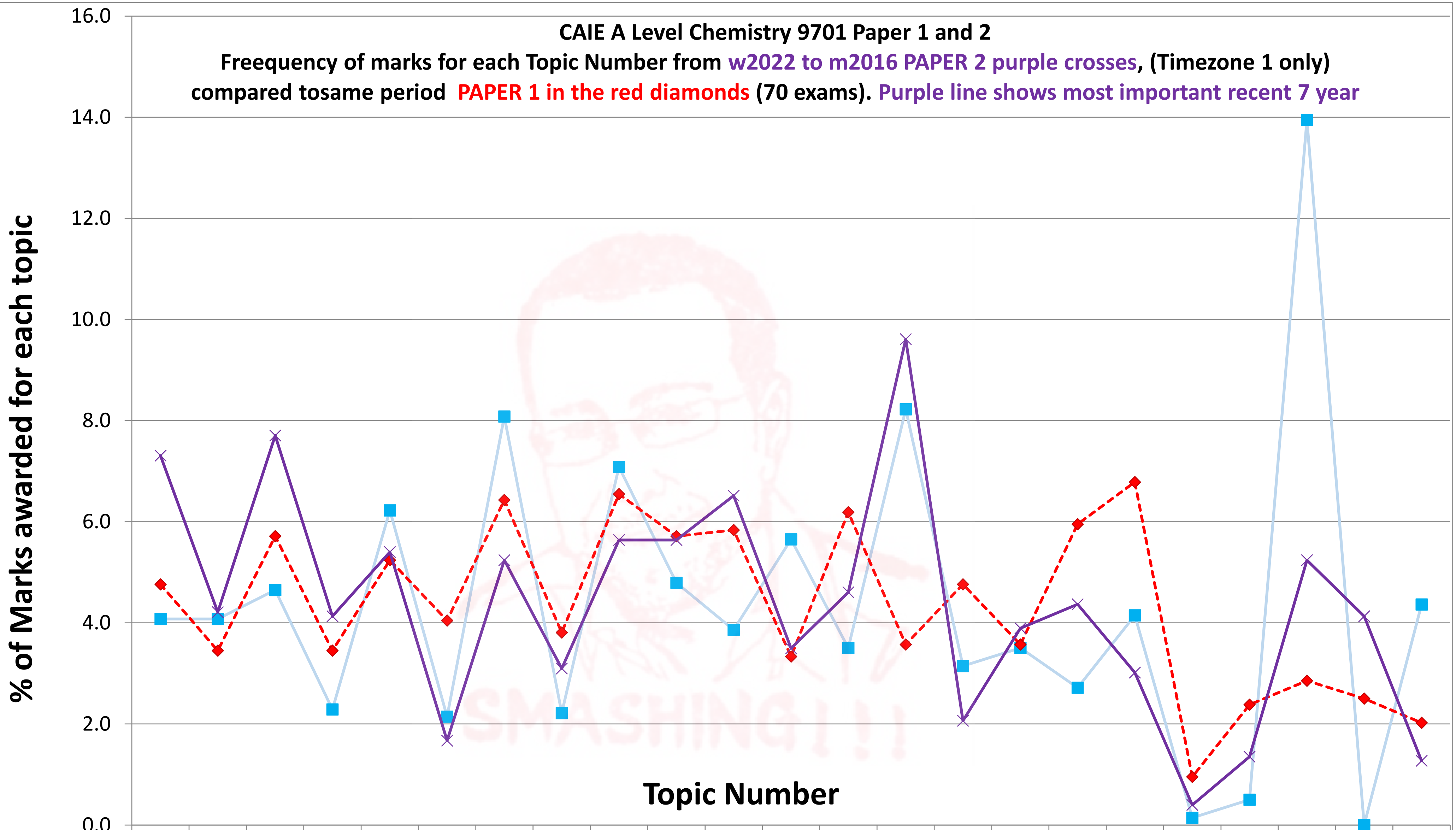
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Chem X
P2 09s-15w	3.7	5.1	4.5	1.6	6.8	1.7	9.3	1.3	7.4	4.9	2.3	6.7	2.1	10.9	2.3	2.3	2.4	2.5	0.0	0.0	18.7	0.0	3.6
P2 09w-22m	5.9	4.6	6.4	3.1	6.0	1.7	6.9	2.4	6.3	5.3	4.8	4.8	3.6	10.1	2.1	3.2	3.6	2.8	0.2	0.8	10.6	2.5	2.2
P2 16m-22w	7.3	4.2	7.7	4.1	5.4	1.7	5.2	3.1	5.6	5.6	6.5	3.5	4.6	9.6	2.1	3.9	4.4	3.0	0.4	1.4	5.2	4.1	1.3

CAIE A Level Chemistry 9701 **Paper 1: Multiple Choice**

Freequency of marks for each Topic Number from w2022 to m2016 purple crosses, (Timezone 1 only) compared to w2015 to s2009 in the blue squares (35 exams). ***Purple line shows most recent 7 year trend***



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Chem X
9w-15w	4.6	2.5	4.8	3.4	5.4	2.9	6.3	3.6	6.6	4.6	6.3	4.1	5.5	4.3	4.5	5.4	3.2	6.6	0.4	1.3	6.8	0.0	5.5
9w-22m	4.7	3.1	5.4	3.4	5.2	3.6	6.4	3.6	6.4	5.3	6.0	3.6	5.9	3.9	4.6	4.3	4.9	6.7	0.7	1.9	4.4	1.5	3.8
16m-22m	4.8	3.5	5.7	3.5	5.2	4.0	6.4	3.8	6.5	5.7	5.8	3.3	6.2	3.6	4.8	3.6	6.0	6.8	1.0	2.4	2.9	2.5	2.0



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Chem X
09w-15w P1+2	4.1	4.1	4.6	2.3	6.2	2.1	8.1	2.2	7.1	4.8	3.9	5.7	3.5	8.2	3.1	3.5	2.7	4.1	0.1	0.5	13.9	0.0	4.4
P1 16m-22w	4.8	3.5	5.7	3.5	5.2	4.0	6.4	3.8	6.5	5.7	5.8	3.3	6.2	3.6	4.8	3.6	6.0	6.8	1.0	2.4	2.9	2.5	2.0
P2 16m-22w	7.3	4.2	7.7	4.1	5.4	1.7	5.2	3.1	5.6	5.6	6.5	3.5	4.6	9.6	2.1	3.9	4.4	3.0	0.4	1.4	5.2	4.1	1.3

Paper 2 By Chemistry Branch	P2 09s-15w	P2 16m-22w	16m-22w P1+2
Physical Chemistry			
1 Atomic structure	3.7	7.3	6.3
2 Atoms, molecules and stoichiometry	5.1	4.2	3.9
3 Chemical bonding	4.5	7.7	6.9
4 States of matter	1.6	4.1	3.9
5 Chemical energetics	6.8	5.4	5.3
6 Electrochemistry	1.7	1.7	2.6
7 Equilibria	9.3	5.2	5.7
8 Reaction kinetics	1.3	3.1	3.4
Physical Chemistry Totals	34.0	38.8	38.0
Inorganic Chemistry			
9 The Periodic Table: chemical periodicity	7.4	5.6	6.0
10 Group 2	4.9	5.6	5.7
11 Group 17	2.3	6.5	6.2
12 Nitrogen and sulfur	6.7	3.5	3.4
Inorganic Chemistry Totals	21.2	21.3	21.3
Organic Chemistry			
13 An introduction to AS Level organic chemistry	2.1	4.6	5.2
14 Hydrocarbons	10.9	9.6	7.2
15 Halogen compounds	2.3	2.1	3.1
16 Hydroxy compounds	2.3	3.9	3.8
17 Carbonyl compounds	2.4	4.4	5.0
18 Carboxylic acids and derivatives	2.5	3.0	4.5
19 Nitrogen compounds	0.0	0.4	0.6
20 Polymerisation	0.0	1.4	1.8
21 Organic synthesis	18.7	5.2	4.3
Organic Chemistry Totals	41.2	34.6	35.5
Analytical Techniques			
22 Analytical techniques	0.0	4.1	3.5
No longer assessed	3.6	1.3	1.6
AS Total (if <100, then because some material moved to A2)	100.0	100.0	100.0

Physical Chemistry Totals	34.0	38.8	38.0
Inorganic Chemistry Totals	21.2	21.3	21.3
Organic Chemistry Totals	41.2	34.6	35.5
22 Analytical techniques	0.0	4.1	3.5

The main change was in Topic 21 Organic Synthesis, which in 2015 and before was a larger part of the course (18.7% of all marks in 2015 and before, to 5.2% in Paper 2 from 2016 onwards). Questions that required several answers from various parts to solve an unknown compound tended to be broken down into smaller steps in 2016 and afterwards and the marks were therefore easier to assign to individual organic topics instead. This is line with a decades long trend away from thrilling subject-specific esoteric riddles towards an increasingly prosaic, quantised and rational assessment approach.

One of the most substantial changes in A2 was a move away from organic chemistry towards allocating a larger share of marks to the other branches of chemistry with the new 2016 syllabus. This change was not really seen at AS level, though organic chemistry is less common.

The 11 topics most frequently given marks in both Paper 1 and Paper 2 were more important from 2016 and onwards, representing almost 2 in 3 of all marks.

Mark were assigned based on when a student, learning in topic order, ought be able to produce an answer that would be awarded that mark, so sometimes material which the examiner may have intended to cover in one topic, say Topic 12 Nitrogen and Sulfur, may have been assigned to a different topic here, for instance Topic 3 Chemical Bonding instead because drawing a dot cross diagram of the triple covalent bond in N_2 is fully covered in Topic 3. But explaining why N_2 is unreactive, but CO, also with a triple covalent bond, is reactive, would be placed in Topic 12 because although bond polarity is covered earlier, this specific example isn't obviously fully covered in Topic 3. This difference between the topics assigned in these workbooks and what part of the syllabus the examiner was intending to assess was somewhat evident in Paper 1, where questions assess topics largely in syllabus order, though this general rule is not at all always followed in Paper 1.

Paper 1 and 2 By Frequency	P1 16m-22w	P2 16m-22w	09w-15w P1+2	16m-22w P1+2
Physical Chemistry				
14 Hydrocarbons	3.6	9.6	8.2	7.2
3 Chemical bonding	5.7	7.7	4.6	6.9
1 Atomic structure	4.8	7.3	4.1	6.3
11 Group 17	5.8	6.5	3.9	6.2
9 The Periodic Table: chemical periodicity	6.5	5.6	7.1	6.0
7 Equilibria	6.4	5.2	8.1	5.7
10 Group 2	5.7	5.6	4.8	5.7
5 Chemical energetics	5.2	5.4	6.2	5.3
13 An introduction to AS Level organic chemistry	6.2	4.6	3.5	5.2
17 Carbonyl compounds	6.0	4.4	2.7	5.0
18 Carboxylic acids and derivatives	6.8	3.0	4.1	4.5
Top half most represented topics totals	62.7	64.9	57.3	64
21 Organic synthesis	2.9	5.2	13.9	4.3
2 Atoms, molecules and stoichiometry	3.5	4.2	4.1	3.9
4 States of matter	3.5	4.1	2.3	3.9
16 Hydroxy compounds	3.6	3.9	3.5	3.8
22 Analytical techniques	2.5	4.1	0.0	3.5
8 Reaction kinetics	3.8	3.1	2.2	3.4
12 Nitrogen and sulfur	3.3	3.5	5.7	3.4
15 Halogen compounds	4.8	2.1	3.1	3.1
6 Electrochemistry	4.0	1.7	2.1	2.6
20 Polymerisation	2.4	1.4	0.5	1.8
19 Nitrogen compounds	1.0	0.4	0.1	0.6
No longer assessed	2.0	1.3	4.4	1.6
AS Total (if <1000, then because some material moved to A2)	99.9	100.0	99.4	100.0

Paper 1 and 2 By Chemistry Branch	P1 16m-22w	P2 16m-22w	09w-15w P1+2	16m-22w P1+2
Physical Chemistry				
1 Atomic structure	4.8	7.3	4.1	6.3
2 Atoms, molecules and stoichiometry	3.5	4.2	4.1	3.9
3 Chemical bonding	5.7	7.7	4.6	6.9
4 States of matter	3.5	4.1	2.3	3.9
5 Chemical energetics	5.2	5.4	6.2	5.3
6 Electrochemistry	4.0	1.7	2.1	2.6
7 Equilibria	6.4	5.2	8.1	5.7
8 Reaction kinetics	3.8	3.1	2.2	3.4
Physical Chemistry Totals	36.9	38.8	33.8	38.0
Inorganic Chemistry				
9 The Periodic Table: chemical periodicity	6.5	5.6	7.1	6.0
10 Group 2	5.7	5.6	4.8	5.7
11 Group 17	5.8	6.5	3.9	6.2
12 Nitrogen and sulfur	3.3	3.5	5.7	3.4
Inorganic Chemistry Totals	21.4	21.3	21.4	21.3
Organic Chemistry				
13 An introduction to AS Level organic chemistry	6.2	4.6	3.5	5.2
14 Hydrocarbons	3.6	9.6	8.2	7.2
15 Halogen compounds	4.8	2.1	3.1	3.1
16 Hydroxy compounds	3.6	3.9	3.5	3.8
17 Carbonyl compounds	6.0	4.4	2.7	5.0
18 Carboxylic acids and derivatives	6.8	3.0	4.1	4.5
19 Nitrogen compounds	1.0	0.4	0.1	0.6
20 Polymerisation	2.4	1.4	0.5	1.8
21 Organic synthesis	2.9	5.2	13.9	4.3
Organic Chemistry Totals	37.0	34.6	39.8	35.5
Analytical Techniques				
22 Analytical techniques	2.5	4.1	0.0	3.5
No longer assessed	2.0	1.3	4.4	1.6
AS Total (if <100, then because some material moved to A2)	99.9	100.0	99.4	100.0
Physical Chemistry Totals	36.9	38.8	33.8	38.0
Inorganic Chemistry Totals	21.4	21.3	21.4	21.3
Organic Chemistry Totals	37.0	34.6	39.8	35.5
22 Analytical techniques	2.5	4.1	0.0	3.5

Exam Papers, their marks and their weighting towards the AS and A2 years and the A Level qualification:

Exam Paper	% of AS or A2	% of ALvl	Total (marks)	Time (min)	Time(s)/ marks	mark as % AS or A2	mark as % ALL A-Level/ mark
1	31	15.5	40	75	112.5	0.78	0.39
2	46	23	60	75	75	0.77	0.38
3	23	11.5	30	120	240	0.77	0.38
4	77	38.5	100	120	72	0.77	0.39
5	23	11.5	30	75	150	0.77	0.38

PAPER 2 Exam Questions

Topic Chem 1 Q# 1/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Atoms with nuclei containing an odd number of protons tend to have fewer isotopes than those with an even number of protons.

(b) Potassium also has two stable isotopes. Both isotopes have the same chemical properties.

(i) Explain why both isotopes of potassium have the same chemical properties.

....

.... [1]

(ii) State the full electronic configuration of an atom of potassium.

.... [1]

(iii) The first, second and third ionisation energies of potassium are 418, 3070 and 4600 $kJ mol^{-1}$, respectively.

Use this information to explain why potassium is in Group 1.

....

....

....

.... [2]

Topic **Chem 1 Q# 2/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

(a) Identify the highest energy orbital which contains electrons in a calcium atom. Sketch the shape of this orbital.

identity of highest energy orbital in Ca ....

shape

[1]

(d) (i) $^{25}_{12}Mg$ is an isotope of magnesium.

Determine the number of protons and neutrons in an atom of $^{25}_{12}Mg$.

number of protons ....

number of neutrons ....
[1]

(ii) State the full electronic configuration of an atom of $^{25}_{12}Mg$.

.... [1]

(iii) State **one** similarity and **one** difference in the properties of these isotopes of magnesium. Explain your answer.

....

....

.... [2]

Topic **Chem 1 Q# 3/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 Fig. 1.1 shows how **first** ionisation energies vary across Period 2.

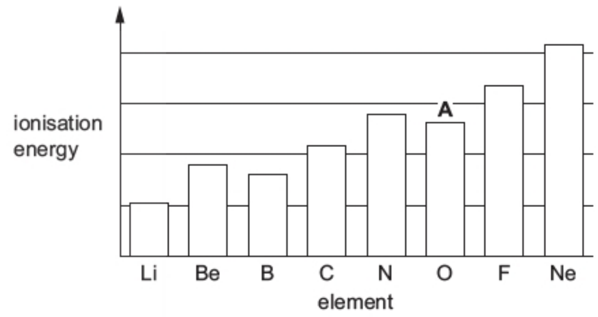


Fig. 1.1

(a) Construct an equation to represent the **first** ionisation energy of oxygen. Include state symbols.

.... [1]

(b) (i) State and explain the general trend in first ionisation energies across Period 2.

....

....

....

....

.... [3]

(ii) Explain why ionisation energy **A** in Fig. 1.1 does **not** follow the general trend in first ionisation energies across Period 2.

....

....

....

.... [2]

(c) Element **E** is in Period 3 of the Periodic Table.
The first eight ionisation energy values of **E** are shown in Table 1.1.

Table 1.1

ionisation	1st	2nd	3rd	4th	5th	6th	7th	8th
ionisation energy / kJ mol^{-1}	577	1820	2740	11600	14800	18400	23400	27500

Deduce the full electronic configuration of **E**.
Explain your answer.

full electronic configuration of **E** = ...

explanation ....

....

.... [3]

[Total: 9]

Topic **Chem 1 Q# 4/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(b) Chlorine has the highest first ionisation energy of the Period 3 elements Na to C*l*.

(i) Construct an equation for the first ionisation energy of chlorine.

Include state symbols.

.... [1]

(ii) Explain the general increase in the first ionisation energies of the Period 3 elements.

....

....

....

.... [2]

Topic **Chem 1 Q# 5/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(iii) Lithium hydride contains the ions Li^+ and H^-.

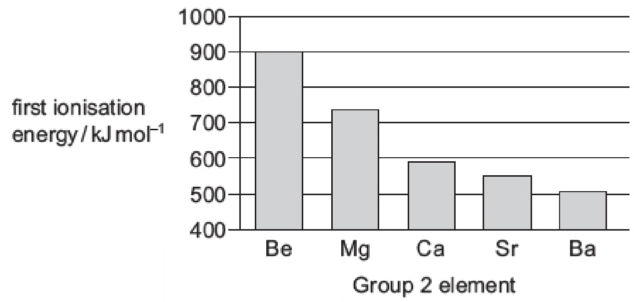
State the electronic configuration of these two ions.

Li^+ .... H^- ....

[1]

Topic **Chem 1 Q# 6/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 The graph shows the first ionisation energies of some of the elements in Group 2.



(a) Write an equation for the first ionisation energy of Mg.

Include state symbols.

.... [1]

(b) Explain the observed trend in first ionisation energies down Group 2.

....

....

....

....

....

.... [3]

(c) The second ionisation energy of Be is 1757 kJ mol^{-1}.

Explain why the second ionisation energy of Be is higher than the first ionisation energy of Be.

....

....

....

....

.... [2]

[Total: 6]

Topic **Chem 1 Q# 7/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga.

(i) State, with reference to subatomic particles, how the isotopes ^{69}Ga and ^{71}Ga differ from each other.

....

.... [1]

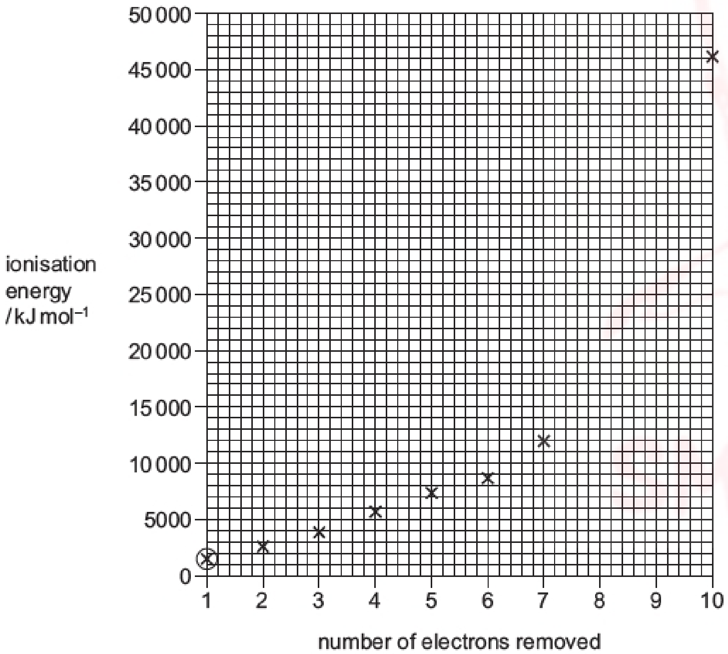
Topic **Chem 1 Q# 8/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** Construct an equation for the **second** ionisation energy of argon.

.... [1]

(b) The graph shows successive ionisation energies for the element argon.

Complete the graph with predictions for the eighth and ninth ionisation energies of argon. Use a cross (×) for each data point. [2]



(c) The energy value required to remove the first electron from an atom of argon is circled on the graph.

Sketch the shape of the orbital that contains this electron.

[1]

Topic **Chem 1 Q# 9/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(b) **(i)** Complete the electronic configuration of a chloride ion.

$1s^2$ .... [1]

Topic **Chem 1 Q# 10/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HCl and CaF_2.

	F_2	HCl	CaF_2
boiling point/K	85	188	2773
relative formula mass	38.0	36.5	78.1

(a) **(i)** State what is meant by the term *relative formula mass*.

....

....

.... [2]

(iv) CaF_2(aq) can be made by the reaction of calcium carbonate with hydrofluoric acid, HF(aq).

Write an equation for this reaction. Include state symbols.

.... [2]

Topic **Chem 1 Q# 11/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Iron pyrite, FeS_2, has a yellow colour that makes it look like gold metal. The compound contains the ions Fe^{2+} and S_2^{2-}.

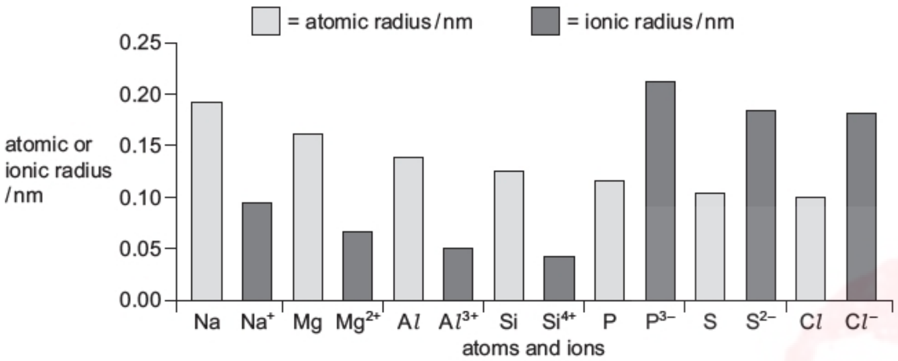
(a) **(i)** Give the full electronic configuration of Fe^{2+}.

$1s^2$ .... [1]

Topic **Chem 1 Q# 12/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The elements in the third period exhibit periodicity in both their chemical and physical properties.

(a) A graph of the atomic and ionic radii across the third period is shown.



(i) Explain the decrease in atomic radius across the third period.

....

....

....

.... [2]

(ii) Explain why, for sodium to silicon, the ionic radii are less than the atomic radii.

....

.... [1]

(iii) Explain why, for phosphorus to chlorine, the ionic radii are greater than the atomic radii.

....

....

.... [2]

(b) The first ionisation energies of the elements across the third period show a general increase.

Aluminium and sulfur do **not** follow this general trend.

(i) Explain why aluminium has a lower first ionisation energy than magnesium.

....

....

.... [2]

(ii) Explain why sulfur has a lower first ionisation energy than phosphorus.

....

....

.... [2]

Topic **Chem 1 Q# 13/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(ii) When silicon reacts with magnesium, Mg_2Si forms. Mg_2Si is thought to contain the Si^{4-} ion.

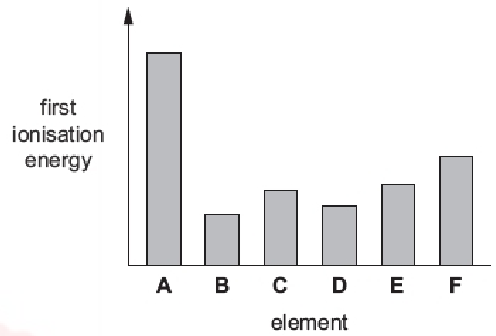
State the full electronic configuration of the Si^{4-} ion.

$1s^2$.. [1]

Topic **Chem 1 Q# 14/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** The graph shows a sketch of the first ionisation energies of six successive elements in the Periodic Table.

The letters are **not** the symbols of the elements.



(i) Explain what is meant by the term *first ionisation energy*.

....

....

....

.... [3]

(ii) Suggest why the first ionisation energy of **B** is much less than that of **A**.

....

....

....

....

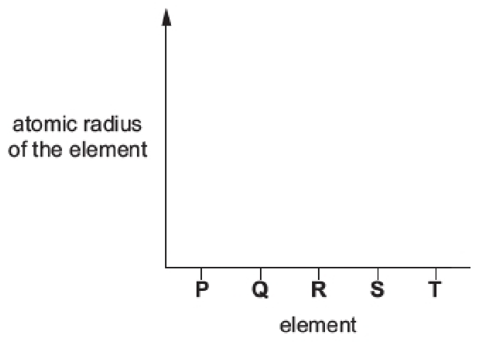
.... [3]

(b) **P**–**T** are successive elements in Period 3 of the Periodic Table.

The letters are **not** the symbols of the elements.

On the axes, sketch a graph to show the trend in the atomic radius of the elements **P**–**T**.

Explain your answer.



explanation ....

....

....

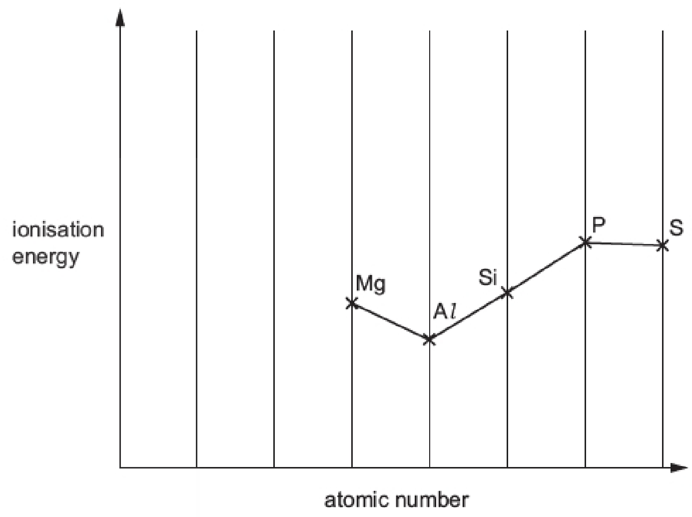
....

.... [3]

[Total: 9]

2 The elements in the third period, and their compounds, show trends in their physical and chemical properties.

(a) A sketch graph of the first ionisation energies of five successive elements in the third period is shown.



(i) Explain why there is a general increase in the first ionisation energy across the third period.

....

....

.... [2]

(ii) Sketch, on the graph, the position of the ionisation energies of the two elements that come before Mg in this sequence. [2]

(iii) Explain, with reference to electron arrangements, the decreases in first ionisation energy between Mg and Al and between P and S.

Mg and Al ....

....

....

P and S ....

....

....

[4]

Topic **Chem 1 Q# 16/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** The table shows information about some of the elements in the third period.

element	Na	Mg	Al	P	S	Cl
atomic radius / nm	0.186	0.160	0.143	0.110	0.104	0.099
radius of most common ion / nm	0.095	0.065	0.050	0.212	0.184	0.181
maximum oxidation number of the element in its compounds	+1					+7

(ii) Explain why the atomic radius of elements in the third period decreases from Na to Cl.

....

....

....

....

.... [3]

(iii) The radius of the most common ion of Mg is much smaller than the radius of the most common ion of S.

Identify both ions and explain the difference in their radii.

....

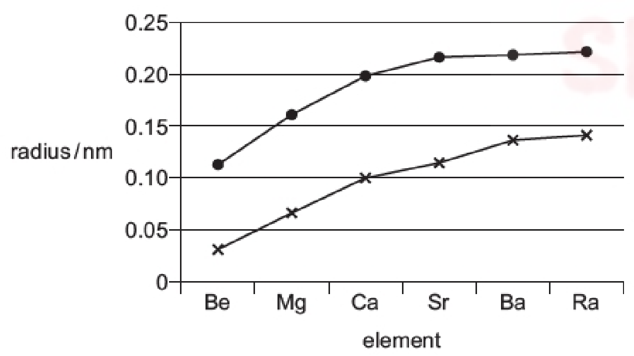
....

.... [2]

Topic **Chem 1 Q# 17/** ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The elements in Group 2 and their compounds show various trends in their physical and chemical properties.

(a) The graph below shows the radius values of the atoms and 2+ ions of the elements in Group 2.



(i) Explain why both lines show a steady increase in the values of the radii down the group.

....

....

.... [2]

(ii) State and explain which line represents the atomic radii and which represents the ionic radii.

....

....

.... [2]

Topic **Chem 1 Q# 18/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Complete the table to show the composition and identity of some atoms and ions.

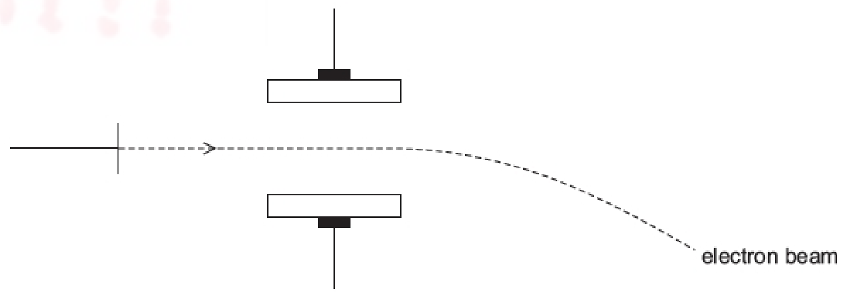
name of element	nucleon number	atomic number	number of protons	number of neutrons	number of electrons	overall charge
lithium	6	3	....	....	....	+1
oxygen	....	....	....	9	10	....
....	54	26	26	....	24	....
....	....	....	17	18	....	0

[4]

(b) Beams of protons, neutrons and electrons behave differently in an electric field due to their differing properties.

The diagram shows the path of a beam of electrons in an electric field.

Add and label lines to represent the paths of beams of protons and neutrons in the same field.



[3]

(c) The fifth to eighth ionisation energies of three elements in the third period of the Periodic Table are given. The symbols used for reference are **not** the actual symbols of the elements.

	ionisation energies, kJ mol^{-1}			
	fifth	sixth	seventh	eighth
X	6274	21 269	25 398	29 855
Y	7012	8496	27 107	31 671
Z	6542	9362	11 018	33 606

(i) State and explain the group number of element **Y**.

group number ....

explanation ....

.... [1]

(ii) State and explain the general trend in **first** ionisation energies across the third period.

....

....

.... [2]

(iii) Explain why the **first** ionisation energy of element **Y** is less than that of element **X**.

....

....

....

.... [2]

(iv) Complete the electronic configuration of element **Z**.

$1s^2$ .... [1]

Topic **Chem 1 Q# 19/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 This question is about Period 3 elements and their compounds.

(a) Give an explanation for each of the following statements.

(i) The atomic radius decreases across Period 3 (Na to Ar).

....

....

....

.... [2]

(ii) The first ionisation energy of sulfur is lower than that of phosphorus.

....

....

....

.... [2]

Topic **Chem 1 Q# 20/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Chemists recognise that atoms are made of three types of particle.

Complete the following table with their names and properties.

name of particle	relative mass	relative charge
		0
	1/1836	

[3]

Topic **Chem 1 Q# 21/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Successive ionisation energies for the elements magnesium to barium are given in the table.

element	1st ionisation energy / kJ mol^{-1}	2nd ionisation energy / kJ mol^{-1}	3rd ionisation energy / kJ mol^{-1}
Mg	736	1450	7740
Ca	590	1150	4940
Sr	548	1060	4120
Ba	502	966	3390

(i) Explain why the first ionisation energies decrease down the group.

....

....

....

.... [3]

(ii) Explain why, for each element, there is a large increase between the 2nd and 3rd ionisation energies.

....

....

.... [2]

(b)

(i) Complete the full electronic configuration of strontium.

$1s^2\ 2s^2\ 2p^6$ .... [1]

Topic **Chem 1 Q# 22/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) Explain what is meant by the term *ionisation energy*.

....

....

.... [3]

(b) The first seven ionisation energies of an element, **A**, in $kJ\,mol^{-1}$, are

1012 1903 2912 4957 6274 21269 25398.

(i) State the group of the Periodic Table to which **A** is most likely to belong. Explain your answer.

....

....

....

.... [2]

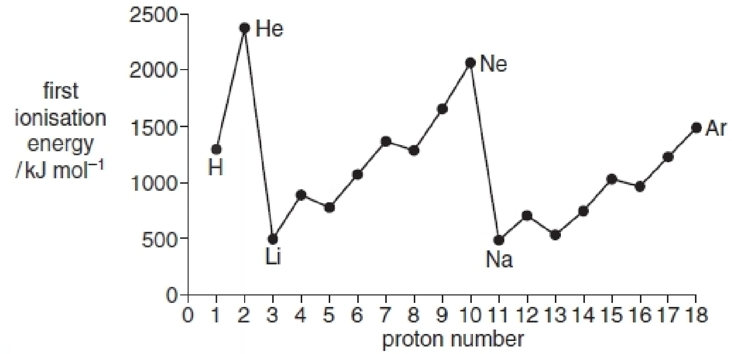
(ii) Complete the electronic configuration of the element in Period 2 that is in the same group as **A**.

$1s^2$ .... [1]

Topic **Chem 1 Q# 23/** ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The Periodic Table we currently use is derived directly from that proposed in 1869 by Mendeleev who had noticed patterns in the physical and chemical properties of the elements he had studied.

The diagram below shows the first ionisation energies of the first 18 elements of the Periodic Table.



(a) Give the equation, including state symbols, for the first ionisation energy of sulfur.

.... [2]

(b) Explain why there is a **general** increase in first ionisation energies across the Period from sodium to argon.

....

....

....

.... [3]

(c) (i) Explain why the first ionisation energy of magnesium is greater than that of aluminium.

....

....

....

(ii) Explain why the first ionisation energy of phosphorus is greater than that of sulfur.

....

....

.... [4]

1 Magnesium, Mg, and radium, Ra, are elements in Group II of the Periodic Table.

Magnesium has three isotopes.

(a) Explain the meaning of the term *isotope*.

....

....

.... [2]

Radium, proton number 88, and uranium, proton number 92, are radioactive elements.

The isotope ^{226}Ra is produced by the radioactive decay of the uranium isotope ^{238}U.

(c) Complete the table below to show the atomic structures of the isotopes ^{226}Ra and ^{238}U.

	number of		
isotopes	protons	neutrons	electrons
^{226}Ra			
^{238}U			

[3]

Topic **Chem 1 Q# 25/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, A*l*, is in the third period of the Periodic Table; copper and titanium are both transition elements.

(a) Complete the electronic configuration of aluminium and of titanium, proton number 22.

A*l*	$1s^2$
Ti	$1s^2$

[2]

Topic Chem 2 Q# 26/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Atoms with nuclei containing an odd number of protons tend to have fewer isotopes than those with an even number of protons.

(a) Gallium has two stable isotopes, ^{69}Ga and ^{71}Ga.

(i) Complete Table 1.1 to show the numbers of protons, neutrons and electrons in the two stable isotopes of gallium.

Table 1.1

isotope	number of protons	number of neutrons	number of electrons
^{69}Ga			
^{71}Ga			

[2]

(ii) Define relative atomic mass.

....

....

.... [2]

(iii) The relative atomic mass of gallium, A_r, is 69.723.
The relative isotopic masses of ^{69}Ga and ^{71}Ga are:

^{69}Ga, 68.926; ^{71}Ga, 70.925.

Use this information to calculate the percentage abundance of ^{69}Ga in elemental gallium.
Show your working.
Assume that the element contains only the ^{69}Ga and ^{71}Ga isotopes.
Give your answer to **four** significant figures.

percentage abundance of ^{69}Ga = ... %
[2]

Topic **Chem 2 Q# 27/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Compound **V** is a liquid.

V contains 77.2% carbon, 11.4% hydrogen and 11.4% oxygen by mass.

V has a relative molecular mass of 280.

(a) Calculate the molecular formula of **V**. Show your working.

molecular formula of **V** = ... [3]

(ii) A 3.196 g sample of Br_2 reacts completely with 2.800 g of **V**.

Calculate how many alkene functional groups are present in one molecule of **V**. Show your working.

number of alkene functional groups in **V** = ... [1]

Topic **Chem 2 Q# 28/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

(e) A sample of magnesium contains three isotopes, ^{25}Mg, ^{26}Mg and **X**.

The percentage abundance of the three isotopes is shown in Table 1.1.

Table 1.1

isotope of Mg	mass / a.m.u.	percentage abundance / %
X		78.99
^{25}Mg	24.99	10.00
^{26}Mg	25.98	11.01

(i) The relative atomic mass, A_r, is calculated by comparing the average mass of the isotopes of an element to the unified atomic mass unit.

Define the unified atomic mass unit.

.... [1]

(ii) Calculate the mass of **X**. Use data from Table 1.1 and A_r (magnesium) = 24.31 in your calculation. Show your working.

mass of **X** = ...
[2]

Topic **Chem 2 Q# 29/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O Al_2O_3 P_4O_6 P_4O_{10} SO_2 SO_3

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(i) Define reducing agent.

....

.... [1]

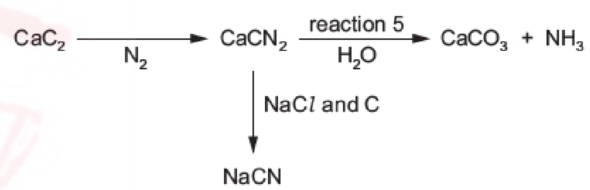
c

(ii) Determine the oxidation number of P in H_3PO_3.

.... [1]

Topic **Chem 2 Q# 30/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(d) The flowchart shows some reactions of CaC_2.



(i) Reaction 5 can be used to prepare NH_3.

$$CaCN_2 + 3H_2O \rightarrow CaCO_3 + 2NH_3$$

Calculate the minimum mass, in tonnes, of calcium cyanamide, $CaCN_2$, that is required to produce 1.50×10^6 tonnes of NH_3.

Show your working.

1 tonne = 1.00×10^6 g

minimum mass of $CaCN_2$ = ... tonnes
[2]

Topic **Chem 2 Q# 31/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) The compound As_2S_3 is a common mineral.

When As_2S_3 is heated strongly in air, it forms a mixture of products, as shown.

$$2As_2S_3(s) + 9O_2(g) \rightarrow As_4O_6(s) + 6SO_2(g)$$

(i) A sample containing 0.198 g As_2S_3 is placed in 0.100 dm^3 of pure oxygen, an excess, in a reaction chamber connected to a gas syringe at room temperature.

The reactants are heated until no further change is observed. The products are then allowed to cool to room temperature.

Calculate the volume, in dm^3, of gas present at the end of the experiment.

The molar volume of gas is 24.0 $dm^3 mol^{-1}$ under these conditions. Assume that the pressure is constant throughout the experiment.

Show your working.

volume of gas remaining = ... dm^3
[4]

Topic **Chem 2 Q# 32/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Ethanedioic acid, HO_2CCO_2H, has a relative molecular mass of 90.0.

(a) (i) Explain what is meant by the term *relative molecular mass*.

....

....

.... [2]

(ii) State the empirical formula of ethanedioic acid.

.... [1]

(iii) Calculate how many atoms of carbon are present in 0.18 g of ethanedioic acid, HO_2CCO_2H.

Show your working.

atoms of carbon present = ... [3]

Topic **Chem 2 Q# 33/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) In the reaction described in **(a)(i)**, a student uses 17.43 g of $CuSO_4\bullet\mathbf{y}H_2O$. By further titration of the reaction products the student concludes that the total amount of $CuSO_4$ in the sample is 0.0982 mol.

Use the *Data Booklet* to complete the table to calculate the value of **y**, where **y** is an integer. Show your working.

mass of 0.0982 mol $CuSO_4$	.... g
amount of H_2O in 17.43 g of $CuSO_4\bullet\mathbf{y}H_2O$	.... mol H_2O
value of **y**	**y** = ...

[4]

[Total: 9]

Topic **Chem 2 Q# 34/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga.

(ii) State what further information is needed to calculate the relative atomic mass of gallium.

.... [1]

Topic **Chem 2 Q# 35/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(d) Chlorine exists as a diatomic gas, $Cl_2(g)$. A sample of $Cl_2(g)$ was made during a chemical reaction. When measured at 404 kPa and 25 °C the sample occupied a volume of 20.0 cm^3.

(i) Calculate the mass, in grams, of $Cl_2(g)$ formed.

For this calculation, assume that chlorine behaves as an ideal gas under these conditions.

mass of $Cl_2(g)$ = ... g [3]

(ii) Calculate the number of chlorine atoms in this sample of $Cl_2(g)$. You may find it helpful to use your answer to **(d)(i)**.

If you are unable to calculate an answer to **(d)(i)**, use 0.36 g of Cl_2. This is **not** the correct answer.

number of chlorine atoms = ... [2]

Topic **Chem 2 Q# 36/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) When solid Mg_2Si is added to water, silane gas, SiH_4, and a solution of magnesium hydroxide are produced.

Construct the equation for this reaction. Include state symbols.

.... [2]

Topic **Chem 2 Q# 37/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 Nitrogen, N_2, is the most abundant gas in the Earth's atmosphere and is very unreactive.

(b) Magnesium and lithium both form nitrides with N_2. These compounds both contain the N^{3-} ion.

(i) Write an equation for the reaction of magnesium with N_2 to form magnesium nitride.

.... [1]

(ii) Solid lithium nitride, Li_3N, reacts with water according to the following equation.

$$Li_3N(s) + 3H_2O(l) \rightarrow 3LiOH(aq) + NH_3(aq)$$

State **one** observation you would make during this reaction.

.... [1]

Topic **Chem 2 Q# 38/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium and its compounds have a large variety of applications.

(a) Calcium metal reacts readily with most acids.

(i) Write an equation for the reaction of calcium with dilute nitric acid. State symbols are **not** required.

.... [1]

Topic **Chem 2 Q# 39/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(iii) Solid Mg_2Si reacts with dilute hydrochloric acid to form gaseous SiH_4 and a solution of magnesium chloride.

Write an equation to show the reaction of solid Mg_2Si with dilute hydrochloric acid.

Include state symbols.

.... [2]

(v) SiH_4 reacts spontaneously with oxygen to produce a white solid and a colourless liquid that turns anhydrous copper(II) sulfate blue. No other products are formed.

Write an equation for the reaction of SiH_4 with oxygen.

State symbols are **not** required.

.... [1]

[Total: 22]

Topic **Chem 2 Q# 40/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds.

(a) Define the term *relative molecular mass*.

....

....

....

.... [2]

Topic **Chem 2 Q# 41/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(iii) A naturally occurring sample of cerium contains only **four** isotopes. Data for **three** of the isotopes are shown in the table.

isotope	^{136}Ce	^{138}Ce	^{140}Ce	^{142}Ce
relative isotopic mass	135.907	137.906	139.905	to be calculated
percentage abundance	0.185	0.251	88.450	to be calculated

The A_r of the sample is 140.116.

Use these data to calculate the **relative isotopic mass** of the fourth isotope in this sample of cerium.

Give your answer to **three** decimal places.

relative isotopic mass = ... [3]

[Total: 17]

Topic **Chem 2 Q# 42/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) A sample of strontium exists as a mixture of four isotopes. Information about three of these isotopes is given in the table.

mass number	86	87	88
abundance	9.86%	7.00%	82.58%

(i) Calculate the abundance of the fourth isotope.

abundance = ... % [1]

(ii) The relative atomic mass of this sample of strontium is 87.71.

Calculate the mass number of the fourth isotope.

mass number = ... [2]

[Total: 16]

Topic **Chem 2 Q# 43/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) Aluminium reacts with chlorine to form a white, solid chloride that contains 79.7% chlorine and sublimes (changes straight from a solid to a gas) at 180 °C.

(ii) Calculate the empirical formula of the chloride. You must show your working.

empirical formula = ... [2]

At 200 °C and 100 kPa, a 1.36 g sample of this chloride occupied a volume of 200 cm^3.

(iii) Calculate the relative molecular mass, M_r, of the chloride. Give your answer to **three** significant figures.

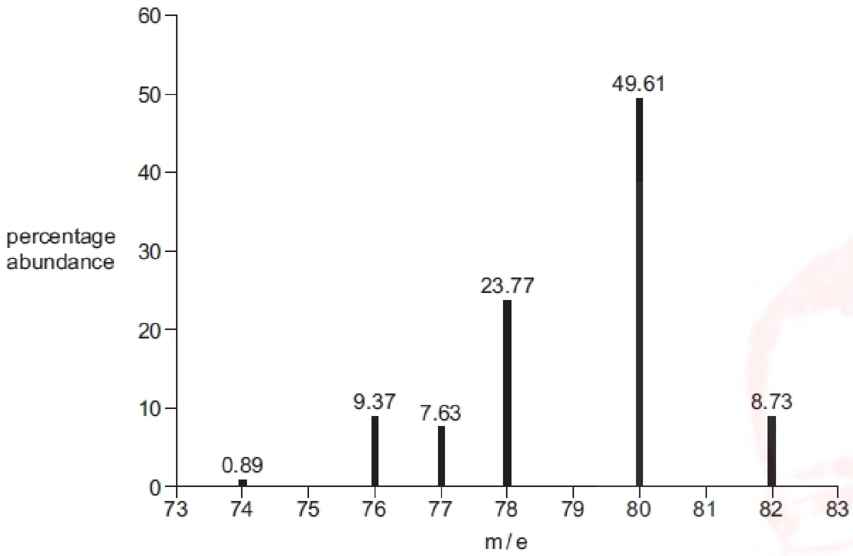
M_r = ... [2]

(iv) Deduce the molecular formula of this chloride at 200 °C.

.... [1]

(b) The relative atomic mass of an element can be determined using data from its mass spectrum.

The mass spectrum of element **X** is shown, with the percentage abundance of each isotope labelled.



(i) Define the terms *relative atomic mass* and *isotope*.

relative atomic mass ....

....

....

isotope ....

.... [3]

(ii) Use the data in the mass spectrum to calculate the relative atomic mass, A_r, of **X**. Give your answer to **two** decimal places and suggest the identity of **X**.

A_r of **X** ....

identity of **X** ....
[2]

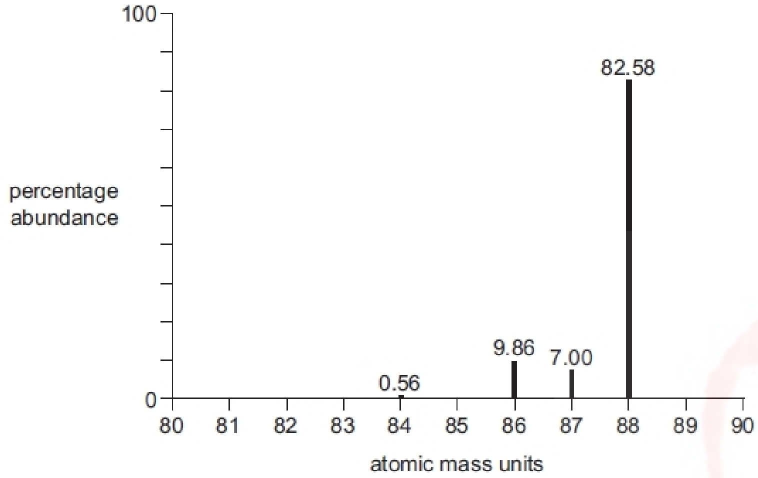
(c) The element tellurium, Te, reacts with chlorine to form a single solid product, with a relative formula mass of 270. The product contains 52.6% chlorine by mass.

(i) Calculate the molecular formula of this chloride.

molecular formula .... [3]

Topic **Chem 2 Q# 45/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) A sample of strontium, atomic number 38, gave the mass spectrum shown. The percentage abundances are given above each peak.



(ii) Explain why there are four different peaks in the mass spectrum of strontium.

....

.... [1]

(iii) Calculate the atomic mass, A_r, of this sample of strontium.
Give your answer to **three** significant figures.

A_r = ... [2]

(c) A compound of barium, **A**, is used in fireworks as an oxidising agent and to produce a green colour.

(ii) **A** has the following percentage composition by mass: Ba, 45.1; C*l*, 23.4; O, 31.5.

Calculate the empirical formula of **A**.

empirical formula of **A** .... [3]

Topic **Chem 2 Q# 46/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) The first seven ionisation energies of an element, **A**, in kJ mol^{-1}, are

1012 1903 2912 4957 6274 21269 25398.

(c) Another element, **Z**, in the same period of the Periodic Table as **A**, reacts with chlorine to form a compound with empirical formula ZCl_2. The percentage composition by mass of ZCl_2 is **Z**, 31.13; C*l*, 68.87.

(i) Define the term *relative atomic mass*.

....

....

.... [2]

(ii) Calculate the relative atomic mass, A_r, of **Z**.
Give your answer to **three** significant figures.

A_r of **Z** = ... [2]

Topic **Chem 2 Q# 47/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Zinc is an essential trace element which is necessary for the healthy growth of animals and plants. Zinc deficiency in humans can be easily treated by using zinc salts as dietary supplements.

(a) One salt which is used as a dietary supplement is a hydrated zinc sulfate, $ZnSO_4.xH_2O$, which is a colourless crystalline solid.

(b) A simple experiment to determine the value of x in the formula $ZnSO_4.xH_2O$ is to heat it carefully to drive off the water.

$$ZnSO_4.xH_2O(s) \rightarrow ZnSO_4(s) + xH_2O(g)$$

A student placed a sample of the hydrated zinc sulfate in a weighed boiling tube and reweighed it. He then heated the tube for a short time, cooled it and reweighed it when cool. This process was repeated four times. The final results are shown below.

mass of empty tube / g	mass of tube + hydrated salt / g	mass of tube + salt after fourth heating / g
74.25	77.97	76.34

(i) Why was the boiling tube heated, cooled and reweighed four times?

....

....

(ii) Calculate the amount, **in moles**, of the anhydrous salt produced.

(iii) Calculate the amount, **in moles**, of water driven off by heating.

(iv) Use your results to **(ii)** and **(iii)** to calculate the value of x in $ZnSO_4.xH_2O$.

[7]

(c) For many people, an intake of approximately 15 mg per day of zinc will be sufficient to prevent deficiencies.

Zinc ethanoate crystals, $(CH_3CO_2)_2Zn.2H_2O$, may be used in this way.

(i) What mass of pure crystalline zinc ethanoate (M_r = 219.4) will need to be taken to obtain a dose of 15 mg of zinc?

(ii) If this dose is taken in solution as 5 cm^3 of aqueous zinc ethanoate, what would be the concentration of the solution used?
Give your answer in mol dm^{-3}.

[4]

[Total: 13]

Topic **Chem 2 Q# 48/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 The gas ethyne, C_2H_2, more commonly known as acetylene, is manufactured for use in the synthesis of organic compounds. It is also used, in combination with oxygen, in 'oxy-acetylene' torches for the cutting and welding of metals.

Industrially, ethyne is made from calcium carbide, CaC_2, or by cracking liquid hydrocarbons.

(a) When calcium carbide is reacted with water, ethyne and calcium hydroxide are formed.

Construct a balanced equation for this reaction.

.... [1]

Topic **Chem 2 Q# 49/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 In 1814, Sir Humphrey Davy and Michael Faraday collected samples of a flammable gas, **A**, from the ground near Florence in Italy.
They analysed **A** which they found to be a hydrocarbon. Further experiments were then carried out to determine the molecular formula of **A**.

(a) What is meant by the term *molecular formula*?

....

....

.... [2]

Topic **Chem 2 Q# 50/** ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Magnesium, Mg, and radium, Ra, are elements in Group II of the Periodic Table.

Magnesium has three isotopes.
A sample of magnesium has the following isotopic composition by mass.

isotope mass	24	25	26
% by mass	78.60	10.11	11.29

(b) Calculate the relative atomic mass, A_r, of magnesium to **four** significant figures.

A_r = ...

[2]

Topic **Chem 2 Q# 51/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, A*l*, is in the third period of the Periodic Table; copper and titanium are both transition elements.

Aluminium reacts with chlorine.

Copper forms two chlorides, CuC*l* and $CuCl_2$.

Titanium also reacts with chlorine.

(d) When an excess of chlorine was reacted with 0.72 g of titanium, 2.85 g of a chloride **A** was formed.

(i) Calculate the amount, in moles, of titanium used.

(ii) Calculate the amount, in moles, of chlorine atoms that reacted.

(iii) Hence, determine the empirical formula of **A**.

(iv) Construct a balanced equation for the reaction between titanium and chlorine.

....

[4]

Topic Chem 3 Q# 52/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chlorides of Period 3 elements are shown in the list.

NaC*l* $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(a) From this list, identify:

(i) all the chlorides that have giant ionic structures in the solid state

.... [1]

Topic **Chem 3 Q# 53/** ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(d) Sulfur, S_8, reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2. SCl_2 forms when sulfur reacts with an excess of chlorine.

reaction **1** $S_8(s) + 4Cl_2(g) \rightarrow 4S_2Cl_2(l)$ $\Delta H_r = -58.2\,kJ\,mol^{-1}$

reaction **2** $S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l)$ $\Delta H_r = -40.6\,kJ\,mol^{-1}$

Fig. 3.1 shows the two structural isomers of S_2Cl_2.

isomer **I** isomer **II**

Fig. 3.1

(v) Suggest a value for the Cl–S–S bond angle in isomer **I**. Explain your answer.

bond angle = ... °

explanation ....

....

....

.... [2]

(vi) Draw a dot-and-cross diagram to show the bonding in isomer **II**. Show outer shell electrons only.

[2]

[Total: 18]

Topic **Chem 3 Q# 54/** ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium shows reactions typical of a Group 2 metal.

(a) Draw a labelled diagram to show the bonding in magnesium metal.

[2]

Topic **Chem 3 Q# 55/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Nitrogen molecules, N_2(g), contain two atoms attracted to each other by a triple covalent bond.

(a) Describe how the triple covalent bond forms in a N_2(g) molecule. Refer to orbital overlap and hybridisation in your answer.

....

....

....

.... [3]

Topic **Chem 3 Q# 56/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O Al_2O_3 P_4O_6 P_4O_{10} SO_2 SO_3

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(c) P_4O_6 is a white solid that has a melting point of 24 °C. Solid P_4O_6 reacts with water to form H_3PO_3.

(i) Deduce the type of structure and bonding shown by P_4O_6. Explain your answer.

....

....

.... [2]

Topic **Chem 3 Q# 57/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Phosphorus is a reactive Period 3 element.

(a) Phosphorus has several allotropes. Details of two allotropes are given.

allotrope of phosphorus	formula	melting point / °C
white	P_4	44
red	P	590

(i) White phosphorus and red phosphorus both have covalent bonding.

Suggest the types of structure shown by white phosphorus (P_4) and red phosphorus (P).

Explain why red phosphorus (P) has a higher melting point than white phosphorus (P_4).

structure of P_4 ....

structure of P ....

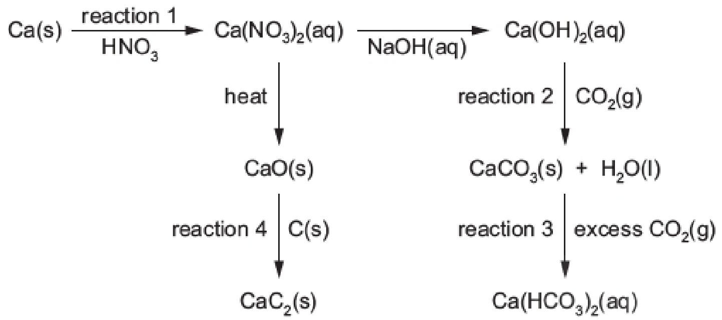
explanation ....

....

.... [3]

Topic **Chem 3 Q# 58/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The reaction scheme shows some reactions of calcium.



(c) In reaction 4, calcium carbide, CaC_2, is formed from CaO.

CaC_2 contains the C_2^{2-} anion. Each carbon in C_2^{2-} is sp hybridised.

(i) Describe how sp hybridised orbitals are formed.

....

.... [1]

(ii) Sketch a diagram to show how two sp hybrid orbitals can form a sigma (σ) bond.

[2]

Topic **Chem 3 Q# 59/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Sulfides are compounds that contain sulfur but not oxygen.

(a) Carbon disulfide, CS_2, is a volatile liquid at room temperature and pressure.

(ii) Draw a 'dot-and-cross' diagram of the CS_2 molecule.

[2]

(iii) Suggest the bond angle in a molecule of CS_2.

.... [1]

(iv) CS_2 is a liquid under room conditions, while CO_2 is a gas.

Explain what causes the difference in the physical properties between CS_2 and CO_2.

....

....

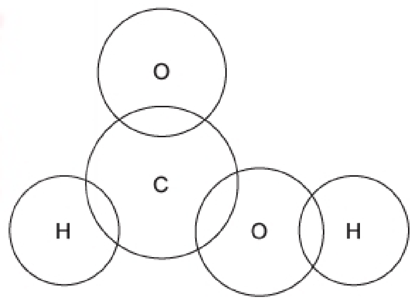
.... [2]

Topic **Chem 3 Q# 60/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Aqueous bromine reacts with methanoic acid to form hydrogen bromide and carbon dioxide gas.

$$Br_2(aq) + HCO_2H(aq) \rightarrow 2HBr(aq) + CO_2(g)$$

(d) Complete the 'dot-and-cross' diagram, showing outer electrons only, to show the bonding in methanoic acid, HCO_2H.

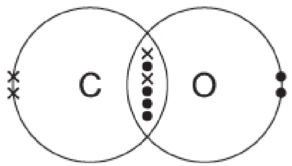


[2]

[Total: 9]

2 Carbon monoxide gas, CO(g), and nitrogen gas, N_2(g), are both diatomic molecules.

(a) The diagram shows the arrangement of outer electrons in a molecule of CO(g).



(i) State **one** similarity and **one** difference in the way the atoms in a carbon monoxide molecule are bonded together compared to the atoms in a nitrogen molecule.

....

....

.... [2]

(ii) The table states the electronegativity values of carbon, nitrogen and oxygen atoms.

	C	N	O
electronegativity	2.5	3.0	3.5

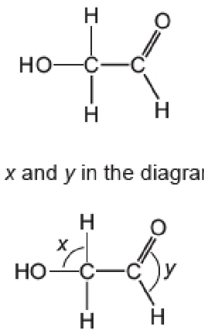
Use the electronegativity values and relevant details from the *Data Booklet* to complete the table below.

	N_2	CO
number of electrons per molecule		
type(s) of intermolecular (van der Waals') force		

[2]

4 Hydroxyethanal, $HOCH_2CHO$, has been observed in dust clouds near the centre of our galaxy.

hydroxyethanal



(a) Predict the bond angles labelled *x* and *y* in the diagram of hydroxyethanal.

x = ... °

y = ... °

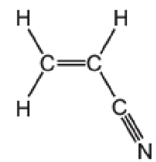
[2]

3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.

P: N≡C—C≡C—C≡N

Q: H—C≡C—C≡N

R



(b) **Q** forms when HCN reacts with ethyne, H—C≡C—H.

(ii) Ethyne, HCN and **Q** all contain triple bonds between two atoms.

A triple bond consists of one sigma (σ) and two pi (π) bonds.

Draw a labelled diagram to show the formation of one pi (π) bond.

[2]

Topic **Chem 3 Q# 64/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(e) Aluminium reacts with chlorine to form aluminium chloride.

Aluminium chloride can exist as the gaseous molecule Al_2Cl_6(g). This molecule contains coordinate bonds.

(i) Draw a diagram that clearly shows all the types of bond present in Al_2Cl_6(g).

[2]

Topic **Chem 3 Q# 65/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

(a) (i) At 200 °C, aluminium chloride exists as Al_2Cl_6(g).

Draw the structure of Al_2Cl_6(g), showing fully any coordinate (dative covalent) bonds in the molecule.

[2]

(ii) At 1000 °C, aluminium chloride exists as $AlCl_3$(g).

State the bond angle in $AlCl_3$(g).

.... ° [1]

(iv) $LiAlH_4$ decomposes slowly to form LiAl(s) and H_2(g).

$$LiAlH_4(s) \rightarrow LiAl(s) + 2H_2(g)$$

LiAl(s) shows metallic bonding.

Describe metallic bonding.

....

....

.... [1]

Topic **Chem 3 Q# 66/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Phosphorus, sulfur and chlorine can all react with oxygen to form oxides.

(iii) State the structure and bonding of solid phosphorus(V) oxide.

.... [1]

(d) Chlorine forms several oxides, including Cl_2O, ClO_2 and Cl_2O_6.

(i) Draw a 'dot-and-cross' diagram of Cl_2O. Show outer-shell electrons only.

[1]

Topic **Chem 3 Q# 67/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Calcium nitrate, $Ca(NO_3)_2$, reacts with ammonia, carbon dioxide and water to form a mixture of ammonium nitrate and calcium carbonate.

$$Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \rightarrow 2NH_4NO_3 + CaCO_3$$

(c) Complete the table to name the shape and give the bond angle of each species.

	name of shape	bond angle / °
CO_2		
NH_3		
H_2O		

[3]

[Total: 6]

Topic **Chem 3 Q# 68/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga.

(b) Gallium and its compounds show similar properties to aluminium and its compounds. Gallium reacts with excess chlorine to form gallium trichloride.

(i) At 500 °C, gallium trichloride is a gas.

Suggest the type of attraction that exists at 500 °C

- between atoms within a gallium trichloride molecule

....

- between gallium trichloride molecules.

.... [2]

(ii) When gallium trichloride is cooled a solid, Ga_2Cl_6, forms.

Suggest the name of the attraction formed between two gallium trichloride molecules to form Ga_2Cl_6.

.... [1]

Topic **Chem 3 Q# 69/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(d) Beryllium oxide reacts with hydrochloric acid to form molecules of $BeCl_2$.

Deduce the bond angle in $BeCl_2$.

.... [1]

Topic **Chem 3 Q# 70/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 **(a)** Complete the table to give details of the type of bonding and structure shown by some of the oxides of Period 3 elements.

	Na_2O	MgO	Al_2O_3	SiO_2	SO_3
boiling point / °C	1275	3670	2977	2950	45
nature of oxide	basic	basic	amphoteric	acidic	acidic
bonding					
structure					

[2]

(b) **(i)** Explain why the boiling point of SiO_2 is much higher than the boiling point of SO_3.

....

....

....

.... [3]

(c) Selenium is a Group 16 element which shows similar chemical reactions to sulfur.

(i) Selenium reacts with fluorine to form SeF_6 molecules.

Predict the shape of a molecule of SeF_6.

.... [1]

Topic **Chem 3 Q# 71/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium silicide, Mg_2Si, is a compound made by heating magnesium with sand.

(a) Draw a 'dot-and-cross' diagram to show the arrangement of outer electrons present in a formula unit of Mg_2Si. Assume magnesium silicide is an ionic compound.

[2]

(c) Suggest, with reference to structure and bonding, why SiH_4 is a gas at room temperature.

....

....

.... [2]

(d) The table shows the electronegativity values of carbon, hydrogen and silicon.

element	carbon	hydrogen	silicon
electronegativity	2.5	2.1	1.8

(i) C–H and Si–H bonds have weak dipoles.

Use the electronegativity values in the table to show the polarity of the C–H and Si–H bonds.

C—H Si—H

[2]

(ii) Explain why methane, CH_4, has no overall dipole moment.

....

....

.... [2]

Topic **Chem 3 Q# 72/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HC*l* and CaF_2.

	F_2	HC*l*	CaF_2
boiling point / K	85	188	2773
relative formula mass	38.0	36.5	78.1

(ii) F_2 and HC*l* are both covalent molecules.

Suggest why the boiling point of HC*l* is higher than that of F_2.

....

....

.... [2]

(iii) Explain why CaF_2 has a very high boiling point.

....

.... [1]

(c) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(i) Draw a 'dot-and-cross' diagram to represent the bonding in a molecule of HOF.

Show the outer shell electrons only.

[2]

(iv) Pure HF is a colourless liquid at 273 K. The liquid contains HF molecules that have strong hydrogen bonds between them.

Draw a fully labelled diagram to suggest how a hydrogen bond can form between two HF molecules.

[3]

Topic **Chem 3 Q# 73/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(ii) Draw a 'dot-and-cross' diagram of a nitrogen molecule. Show outer electrons only.

[1]

Topic **Chem 3 Q# 74/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) Describe the metallic bonding in gold.

....

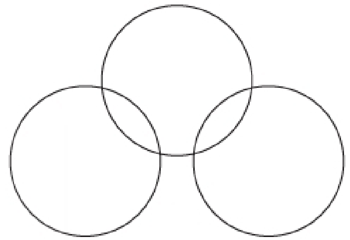
....

.... [2]

Topic **Chem 3 Q# 75/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(f) SO_2 reacts with water to form sulfurous acid.
Sulfurous acid is a weak Brønsted-Lowry acid, while sulfuric acid is a strong Brønsted-Lowry acid.

(i) Complete the 'dot-and-cross' diagram to show the bonding in a molecule of SO_2. Show outer electrons only.



[1]

Topic **Chem 3 Q# 76/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium and its compounds have a large variety of applications.

(b) Calcium ethanedioate is formed when calcium reacts with ethanedioic acid, $(CO_2H)_2$. The compound contains one cation and one anion.

(i) Draw the 'dot-and-cross' diagram of the cation present in calcium ethanedioate. Show **all** electrons.

[1]

(ii) Draw the displayed formula of the anion present in calcium ethanedioate.

[2]

Topic **Chem 3 Q# 77/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(iv) Predict the shape of the SiH_4 molecule.

.... [1]

Topic **Chem 3 Q# 78/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

N≡N = 944 kJ mol^{-1}
H–H = 436 kJ mol^{-1}

(i) Explain the meaning of the term *bond energy*.

....

.... [2]

Topic **Chem 3 Q# 79/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) **(i)** Name the strongest type of intermolecular force in ice.

.... [1]

(ii) Draw a fully labelled diagram of two water molecules in ice, showing the force in **(i)** and how it forms.

[3]

Topic **Chem 3 Q# 80/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

hydrogen halide	HF	HC*l*	HBr	HI
boiling point / °C	19	–85	–67	–35
H–X bond energy / kJ mol^{-1}	562	431	366	299

(a) **(i)** Explain the meaning of the term *bond polarity*.

....

....

.... [1]

(ii) Suggest why the boiling point of HF is **much** higher than the boiling points of the other hydrogen halides.

....

....

....

....

.... [2]

Topic **Chem 3 Q# 81/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

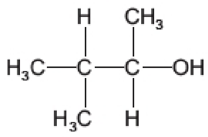
(c) Cerium is a lanthanoid metal that shows similar chemical reactions to some elements in the third period. Most of cerium's compounds contain Ce^{3+} or Ce^{4+} ions.

(i) Cerium shows the same structure and bonding as a typical metal.

Draw a labelled diagram to show the structure and bonding in cerium.

[2]

4 The following compounds were all found to be components of a sample of petrol.

$CH_3(CH_2)_2CH_3$ $(CH_3)_3CCH_2CH(CH_3)_2$ 

G   **H**   **J**

(d) The boiling points of compounds **G**, **H** and **J** are shown below.

compound	**G**	**H**	**J**
boiling point/°C	0	99	112

Explain the differences in the boiling points of the three compounds.

....

....

....

....

....

....

.... [4]

3 Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(a) **(i)** Draw a dot-and-cross diagram to represent the bonding in a molecule of ammonia, NH_3, and state the shape of the molecule.

shape of molecule .... [3]

3 Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(a) **(i)** Draw a dot-and-cross diagram to represent the bonding in a molecule of ammonia, NH_3, and state the shape of the molecule.

shape of molecule .... [3]

(ii) A molecule of hydrogen cyanide, HCN, is shown.

H—C≡N

The bonding between the carbon and nitrogen atoms consists of one sigma (σ) bond and two pi (π) bonds.

Sketch the shape of the sigma bond and one of the pi bonds in the space below. Show clearly the position of the atomic nuclei in each diagram.

sigma (σ)	pi (π)

[2]

Topic **Chem 3 Q# 84/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Aluminium is a metal in Period 3 and Group III of the Periodic Table.

(a) Describe the structure of solid aluminium.

....

....

.... [2]

(b) A common use of aluminium is to make the conducting cables in long distance overhead power lines.

(i) Suggest two properties of aluminium that make it suitable for this use.

....

....

.... [2]

(c) Aluminium reacts with chlorine to form a white, solid chloride that contains 79.7% chlorine and sublimes (changes straight from a solid to a gas) at 180 °C.

(i) Describe the structure and bonding in this compound. Suggest how it explains the low sublimation temperature.

....

....

....

....

.... [2]

Topic **Chem 3 Q# 85/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) **(i)** Sulfur dioxide and sulfur trioxide both contain only S=O double bonds.

Draw labelled diagrams to show the shapes of these two molecules.

SO_2 SO_3

[2]

(ii) For your diagrams in **(i)**, name the shapes and suggest the bond angles.

SO_2 shape .... SO_3 shape ....

SO_2 bond angle .... SO_3 bond angle ....

[2]

Topic **Chem 3 Q# 86/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(e) Sulfur reacts with fluorine to form SF_6. State the shape and bond angle of SF_6.

shape of SF_6 ....

bond angle of SF_6 ....

[2]

[Total: 18]

1 Valence Shell Electron Pair Repulsion theory (VSEPR) is a model of electron-pair repulsion (including lone pairs) that can be used to deduce the shapes of, and bond angles in, simple molecules.

(a) Complete the table below by using simple hydrogen-containing compounds. One example has been included.

number of bond pairs	number of lone pairs	shape of molecule	formula of a molecule with this shape
3	0	trigonal planar	BH_3
4	0		
3	1		
2	2		

[3]

(b) Tellurium, Te, proton number 52, is used in photovoltaic cells.

When fluorine gas is passed over tellurium at 150 °C, the colourless gas TeF_6 is formed.

(i) Draw a 'dot-and-cross' diagram of the TeF_6 molecule, showing outer electrons only.

(ii) What will be the shape of the TeF_6 molecule?

....

(iii) What is the F–Te–F bond angle in TeF_6?

....

[3]

[Total: 6]

(c) Fluorine reacts with other elements in Group VII to form a number of different compounds. Two such compounds and their boiling points are given in the table.

compound	ClF_3	BrF_3
boiling point / °C	12	127

(i) The two molecules have similar electronic configurations. Showing outer electrons only, draw a 'dot-and-cross' diagram of the bonding in ClF_3.

(ii) The two molecules have the same shape. Suggest why the boiling points are significantly different.

....

....

....

....

[4]

[Total: 15]

(f) Another sulfur compound which is present in the Earth's atmosphere is carbonyl sulfide, OCS. The sequence of atoms in the molecule is oxygen-carbon-sulfur and the molecule is **not** cyclic.

(i) Draw a 'dot-and-cross' diagram of the OCS molecule. Show outer electrons only.

(ii) Suggest a value for the O – C – S bond angle.

....

[2]

[Total: 15]

Topic **Chem 3 Q# 90/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Crude oil contains a mixture of hydrocarbons together with other organic compounds which may contain nitrogen, oxygen or sulfur in their molecules.

At an oil refinery, after the fractional distillation of crude oil, a number of other processes may be used including 'cracking', 'isomerisation', and 'reforming'.
One of the sulfur-containing compounds present in crude oil is ethanethiol, C_2H_5SH, the sulfur-containing equivalent of ethanol. Ethanethiol is toxic and is regarded as one of the smelliest compounds in existence.

(b) The boiling point of ethanol, C_2H_5OH, is higher than that of C_2H_5SH.
Suggest a reason for this difference.

....

....[1]

Topic **Chem 3 Q# 91/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

The formulae and melting points of the fluorides of the elements in Period 3, Na to Cl, are given in the table.

formula of fluoride	NaF	MgF_2	AlF_3	SiF_4	PF_5	SF_6	ClF_5
m.p./K	1268	990	1017	183	189	223	170

(c) **(i)** Suggest the formulae of **two** fluorides that could possibly be ionic.

....

(ii) What is the shape of the SF_6 molecule?

....

(iii) In the sequence of fluorides above, the oxidation number of the elements increases from NaF to SF_6 and then falls at ClF_5.
Attempts to make ClF_7 have failed but IF_7 has been prepared.
Suggest an explanation for the existence of IF_7 and for the non-existence of ClF_7.

....

....

....

[4]

[Total: 12]

Topic **Chem 3 Q# 92/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Elements and compounds which have small molecules usually exist as gases or liquids.

(a) Chlorine, Cl_2, is a gas at room temperature whereas bromine, Br_2, is a liquid under the same conditions.

Explain these observations.

....

....

.... [2]

(b) The gases nitrogen, N_2, and carbon monoxide, CO, are isoelectronic, that is they have the same number of electrons in their molecules.

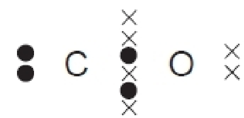
Suggest why N_2 has a lower boiling point than CO.

....

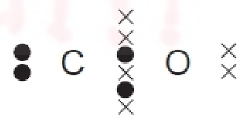
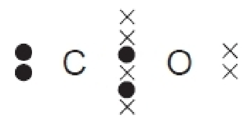
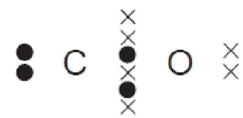
....

.... [2]

(c) A 'dot-and-cross' diagram of a CO molecule is shown below. Only electrons from outer shells are represented.



In the table below, there are three copies of this structure.
On the structures, draw a circle round a pair of electrons that is associated with **each** of the following.

(i) a co-ordinate bond	**(ii)** a covalent bond	**(iii)** a lone pair
		

[3]

Topic **Chem 3 Q# 93/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, Al, is in the third period of the Periodic Table; copper and titanium are both transition elements.

Aluminium reacts with chlorine.

(iii) At low temperatures, aluminium chloride vapour has the formula Al_2Cl_6.
Draw a 'dot-and-cross' diagram to show the bonding in Al_2Cl_6.
Show outer electrons only.
Represent the aluminium electrons by ●.
Represent the chlorine electrons by ***x***.

[2]

Topic Chem 4 Q# 94/ ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Carbon monoxide gas, CO(g), and nitrogen gas, N_2(g), are both diatomic molecules.

(c) Both carbon monoxide and nitrogen are gases at room temperature and pressure.

They both behave like ideal gases under certain conditions.

(i) State the **two** conditions necessary for these two gases to approach ideal gas behaviour.

....

.... [1]

(ii) Explain why N_2(g) behaves more like an ideal gas than CO(g) does at 20.0 °C and 101 kPa.

....

....

.... [2]

(d) Calculate the amount, in mol, of pure nitrogen gas which occupies 100 cm^3 at 101 kPa and 20.0 °C.

Use relevant information from the *Data Booklet*. Show your working.

Assume nitrogen behaves as an ideal gas.

.... mol [3]

[Total: 11]

Topic **Chem 4 Q# 95/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 The rate of chemical reactions is affected by changes in temperature and pressure.

(ii) 2.00 g of krypton gas, Kr(g), is placed in a sealed 5.00 dm^3 container at 120 °C.

Calculate the pressure, in Pa, of Kr(g) in the container.
Assume Kr(g) behaves as an ideal gas.

Show your working.

pressure = ... Pa [3]

(iii) State and explain the conditions at which krypton behaves most like an ideal gas.

....

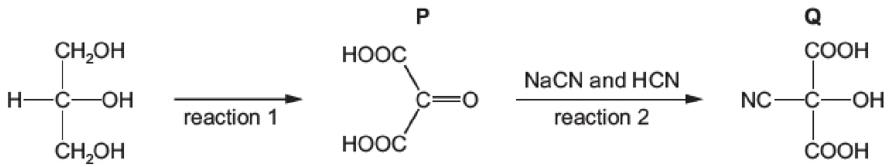
....

....

.... [2]

3 Glycerol, $CH_2(OH)CH(OH)CH_2OH$, is widely used in the food industry and in pharmaceuticals.

(a) A series of reactions starting from glycerol is shown.



(b) Glycerol can be used as a starting material in the manufacture of nitroglycerine, $C_3H_5N_3O_9$.

Nitroglycerine decomposes rapidly on heating to form a mixture of gases.

$$4C_3H_5N_3O_9(l) \rightarrow 12CO_2(g) + 10H_2O(g) + 6N_2(g) + O_2(g)$$

A sample of nitroglycerine decomposes, releasing 1.06 dm³ of $O_2(g)$ at 850 K and 1.00×10^5 Pa.

(i) Calculate the mass of nitroglycerine that decomposes.

mass of nitroglycerine = ... g [3]

(ii) Calculate the total volume of gas released by this decomposition at 850 K and 1.00×10^5 Pa.

total volume of gas = ... dm³ [1]

(iii) $Cl_2(g)$ does **not** behave as an ideal gas under these conditions.

Explain why $Cl_2(g)$ behaves even **less** ideally at:

- very high pressures

....

....

....

- very low temperatures.

....

....

.... [2]

[Total: 11]

Topic **Chem 4 Q# 98/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(c) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(d) Interhalogen compounds, such as $BrCl$ or IF_5, contain two or more different halogen atoms that are covalently bonded.

D is an interhalogen compound that contains only chlorine and fluorine.

At 0 °C and 101 325 Pa, 1 dm³ of **D** has a mass of 4.13 g.

(i) Use the general gas equation to calculate the relative molecular mass, M_r, of **D**.

M_r = ...
[3]

(ii) Use your answer to **(i)** to determine the molecular formula of **D**.

If you were unable to calculate the M_r in **(i)**, assume that the M_r is 130.5. This is **not** the correct value.

molecular formula of **D** = ...
[1]

Topic **Chem 4 Q# 99/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Carbon and silicon are elements in Group 14.

(a) C_{60} and diamond are allotropes of carbon.

(i) Describe the lattice structure of solid C_{60}.

....

....

....

.... [2]

(ii) C_{60} sublimes (turns directly from solid to gas) at about 800 K. Diamond also sublimes but only above 3800 K.

Explain why C_{60} and diamond sublime at such different temperatures.

....

....

....

....

....

....

....

.... [4]

(b) C_{60} forms hydrocarbons with similar chemical properties to those of alkenes. One such hydrocarbon is $C_{60}H_{18}$.

(i) State what is meant by the term *hydrocarbon*.

....

.... [1]

(ii) Describe a test to indicate the presence of double bonds between carbon atoms in $C_{60}H_{18}$. Give the result of the test.

test ....

....

result ....

....
[2]

(c) 0.144 g of C_{60} was placed in a 100 cm^3 container of hydrogen gas at 20 °C and 1.00×10^5 Pa.

The container was heated to make the C_{60} and hydrogen gas react.

The reaction occurred as shown in the equation.

$$C_{60}(s) + xH_2(g) \rightarrow C_{60}H_{2x}(s)$$

After the reaction, the container was allowed to cool to 20 °C. The pressure decreased to 2.21×10^4 Pa. All of the C_{60} had reacted.

(i) Name the type of reaction that occurred.

.... [1]

(ii) Calculate the amount, in moles, of C_{60} that reacted.

amount of C_{60} = ... mol [1]

(iii) Calculate the amount, in moles, of hydrogen gas that reacted with the C_{60}.

amount of hydrogen gas = ... mol [2]

(iv) Use your answers from **(ii)** and **(iii)** to deduce the molecular formula of the hydrocarbon, $C_{60}H_{2x}$.

If you were unable to calculate the amount of hydrogen gas, assume that 0.00240 mol of hydrogen gas reacted. This is **not** the correct value for the amount of hydrogen gas that reacted.

molecular formula = ... [2]

(d) Silicon shows the same kind of bonding and structure as diamond.

(i) State the type of bonding and structure shown by silicon.

....

....

.... [2]

Topic **Chem 4 Q# 100/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Structure and bonding can be used to explain many of the properties of substances.

(a) Copper, ice, silicon(IV) oxide, iodine and sodium chloride are all crystalline solids.

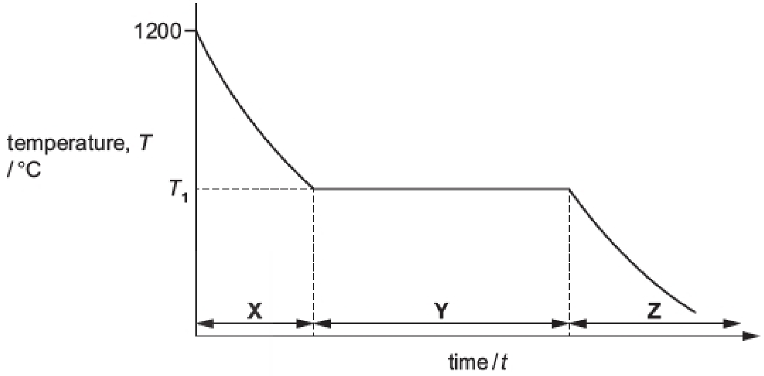
Complete the table with:

- the name of a type of bonding found in each crystalline solid,
- the type of lattice structure for each crystalline solid.

crystalline solid	type of bonding	type of lattice structure
copper		
ice		
silicon(IV) oxide		
iodine		
sodium chloride		

[5]

(c) The graph represents how the temperature of a sample of copper (melting point 1085 °C) changes as it is gradually cooled from 1200 °C.



(i) Identify the state(s) of matter present during each stage of the process shown in the graph.

X ....

Y ....

Z ....

[2]

(ii) State what is happening to the energy and movement of the particles in the copper during stage **X**.

....

....

.... [2]

(iii) Explain why the temperature stays constant at T_1 during stage **Y**.

....

....

....

.... [2]

[Total: 15]

Topic **Chem 4 Q# 101/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 This question is about Period 3 elements and their compounds.

(a) Give an explanation for each of the following statements.

(iii) Sodium is a better electrical conductor than phosphorus.

....

....

....

.... [2]

(iv) Magnesium is a better electrical conductor than sodium.

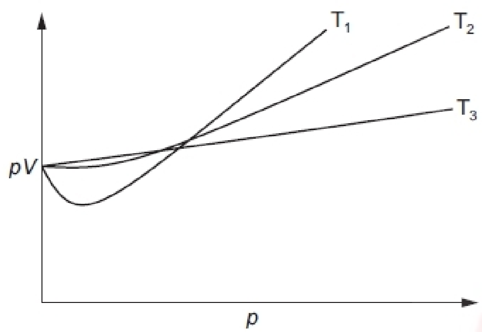
....

.... [1]

Topic **Chem 4 Q# 102/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The relationship $pV = nRT$ can be derived from the laws of mechanics by assuming ideal behaviour for gases.

(a) The graph represents the relationship between pV and p for a real gas at three different temperatures, T_1, T_2 and T_3.



(i) Draw **one** line on the graph to show what the relationship should be for the same amount of an **ideal** gas. [1]

(ii) State and explain, with reference to the graph, which of T_1, T_2 or T_3 is the lowest temperature.

....

.... [1]

(iii) Explain your answer to **(ii)** with reference to intermolecular forces.

....

.... [1]

(iv) State and explain the effect of pressure on the extent to which a gas deviates from ideal behaviour.

....

....

....

.... [2]

(b) A flask with a volume of $100\,cm^3$ was first weighed with air filling the flask, and then with another gas, **Y**, filling the flask. The results, measured at 26 °C and 1.00×10^5 Pa, are shown.

Mass of flask containing air	= 47.930 g
Mass of flask containing **Y**	= 47.989 g
Density of air	= $0.00118\,g\,cm^{-3}$

Calculate the relative molecular mass, M_r, of **Y**.

M_r of Y = ... [4]

Topic **Chem 4 Q# 103/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Some intercontinental jet airliners use kerosene as fuel. The formula of kerosene may be taken as $C_{14}H_{30}$.

Bicycles may be carried on commercial airliners. When carried on airliners, bicycles are placed in the luggage hold. This is a part of the aircraft which, in flight, will have different temperatures and air pressures from those at sea level.

This question concerns the change in pressure in an inflated bicycle tyre from when it is at sea level to when it is in the hold of an airliner in flight.

(d) At sea level and a temperature of 20 °C an inflated bicycle tyre contains 710 cm^3 of air at an internal pressure of 6×10^5 Pa.

Use the general gas equation $PV = nRT$ to calculate the amount, in moles, of air in the tyre at sea level.

[2]

The same bicycle, with its tyres inflated at sea level as described in **(d)** above, is placed in the luggage hold of an airliner. At a height of 10 000 m, the temperature in the luggage hold is 5 °C and the air pressure is 2.8×10^4 Pa.

(e) Assuming the volume of the tyre does not change, use your answer to **(d)** to calculate the pressure inside the tyre at a height of 10 000 m.

[2]

[Total: 10]

Topic Chem 5 Q# 104/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chlorides of Period 3 elements are shown in the list.

$NaCl$ $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(d) Sulfur, S_8, reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2. SCl_2 forms when sulfur reacts with an excess of chlorine.

reaction **1** $S_8(s) + 4Cl_2(g) \rightarrow 4S_2Cl_2(l)$ $\Delta H_r = -58.2\ kJ\,mol^{-1}$

reaction **2** $S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l)$ $\Delta H_r = -40.6\ kJ\,mol^{-1}$

(ii) Calculate the enthalpy change of formation, ΔH_f, of $SCl_2(l)$. You may find it useful to use Hess's Law to construct an energy cycle.

enthalpy change of formation of $SCl_2(l)$, ΔH_f = ... kJ mol^{-1} [2]

Topic **Chem 5 Q# 105/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

(f) Magnesium, Mg, burns in oxygen, O_2.
The activation energy, E_a, for this reaction is +148 kJ mol^{-1}.

(ii) On Fig. 1.1:

- sketch a reaction pathway diagram for the reaction that occurs when Mg burns in O_2
- label the diagram to show the enthalpy change, ΔH, and the activation energy, E_a, for the reaction.

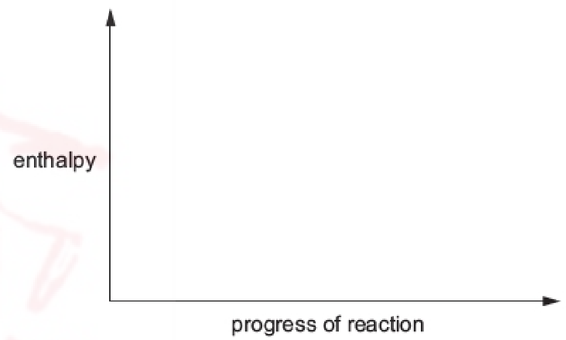


Fig. 1.1

[3]

Topic **Chem 5 Q# 106/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O Al_2O_3 P_4O_6 P_4O_{10} SO_2 SO_3

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(d)

(iii) When P_4O_6(s) is heated with oxygen it forms P_4O_{10}(s).

$$P_4O_6(s) + 2O_2(g) \rightarrow P_4O_{10}(s) \qquad \Delta H_r = -1372\ kJ\ mol^{-1}$$

The enthalpy change of formation, ΔH_f, of P_4O_{10}(s) is –3012 kJ mol^{-1}.

Calculate the enthalpy change of formation, ΔH_f, of P_4O_6(s).

ΔH_f of P_4O_6(s) = ... kJ mol^{-1} [1]

Topic **Chem 5 Q# 107/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Phosphorus is a reactive Period 3 element.

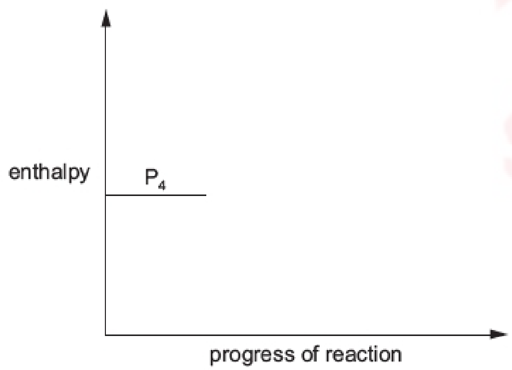
(a) Phosphorus has several allotropes. Details of two allotropes are given.

allotrope of phosphorus	formula	melting point/°C
white	P_4	44
red	P	590

(ii) Red phosphorus (P) forms when white phosphorus (P_4) is exposed to sunlight.

$$\tfrac{1}{4}P_4(s) \rightarrow P(s) \qquad \Delta H = -17.6\ kJ\ mol^{-1}$$
white → red

Use this information to draw a reaction pathway diagram to show the formation of red phosphorus (P) from white phosphorus (P_4).



[1]

Topic **Chem 5 Q# 108/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Sulfides are compounds that contain sulfur but not oxygen.

(a) Carbon disulfide, CS_2, is a volatile liquid at room temperature and pressure.

(b) The enthalpy change of combustion of CS_2(l) is represented by the following equation.

$$CS_2(l) + 3O_2(g) \xrightarrow{\Delta H_c} CO_2(g) + 2SO_2(g)$$

(i) Define *enthalpy change of combustion*.

....

....

.... [2]

(ii) The table shows the enthalpy changes of formation of CS_2(l), CO_2(g) and SO_2(g).

compound	enthalpy change of formation, ΔH_f/kJ mol^{-1}
CS_2(l)	+89.7
CO_2(g)	–394
SO_2(g)	–297

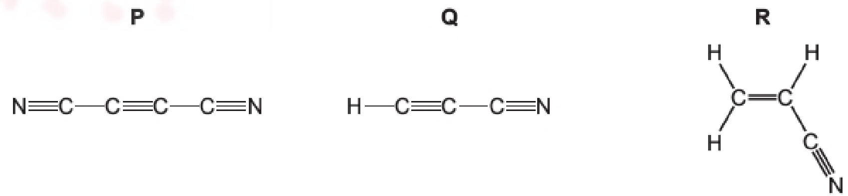
Use the data in the table to calculate the enthalpy change of combustion, ΔH_c, of CS_2(l), in kJ mol^{-1}.

Show your working.

ΔH_c of CS_2(l) = ... kJ mol^{-1} [2]

Topic **Chem 5 Q# 109/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.



(a) The equation for the complete combustion of **P**, C_4N_2(l), is shown.

$$C_4N_2(l) + 4O_2(g) \rightarrow 4CO_2(g) + N_2(g) \qquad \Delta H = -2036\ kJ\ mol^{-1}$$

(i) The enthalpy change of formation, ΔH_f, of $CO_2(g)$ is –384 kJ mol^{-1}.

Calculate the enthalpy change of formation, ΔH_f, of **P**, in kJ mol^{-1}.

ΔH_f of **P** = ... kJ mol^{-1} [2]

Topic **Chem 5 Q# 110/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(c) Krypton reacts with fluorine in the presence of ultraviolet light to make krypton difluoride, $KrF_2(g)$.

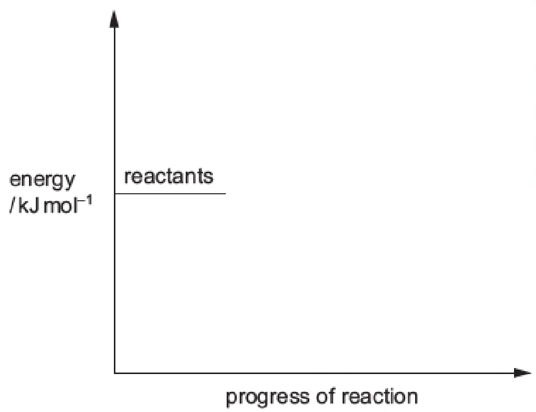
$$Kr(g) + F_2(g) \rightarrow KrF_2(g)$$

activation energy for the reaction, E_a = +385 kJ mol^{-1}

enthalpy change of formation of KrF_2, ΔH_f = +60.2 kJ mol^{-1}

(i) Use this information to complete the reaction profile diagram for the formation of KrF_2. Label E_a and ΔH_f on the diagram.

Assume the reaction proceeds in one step.



[2]

Topic **Chem 5 Q# 111/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) Emissions of SO_2 from coal-fired power stations can be reduced by mixing the coal with powdered limestone.

Limestone is heated to form CaO in reaction 1. This then reacts with SO_2 and O_2 to form $CaSO_4$ in reaction 2.

reaction 1: $CaCO_3(s) \rightarrow CaO(s) + CO_2(s)$

reaction 2: $CaO(s) + SO_2(g) + \frac{1}{2}O_2(g) \rightarrow CaSO_4(s)$

(i) State the type of reaction occurring in reaction 1.

.... [1]

(ii) Use the data to calculate the enthalpy change of reaction 2.

compound	ΔH_f/kJ mol^{-1}
CaO(s)	–635
$SO_2(g)$	–297
$CaSO_4(s)$	–1434

enthalpy change of reaction 2 = ... kJ mol^{-1} [2]

3 Nitric acid, HNO_3, can be made by reacting nitrogen dioxide with water.

The enthalpy change for the reaction can be measured indirectly using a Hess' cycle.

$$3NO_2(g) + H_2O(l) \xrightarrow{\Delta H_r} 2HNO_3(l) + NO(g)$$

(a) Explain what is meant by the term *enthalpy change of formation*.

....

....

.... [2]

(b) Complete the Hess' cycle using the values given in the table and hence calculate the enthalpy change, ΔH_r, for this reaction.

Show your working.

substance	ΔH_f / kJ mol^{-1}
$NO_2(g)$	34.0
$H_2O(l)$	–286
$HNO_3(l)$	–173
$NO(g)$	91.1

$$3NO_2(g) \quad + \quad H_2O(l) \xrightarrow{\Delta H_r} 2HNO_3(l) \quad + \quad NO(g)$$

ΔH_r = ... kJ mol^{-1} [3]

(g) Magnesium peroxide, MgO_2, is made in the following reaction.

$$MgO(s) + H_2O_2(l) \rightarrow MgO_2(s) + H_2O(l) \qquad \Delta H = -96\,kJ\,mol^{-1}$$

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$MgO(s)$	–602
$H_2O_2(l)$	–188
$H_2O(l)$	–286

(i) The peroxide ion is O_2^{2-}.

Deduce the average oxidation number of oxygen in the peroxide ion.

.... [1]

(ii) Define the term *enthalpy change of formation*.

....

....

.... [2]

(iii) Use the data given to calculate the enthalpy change of formation of $MgO_2(s)$.

ΔH_f $MgO_2(s)$ = ... kJ mol^{-1} [2]

(iv) Magnesium peroxide decomposes slowly to form magnesium oxide and oxygen.

$$MgO_2(s) \rightarrow MgO(s) + \frac{1}{2}O_2(g)$$

Use your answer to **(g)(iii)** and the data in the table to calculate the enthalpy change of this reaction.

If you were unable to obtain an answer to **(g)(iii)**, *use the value* ΔH_f = –550 kJ mol[–1]. *This is* ***not*** *the correct answer.*

enthalpy change of reaction = ... kJ mol^{-1} [1]

[Total: 19]

Topic **Chem 5 Q# 114/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Crude oil is a natural source of hydrocarbons that are used as fuels.

(b) Thiophene, $C_4H_4S(l)$, is an organic compound that is found as a contaminant in crude oil.

(ii) A student carries out an experiment to determine the enthalpy change of combustion of $C_4H_4S(l)$.

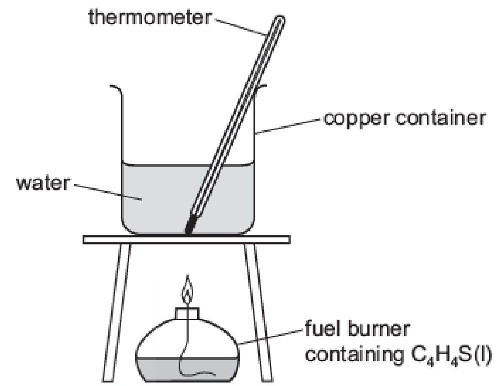
Explain the meaning of the term *enthalpy change of combustion*.

....

....

.... [2]

(iii) The student uses the following apparatus in the experiment.



mass of water in copper container / g	200
initial temperature of water / °C	18.5
highest temperature of water / °C	37.5

Calculate the heat energy released, in J, by the reaction.

Assume that 4.18 J of heat energy changes the temperature of 1.0 cm^3 of water by 1.0 °C.

Assume no heat is lost to the surroundings.

heat energy released = ... J [2]

(iv) The student used 0.63 g of $C_4H_4S(l)$ in the experiment.

Calculate the enthalpy change of combustion of thiophene, $\Delta H_c(C_4H_4S(l))$. Include a sign in your answer.

$\Delta H_c(C_4H_4S(l))$ = ... kJ mol^{-1} [2]

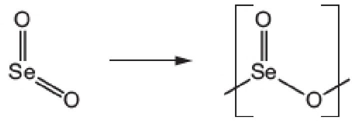
[Total: 13]

Topic **Chem 5 Q# 115/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c)

(ii) The most stable oxide of selenium is SeO_2.

Gaseous SeO_2 reacts to form a solid polymer, as shown. In the reaction one Se=O is replaced by two Se–O to form a polymer.



$\Delta H = -346\,kJ\,mol^{-1}$

The bond enthalpy of Se=O is $514\,kJ\,mol^{-1}$.

Use these data to calculate the bond enthalpy, in $kJ\,mol^{-1}$, of Se–O.

bond enthalpy of Se–O = ... $kJ\,mol^{-1}$ [2]

Topic **Chem 5 Q# 116/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(e) SiH_4 reacts in air without heating but CH_4 must be ignited before combustion occurs.

$$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Suggest, with reference to bond energies from the *Data Booklet*, why SiH_4 reacts in air without heating but CH_4 must be ignited.

....

....

.... [2]

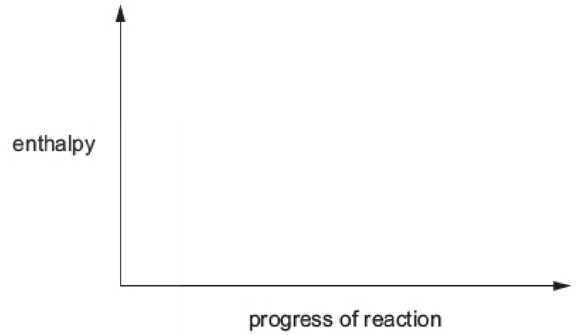
Topic **Chem 5 Q# 117/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(c) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(iii) HOF is an unstable compound and decomposes to form HF and O_2.

$$HOF \rightarrow HF + \tfrac{1}{2}O_2 \qquad \Delta H = -139\,kJ\,mol^{-1}$$

Draw a fully labelled reaction pathway diagram on the axes provided to show the decomposition of HOF into HF and O_2.



[2]

Topic **Chem 5 Q# 118/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 Nitrogen, N_2, is the most abundant gas in the Earth's atmosphere and is very unreactive.

(iii) Molecules of N_2O can be formed by the reaction between N_2 and O_2. The bond between the N and O atoms (N→O) is a co-ordinate (dative covalent) bond.

$$2N_2(g) + O_2(g) \rightarrow 2N{\equiv}N{\rightarrow}O(g)$$

The enthalpy change of reaction for this reaction is $+82\,kJ\,mol^{-1}$.

Calculate the bond enthalpy, in $kJ\,mol^{-1}$, of the N→O bond.

Use relevant data from the *Data Booklet* to answer this question.

bond enthalpy of the N→O bond = ... $kJ\,mol^{-1}$ [2]

Topic **Chem 5 Q# 119/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(ii) An important reaction of $CHCl_3$(g) is the manufacture of $CHClF_2$(g), using the following reversible reaction.

$$CHCl_3(g) + 2HF(g) \rightleftharpoons CHClF_2(g) + 2HCl(g)$$

Use the data to calculate the enthalpy change of reaction, ΔH_r, for the formation of $CHClF_2$(g) as shown in the equation.

compound	enthalpy change of formation, ΔH_f / kJ mol^{-1}
$CHCl_3$(g)	–103.2
$CHClF_2$(g)	–482.2
HF(g)	–273.3
HCl(g)	–92.3

enthalpy change of reaction, ΔH_r = ... kJ mol^{-1} [3]

Topic **Chem 5 Q# 120/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2O{=}\overset{\displaystyle O \atop \|}{S}{=}O(g) \qquad \Delta H = -196\ kJ\ mol^{-1}$$

(b) Some bond energies are given.

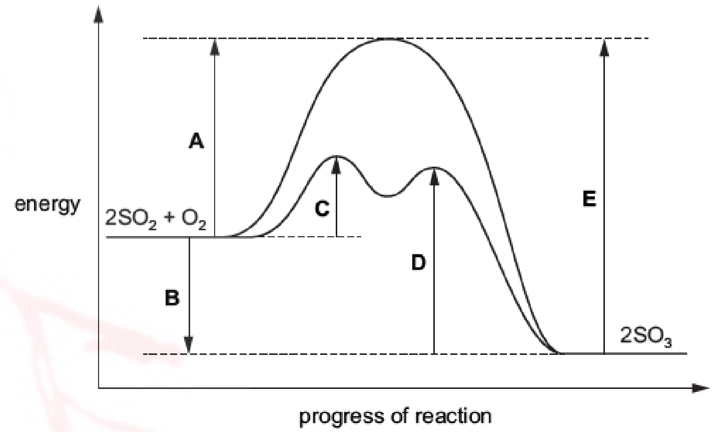
bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO_3.

S=O bond energy in SO_3 = ... kJ mol^{-1} [2]

The Contact process is usually carried out at a temperature of about 400 °C and a pressure just above atmospheric pressure. Using a higher or lower temperature and pressure would affect both the rate of production of sulfur trioxide and the yield of sulfur trioxide.

(c) A reaction pathway diagram for both the catalysed and uncatalysed reactions between SO_2 and O_2 is shown.



The letters **A**–**E** represent energy changes.

Complete the table by stating which letter, **A**–**E**, represents the energy change described.

energy change	letter
the energy change for the production of SO_3	
the activation energy for the production of SO_3 in the absence of a catalyst	
the activation energy for the first step in the **decomposition** of SO_3 in the presence of a catalyst	

[3]

Topic **Chem 5 Q# 121/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

N≡N = 944 kJ mol^{-1}
H–H = 436 kJ mol^{-1}

(ii) Use the data to calculate a value for the N–H bond energy.
You must show your working.

N–H bond energy = ... kJ mol^{-1} [2]

Topic **Chem 5 Q# 122/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(c) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(i) Use the data in the table to calculate the overall enthalpy change of reaction.

compound	enthalpy change of formation / kJ mol^{-1}
$HCl(g)$	–92
$H_2O(g)$	–242

enthalpy change of reaction = ... kJ mol^{-1} [2]

Topic **Chem 5 Q# 123/** ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 For many compounds the enthalpy change of formation cannot be calculated directly. An indirect method based on enthalpy changes of combustion can be used.

The enthalpy change of combustion can be found by a calorimetry experiment in which the heat energy given off during combustion is used to heat a known mass of water and the temperature change recorded.

(a) **(i)** Explain the meaning of the term *standard enthalpy change of combustion*.

....

....

.... [3]

(ii) Write the equation for the complete combustion of ethanol, C_2H_5OH.

.... [1]

(b) In an experiment to determine the enthalpy change of combustion of ethanol, 0.23 g of ethanol was burned and the heat given off raised the temperature of 100 g of water by 16.3 °C.

(i) Calculate the heat energy change, q, during the combustion of 0.23 g of ethanol.

q = ... J [1]

(ii) Calculate the enthalpy change on burning 1 mole of ethanol. Include a sign in your answer.

ΔH = ... kJ mol^{-1} [1]

(iii) Suggest **two** reasons why the value for the enthalpy change of combustion of ethanol determined by a simple laboratory calorimetry experiment is likely to be lower than the true value.

....

....

....

.... [2]

(c) The table gives some enthalpy change of combustion values.

substance	enthalpy change of combustion / kJ mol^{-1}
C(s)	–393.5
H_2(g)	–285.8
C_3H_7OH(l)	–2021.0

(i) Construct a labelled energy cycle to show how these values could be used to calculate the enthalpy change of formation of C_3H_7OH(l), ΔH_f.

$$3C(s) + 4H_2(g) + \frac{1}{2}O_2(g) \xrightarrow{\Delta H_f} C_3H_7OH(l)$$

[3]

(ii) Calculate the enthalpy change of formation, ΔH_f, of C_3H_7OH(l).

ΔH_f = ... kJ mol^{-1} [2]

[Total: 13]

2 **(a)** **(i)** Explain the meaning of the term *enthalpy change of formation*.

....

....

.... [2]

(ii) Give the equation for the reaction for which the enthalpy change corresponds to the standard enthalpy change of formation of liquid sulfur trioxide, SO_3. Include state symbols.

.... [1]

(b) Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(i) Use bond energies from the *Data Booklet* to calculate the enthalpy change of reaction for the Haber process. Include a sign in your answer.

enthalpy change .... kJ mol^{-1} [3]

3 Ethanal reacts with hydrogen cyanide, in the presence of a small amount of NaCN, as shown.

$$CH_3CHO + HCN \rightarrow CH_3CH(OH)CN$$

(a) Use bond energies from the *Data Booklet* to calculate the enthalpy change for this reaction. Include a sign with your answer.

enthalpy change = ... kJ mol^{-1} [3]

5 Propane, C_3H_8, and butane, C_4H_{10}, are components of Liquefied Petroleum Gas (LPG) which is widely used as a fuel for domestic cooking and heating.

(c) Propane and butane have different values of standard enthalpy change of combustion.

Define the term *standard enthalpy change of combustion*.

....

....

.... [2]

(d) A 125 cm^3 sample of propane gas, measured at 20 °C and 101 kPa, was completely burnt in air.
The heat produced raised the temperature of 200 g of water by 13.8 °C.
Assume no heat losses occurred during this experiment.

(i) Use the equation $pV = nRT$ to calculate the mass of propane used.

(ii) Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

(iii) Use the data above and your answers to **(i)** and **(ii)** to calculate the energy produced by the burning of 1 mol of propane.

[5]

Topic **Chem 5 Q# 127/** ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Ammonium nitrate fertiliser is manufactured from ammonia. The first reaction in the manufacture of the fertiliser is the catalytic oxidation of ammonia to form nitrogen monoxide, NO. This is carried out at about 1×10^3 kPa (10 atmospheres) pressure and a temperature of 700 to 850 °C.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^{\ominus} = -906\ kJ\ mol^{-1}$$

(c) The standard enthalpy changes of formation of $NH_3(g)$ and $H_2O(g)$ are as follows.

$NH_3(g)$, $\Delta H_f^{\ominus} = -46.0\ kJ\ mol^{-1}$ $\qquad$ $H_2O(g)$, $\Delta H_f^{\ominus} = -242\ kJ\ mol^{-1}$

Use these data and the value of $\Delta H^{\ominus}_{reaction}$ given below to calculate the standard enthalpy change of formation of NO(g).
Include a sign in your answer.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^{\ominus} = -906\ kJ\ mol^{-1}$$

[4]

[Total: 10]

Topic **Chem 5 Q# 128/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Methanol, CH_3OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

(a) Define, with the aid of an equation which includes state symbols, the standard enthalpy change of formation of carbon dioxide.

equation ....

definition ....

....

.... [3]

(b) Relevant $\Delta H_f^\ominus$ values for the reaction that synthesises methanol are given in the table.

compound	$\Delta H_f^\ominus$ / kJ mol^{-1}
$CO_2(g)$	–394
$CH_3OH(g)$	–201
$H_2O(g)$	–242

(i) Use these values to calculate $\Delta H^\ominus_{reaction}$ for this synthesis of methanol.

Include a sign in your answer.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g)$$

$\Delta H^\ominus_{reaction}$ = ... kJ mol^{-1} [3]

Topic **Chem 5 Q# 129/** ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 For some chemical reactions, such as the thermal decomposition of potassium hydrogencarbonate, $KHCO_3$, the enthalpy change of reaction cannot be measured directly.

In such cases, the use of Hess' Law enables the enthalpy change of reaction to be calculated from the enthalpy changes of other reactions.

(a) State Hess' Law.

....

....

.... [2]

In order to determine the enthalpy change for the thermal decomposition of potassium hydrogencarbonate, two separate experiments were carried out.

experiment 1

30.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid (an excess) was placed in a conical flask and the temperature recorded as 21.0 °C.
When 0.0200 mol of potassium carbonate, K_2CO_3, was added to the acid and the mixture stirred with a thermometer, the maximum temperature recorded was 26.2 °C.

(b) (i) Construct a balanced equation for this reaction.

....

(ii) Calculate the quantity of heat produced in **experiment 1**, stating your units.
Use relevant data from the *Data Booklet* and assume that all solutions have the same specific heat capacity as water.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of K_2CO_3.
Give your answer in kJ mol^{-1} and include a sign in your answer.

(iv) Explain why the hydrochloric acid must be in an excess.

....

.... [4]

experiment 2

The experiment was repeated with 0.0200 mol of potassium hydrogencarbonate, $KHCO_3$.
All other conditions were the same.
In the second experiment, the temperature fell from 21.0 °C to 17.3 °C.

(c) (i) Construct a balanced equation for this reaction.

....

(ii) Calculate the quantity of heat absorbed in **experiment 2**.

(iii) Use your answer to **(ii)** to calculate the enthalpy change per mole of $KHCO_3$.
Give your answer in kJ mol^{-1} and include a sign in your answer.

[3]

(d) When $KHCO_3$ is heated, it decomposes into K_2CO_3, CO_2 and H_2O.

$$2KHCO_3 \rightarrow K_2CO_3 + CO_2 + H_2O$$

Use Hess' Law and your answers to **(b)(iii)** and **(c)(iii)** to calculate the enthalpy change for this reaction.
Give your answer in kJ mol^{-1} and include a sign in your answer.

[2]

Topic **Chem 5 Q# 130/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(d) The standard enthalpy change of combustion of C_2H_2, ΔH°_c, is –1300 kJ mol^{-1} at 298 K.

Values of relevant standard enthalpy changes of formation, ΔH°_f, measured at 298 K, are given in the table.

substance	ΔH°_f/kJ mol^{-1}
$CO_2(g)$	–394
$H_2O(l)$	–286

(i) Write balanced equations, with state symbols, that represent

the standard enthalpy change of combustion, ΔH°_c, of C_2H_2, and

....

the standard enthalpy change of formation, ΔH°_f, of C_2H_2.

....

(ii) Use the data above and your answer to **(i)** to calculate the standard enthalpy change of formation, ΔH°_f, of C_2H_2.
Show clearly whether the standard enthalpy change of formation of C_2H_2 has a positive or negative value.

[6]

Topic **Chem 5 Q# 131/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

The unsaturated hydrocarbon, **E**, is obtained by cracking hexane and is important in the chemical industry.

The standard enthalpy change of combustion of **E** is –2059 kJ mol^{-1}.

(d) Define the term *standard enthalpy change of combustion.*

....

.... [2]

Topic **Chem 5 Q# 132/** ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Alkanes such as methane, CH_4, undergo few chemical reactions. Methane will, however, react with chlorine but not with iodine.

Relevant standard enthalpy changes of formation for the reaction of methane with chlorine to form chloromethane, CH_3Cl, are given below.

	ΔH°_f/kJ mol^{-1}
CH_4	–75
CH_3Cl	–82
HCl	–92

(a) **(i)** Use the data to calculate $\Delta H^{\circ}_{reaction}$ for the formation of CH_3Cl.

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

(ii) The corresponding reaction with iodine does **not** take place.

Use bond energy data from the *Data Booklet* to calculate a 'theoretical value' for $\Delta H_{reaction}$ for the following equation.

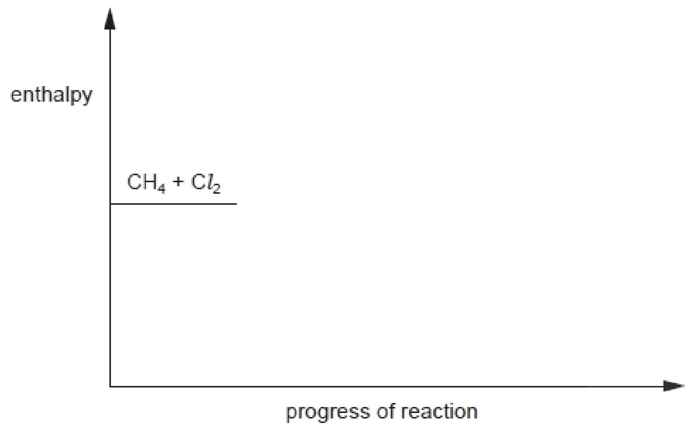
$$CH_4 + I_2 \rightarrow CH_3I + HI$$

(iii) Suggest why this reaction does **not** in fact occur.

....

.... [5]

(c) The energy of activation for the formation of CH_3Cl is 16 kJ mol^{-1}.
Use this figure and your answer to **(a)(i)** to complete the reaction pathway diagram below showing the formation of CH_3Cl from CH_4 and Cl_2.
Show clearly the intermediate organic species and the final products.
Indicate on your sketch the relevant enthalpy changes and their values.



[4]

[Total: 16]

Topic **Chem 5 Q# 133/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium will react on heating with chlorine, or oxygen, or nitrogen to give the chloride, or oxide, or nitride respectively. Each of these compounds is ionic and in them magnesium has the same +2 oxidation state.

(a) **(i)** Write an equation, with state symbols, for the **second** ionisation energy of magnesium.

....

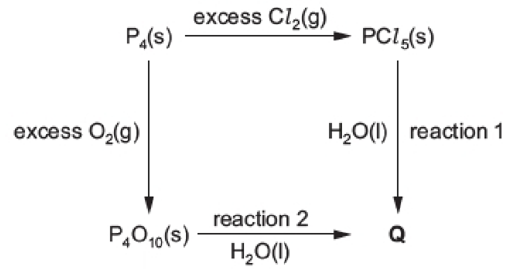
(ii) Use the *Data Booklet* to calculate the enthalpy change that occurs when one mole of gaseous magnesium ions, Mg^{2+}, is formed from one mole of gaseous magnesium atoms.

Include a sign in your answer.

enthalpy change = ... kJ mol^{-1} [3]

Topic Chem 6 Q# 134/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) Some reactions of $P_4(s)$ are shown in the reaction scheme.



(i) State the oxidation number of phosphorus in P_4O_{10}.

.... [1]

Topic **Chem 6 Q# 135/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(iii) $H_2S(aq)$ reacts slowly with oxygen dissolved in water. The reaction is represented by the following equation.

$$H_2S(aq) + \frac{1}{2}O_2(aq) \rightarrow H_2O(l) + S(s)$$

Explain, with reference to oxidation numbers, why this reaction is a redox reaction.

....

....

....

.... [2]

Topic **Chem 6 Q# 136/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 **(a)** The equation shown in **(a)(i)** describes the reaction which occurs when aqueous potassium iodide is added to aqueous copper(II) sulfate. A white precipitate of copper(I) iodide forms in a brown solution of iodine and potassium sulfate.

(i) Balance the equation and include state symbols.

......$CuSO_4$(.....) + ...KI(.....) → ......CuI(.....) + ...I_2(.....) + ...K_2SO_4(.....)

[2]

The table gives the oxidation numbers of iodine in the different species in the equation.

iodine-containing species	oxidation number of iodine
KI	–1
CuI	–1
I_2	0

(ii) Deduce the oxidation number of copper in $CuSO_4$ and CuI.

- oxidation number of copper in $CuSO_4$ ....
- oxidation number of copper in CuI ....

[1]

(iii) Describe the type of reaction shown by the equation in **(a)(i)**. Explain your answer in terms of electron transfer.

....

....

.... [2]

Topic **Chem 6 Q# 137/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Chlorine can be prepared using the following reaction.

$$MnO_2(s) + 4HCl(aq) \rightarrow MnCl_2(aq) + 2H_2O(l) + Cl_2(g)$$

(i) Explain why $MnO_2(s)$ is described as an oxidising agent in this reaction.

Refer to oxidation numbers in your answer.

....

.... [1]

Topic **Chem 6 Q# 138/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Iron pyrite, FeS_2, has a yellow colour that makes it look like gold metal. The compound contains the ions Fe^{2+} and S_2^{2-}.

(ii) Calculate the oxidation number of sulfur in the S_2^{2-} ion.
Assume that each sulfur atom in the ion has the same oxidation number.

oxidation number of sulfur in the S_2^{2-} ion = ... [1]

Topic **Chem 6 Q# 139/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** The table shows information about some of the elements in the third period.

element	Na	Mg	Al	P	S	Cl
atomic radius / nm	0.186	0.160	0.143	0.110	0.104	0.099
radius of most common ion / nm	0.095	0.065	0.050	0.212	0.184	0.181
maximum oxidation number of the element in its compounds	+1					+7

(i) Complete the table to show the maximum oxidation number of each element in its compounds. [1]

Topic **Chem 6 Q# 140/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Spathose is an iron ore that contains iron(II) carbonate, $FeCO_3$. The percentage of iron(II) carbonate in spathose can be determined by titration with acidified potassium dichromate(VI) solution using a suitable indicator.

The ionic equation is shown below.

$$Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6Fe^{2+}(aq) \rightarrow 2Cr^{3+}(aq) + 6Fe^{3+}(aq) + 7H_2O(l)$$

(a) A 5.00 g sample of spathose was reacted with excess concentrated hydrochloric acid and then filtered.
The filtrate was made up to 250 cm^3 in a volumetric flask with distilled water.

A 25.0 cm^3 sample of the standard solution required 27.30 cm^3 of 0.0200 mol dm^{-3} dichromate(VI) solution for complete reaction.

(i) Calculate the amount, in moles, of dichromate(VI) ions used in the titration.

amount = ... mol [1]

(ii) Use your answer to **(i)** to calculate the amount, in moles, of Fe^{2+} present in the 25.0 cm^3 sample.

amount = ... mol [1]

(iii) Use your answer to **(ii)** to calculate the amount, in moles, of Fe^{2+} present in the 250 cm^3 volumetric flask.

amount = ... mol [1]

(iv) Use your answer to **(iii)** to calculate the mass of iron(II) carbonate present in the sample of spathose.

mass = ... g [2]

(v) Calculate the percentage of iron(II) carbonate in the sample of spathose.

percentage of iron(II) carbonate = ... % [1]

(b) Iron ores containing iron(III) compounds can be analysed using a similar method.

A standard solution of an aqueous iron(III) compound is reacted with aqueous tin(II) chloride. Aqueous tin(IV) chloride and aqueous iron(II) chloride are the products of this reaction.

(i) Write an **ionic** equation for this reaction. Do not include state symbols.

.... [2]

(ii) Any excess tin(II) chloride can be removed by reaction with $HgCl_2(aq)$. A white precipitate of Hg_2Cl_2 is produced.

Complete the equation for this reaction.

..........(.....) + ...$HgCl_2(aq) \rightarrow SnCl_4(.....) + Hg_2Cl_2(.....)$

[2]

[Total: 10]

Topic **Chem 6 Q# 141/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) A compound of barium, **A**, is used in fireworks as an oxidising agent and to produce a green colour.

(i) Explain, in terms of electron transfer, what is meant by the term *oxidising agent*.

....

.... [1]

Topic **Chem 6 Q# 142/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The commonest form of iron(II) sulfate is the heptahydrate, $FeSO_4.7H_2O$. On heating at 90 °C this loses **some** of its water of crystallisation to form a different hydrated form of iron(II) sulfate, $FeSO_4.xH_2O$.

3.40 g of $FeSO_4.xH_2O$ was dissolved in water to form 250 cm^3 of solution.

A 25.0 cm^3 sample of this solution was acidified and titrated with 0.0200 mol dm^{-3} potassium manganate(VII).

In this titration 20.0 cm^3 of this potassium manganate(VII) solution was required to react fully with the Fe^{2+} ions present in the sample.

(a) The MnO_4^- ions in the potassium manganate(VII) *oxidise* the Fe^{2+} ions in the acidified solution.

(i) Explain, in terms of electron transfer, the meaning of the term *oxidise* in the sentence above.

....

.... [1]

(ii) Complete and balance the ionic equation for the reaction between the manganate(VII) ions and the iron(II) ions.

$MnO_4^-(aq) + 5Fe^{2+}(aq) +$ ....$H^+(aq) \rightarrow$ ....$(aq) + 5Fe^{3+}(aq) +$ ....$H_2O(l)$

[3]

(b) **(i)** Calculate the number of moles of manganate(VII) used in the titration.

[1]

(ii) Use the equation in **(a)(ii)** and your answer to **(b)(i)** to calculate the number of moles of Fe^{2+} present in the 25.0 cm^3 sample of solution used.

[1]

(iii) Calculate the number of moles of $FeSO_4.xH_2O$ in 3.40 g of the compound.

[1]

(iv) Calculate the relative formula mass of $FeSO_4.xH_2O$.

[1]

(v) The relative formula mass of anhydrous iron(II) sulfate, $FeSO_4$, is 151.8.

Calculate the value of x in $FeSO_4.xH_2O$.

[1]

[Total: 9]

Topic **Chem 6 Q# 143/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium will react on heating with chlorine, or oxygen, or nitrogen to give the chloride, or oxide, or nitride respectively. Each of these compounds is ionic and in them magnesium has the same +2 oxidation state.

(c) Magnesium burns in nitrogen to give magnesium nitride, a yellow solid which has the formula Mg_3N_2.

Magnesium nitride reacts with water to give ammonia and magnesium hydroxide.

(i) Construct an equation for the reaction of magnesium nitride with water.

....

(ii) Does a redox reaction occur when magnesium nitride reacts with water?

Use the oxidation numbers of nitrogen to explain your answer.

....

....

....

....

[4]

Topic Chem 7 Q# 144/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chlorides of Period 3 elements are shown in the list.

$NaCl$ $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(d) Sulfur, S_8, reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2. SCl_2 forms when sulfur reacts with an excess of chlorine.

reaction **1** $S_8(s) + 4Cl_2(g) \rightarrow 4S_2Cl_2(l)$ $\Delta H_r = -58.2\,kJ\,mol^{-1}$

reaction **2** $S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l)$ $\Delta H_r = -40.6\,kJ\,mol^{-1}$

(iii) State the effect of a decrease in pressure on the position of equilibrium in reaction **2**. Explain your answer.

....

....

.... [1]

Topic **Chem 7 Q# 145/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Nitrogen molecules, $N_2(g)$, contain two atoms attracted to each other by a triple covalent bond.

(d) 25 cm^3 of 0.10 $mol\,dm^{-3}$ $HCl(aq)$ is added to a beaker and its pH is recorded.

50 cm^3 of 0.10 $mol\,dm^{-3}$ $NH_3(aq)$ is added to the $HCl(aq)$ in 5 cm^3 portions.

The pH of the mixture is monitored until all the $NH_3(aq)$ is added.

HCl is a strong Brønsted-Lowry acid.

(i) Describe what is meant by a strong Brønsted-Lowry acid.

....

.... [2]

(ii) NH_3 is a weak base.

Construct an equation that shows the behaviour of NH_3 as a weak Brønsted-Lowry base when dissolved in water.

.... [1]

(iii) On Fig. 2.1 sketch a graph to show the change in pH which occurs when $HCl(aq)$ is titrated with $NH_3(aq)$ as described in **(d)**.

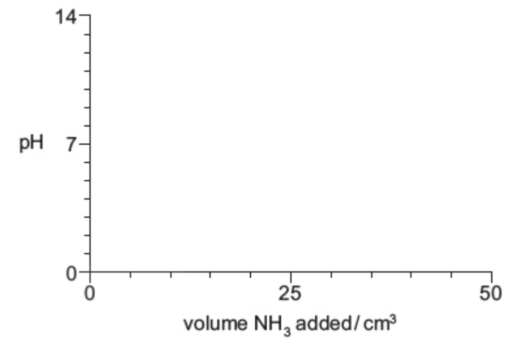


Fig. 2.1

[2]

Topic **Chem 7 Q# 146/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 The hydrogen halides HCl, HBr and HI are all colourless gases at room temperature.

(d) The hydrogen halides dissolve in water to form strong Brønsted–Lowry acids.

The concentration of a strong acid can be determined by titration.

(i) State what is meant by strong Brønsted–Lowry acid.

....

....

.... [2]

(ii) On Fig. 3.2, sketch the pH titration curves produced when:

- 0.1 $mol\,dm^{-3}$ NaOH(aq) is added to 25 cm^3 of 0.1 $mol\,dm^{-3}$ HBr(aq), to excess
- 0.1 $mol\,dm^{-3}$ $NH_3(aq)$ is added to 25 cm^3 of 0.1 $mol\,dm^{-3}$ HBr(aq), to excess.

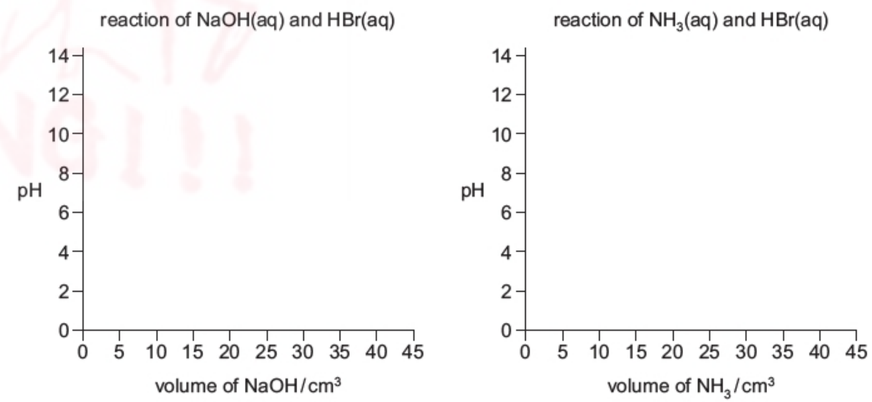


Fig. 3.2

[3]

Topic **Chem 7 Q# 147/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O Al_2O_3 P_4O_6 P_4O_{10} SO_2 SO_3

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(iii) Fig. 2.2 shows how the temperature of the atmosphere varies with height from the ground.

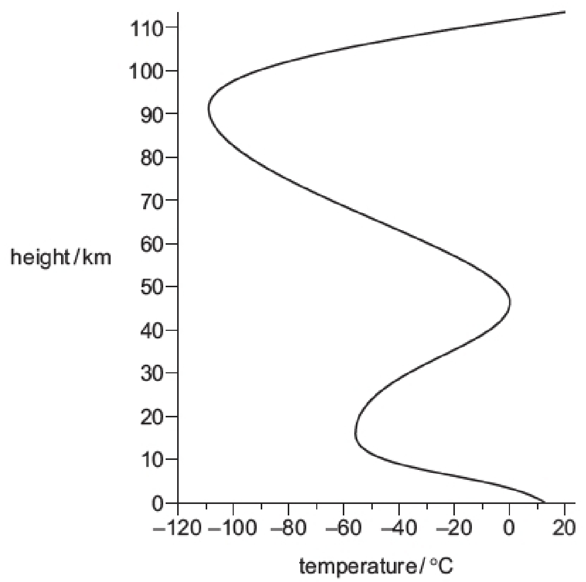


Fig. 2.2

The equilibrium reaction in equation 1 has $\Delta H_r = -168\,kJ\,mol^{-1}$.

Suggest how the position of this equilibrium differs at a height of 20 km compared with a height of 50 km from the ground.
Explain your answer.

....

....

.... [2]

[Total: 16]

Topic **Chem 7 Q# 148/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) Hydrogen sulfide gas, $H_2S(g)$, is slightly soluble in water. It acts as a weak acid in aqueous solution.

(i) State the meaning of *weak acid*.

....

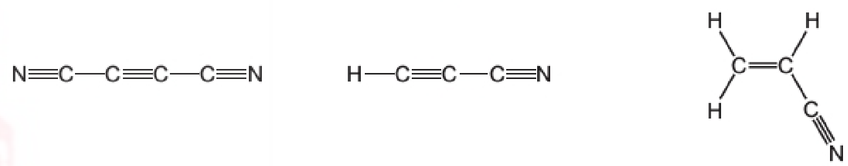
.... [1]

(ii) Give the formula of the conjugate base of H_2S.

.... [1]

Topic **Chem 7 Q# 149/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.



(b) **Q** forms when HCN reacts with ethyne, H—C≡C—H.

(i) Ethyne, HCN and **Q** are all weak Brønsted–Lowry acids.

Explain what is meant by the term *weak Brønsted–Lowry acid*.

....

....

.... [2]

Topic **Chem 7 Q# 150/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) The two most common oxides of sulfur are SO_2 and SO_3.

When SO_2 dissolves in water, a small proportion of it reacts with water to form a weak Brønsted-Lowry acid.

(i) Explain the meaning of the term *weak Brønsted-Lowry acid*.

....

.... [2]

Topic **Chem 7 Q# 151/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(d) Chlorine forms several oxides, including Cl_2O, ClO_2 and Cl_2O_6.

(iii) Cl_2O_6(g) is produced by the reaction of ClO_2(g) with O_3(g).

$$2ClO_2(g) + 2O_3(g) \rightleftharpoons Cl_2O_6(g) + 2O_2(g) \qquad \Delta H = -216\,\text{kJ mol}^{-1}$$

The reaction takes place at 500 K and 100 kPa.

State and explain the effect on the yield of Cl_2O_6(g) when the experiment is carried out:

- at 1000 K and 100 kPa

....

....

....

....

- at 500 K and 500 kPa.

....

....

....

.... [4]

Topic **Chem 7 Q# 152/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Calcium nitrate, $Ca(NO_3)_2$, reacts with ammonia, carbon dioxide and water to form a mixture of ammonium nitrate and calcium carbonate.

$$Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \rightarrow 2NH_4NO_3 + CaCO_3$$

(a) Explain why ammonia is described as a Brønsted-Lowry base in this reaction.

.... [1]

Topic **Chem 7 Q# 153/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(f) Magnesium oxide reacts reversibly with chlorine according to the following equation.

$$2MgO(s) + 2Cl_2(g) \rightleftharpoons 2MgCl_2(s) + O_2(g)$$

Under certain conditions, a dynamic equilibrium is established.

(i) State **two** features of a reaction that is in dynamic equilibrium.

1 ....

2 .... [2]

(ii) The equilibrium constant, K_p, is given by the following expression.

$$K_p = \frac{p_{O_2}}{p^2_{Cl_2}}$$

At 1.00×10^5 Pa and 500 K, 70% of the initial amount of Cl_2(g) has reacted.

Calculate K_p and state its units.

K_p = ...

units = ... [3]

Topic **Chem 7 Q# 154/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2O{=}S({=}O){=}O(g) \qquad \Delta H = -196\,\text{kJ mol}^{-1}$$

The equation for this stage of the Contact Process is shown.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(d) **(i)** State and explain the effect of increasing temperature on the rate of production of SO_3.

....

....

....

.... [3]

(ii) State and explain the effect of increasing temperature on the yield of SO_3.

....

....

....

.... [3]

(e) The SO_3 produced is converted to sulfuric acid in two stages. In the first stage the SO_3 is reacted with concentrated sulfuric acid to produce oleum, $H_2S_2O_7$.
The oleum is then reacted with water to form sulfuric acid.

Suggest an equation for the reaction of oleum, $H_2S_2O_7$, with water to form sulfuric acid.

.... [1]

(f) SO_2 reacts with water to form sulfurous acid.
Sulfurous acid is a weak Brønsted-Lowry acid, while sulfuric acid is a strong Brønsted-Lowry acid.

(ii) State the meaning of the term *strong Brønsted-Lowry acid*.

....

....

.... [2]

(iii) Write an equation to show the acid-base behaviour of sulfuric acid with water. Include state symbols.

.... [2]

[Total: 20]

1 Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

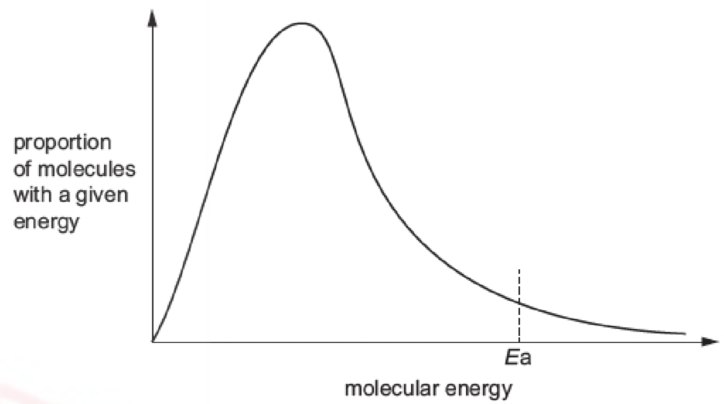
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

N≡N = 944 kJ mol^{-1}
H–H = 436 kJ mol^{-1}

(b) The Haber process is usually carried out at a temperature of approximately 400 °C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400 °C is shown.
Ea represents the activation energy for the reaction.



(iii) State and explain the effect of increasing temperature on the yield of ammonia.
Use Le Chatelier's principle to explain your answer.

....

....

....

.... [3]

(c) At a pressure of 2.00×10^7 Pa, 1.00 mol of nitrogen, $N_2(g)$, was mixed with 3.00 mol of hydrogen, $H_2(g)$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $NH_3(g)$.

(i) Calculate the amounts, in mol, of $N_2(g)$ and $H_2(g)$ in the equilibrium mixture.

$N_2(g)$ = ... mol

$H_2(g)$ = ... mol
[2]

(ii) Calculate the partial pressure of ammonia, pNH_3, in the equilibrium mixture.

Give your answer to **three** significant figures.

pNH_3 = ... Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure / Pa
$N_2(g)$	2.20×10^6
$H_2(g)$	9.62×10^5
$NH_3(g)$	1.40×10^4

(i) Write the expression for the equilibrium constant, K_p, for the production of ammonia from nitrogen and hydrogen.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction.

State the units.

K_p = ...

units = ...
[2]

(iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p.

effect on yield of ammonia ....

effect on value of K_p ....
[2]

[Total: 22]

Topic **Chem 7 Q# 156/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

hydrogen halide	HF	HC*l*	HBr	HI
boiling point / °C	19	–85	–67	–35
H–X bond energy / kJ mol^{-1}	562	431	366	299

(b) The equation for the preparation of hydrogen chloride using concentrated sulfuric acid is shown.

$$H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl$$

(i) Use the Brønsted-Lowry theory of acids and bases to identify the base and its conjugate acid in this reaction. Explain your answer.

Brønsted-Lowry base (base-I) = ...

conjugate acid (acid-II) = ...

....

....

.... [2]

(c) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(iii) The reaction exists in dynamic equilibrium.

The reaction was repeated at 1000 °C and the same pressure.

State and explain the effect on the composition of the equilibrium mixture of the change in temperature.

....

....

....

.... [2]

(iv) When 1.60 mol of HCl are mixed in a sealed container with 0.500 mol of O_2 at 400 °C, 0.600 mol of Cl_2 and 0.600 mol of H_2O are formed.

The total pressure inside the container is 1.50×10^5 Pa.

- Calculate the amounts, in mol, of HCl and O_2 in the equilibrium mixture.

HCl = ... mol

O_2 = ... mol

- Calculate the mole fraction of Cl_2 and hence the partial pressure of Cl_2 in the equilibrium mixture.

mole fraction of Cl_2 = ...

p_{Cl_2} = ... Pa [3]

(v) In a separate experiment, an equilibrium reaction mixture was found to contain the four gases at the partial pressures shown in the table.

gas	HCl	O_2	Cl_2	H_2O
partial pressure / Pa	4.8×10^4	3.0×10^4	3.6×10^4	3.6×10^4

$$K_p = \frac{(p_{Cl_2})^2 \times (p_{H_2O})^2}{(p_{HCl})^4 \times p_{O_2}}$$

Use this information and the expression given for K_p to calculate a value for K_p. State the units of K_p.

K_p = ...

units = ... [2]

(vi) The reaction is repeated without a catalyst.

State the effect of this on K_p.

.... [1]

[Total: 22]

Topic **Chem 7 Q# 157/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(b) The reaction exists as a dynamic equilibrium.

(i) Explain what is meant by the term *dynamic equilibrium*.

....

.... [1]

(ii) State and explain how the amounts of the chemicals present in the equilibrium mixture will change when the pressure is increased.

....

....

.... [2]

Topic **Chem 7 Q# 158/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(ii) State the essential operating conditions for the Haber process.

....

....

.... [3]

(iii) Explain the choices of temperature and pressure for the Haber process.

....

....

....

....

.... [4]

(c) One of the major uses of ammonia is in the manufacture of fertilisers such as diammonium hydrogen phosphate, $(NH_4)_2HPO_4$.

(i) Write an equation for the formation of diammonium hydrogen phosphate by the reaction between ammonia and phosphoric acid, H_3PO_4.

.... [1]

(ii) Explain this reaction in terms of the Brønsted-Lowry theory.

....

....

....

.... [2]

Topic **Chem 7 Q# 159/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Compound **R** is a weak diprotic (dibasic) acid which is very soluble in water.

(a) A solution of **R** was prepared which contained 1.25 g of **R** in 250 cm^3 of solution. When 25.0 cm^3 of this solution was titrated with 0.100 mol dm^{-3} NaOH, 21.6 cm^3 of the alkali were needed for complete reaction.

(i) Using the formula H_2X to represent **R**, construct a balanced equation for the reaction between H_2X and NaOH.

....

(ii) Use the data above to calculate the amount, in moles, of OH^- ions used in the titration.

(iii) Use your answers to **(i)** and **(ii)** to calculate the amount, in moles, of **R** present in 25.0 cm^3 of solution.

(iv) Calculate the amount, in moles, of **R** present in 250 cm^3 of solution.

(v) Calculate M_r of **R**.

[5]

(b) Three possible structures for **R** are shown below.

S	T	U
$HO_2CCH{=}CHCO_2H$	$HO_2CCH(OH)CH_2CO_2H$	$HO_2CCH(OH)CH(OH)CO_2H$

(i) Calculate the M_r of each of these acids.

M_r of **S** = ... M_r of **T** = ... M_r of **U** = ...

(ii) Deduce which of the structures, **S**, **T** or **U**, correctly represents the structure of the acid, **R**.

R is represented by ....

[2]

Topic **Chem 7 Q# 160/** ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Ammonium nitrate fertiliser is manufactured from ammonia. The first reaction in the manufacture of the fertiliser is the catalytic oxidation of ammonia to form nitrogen monoxide, NO. This is carried out at about 1×10^3 kPa (10 atmospheres) pressure and a temperature of 700 to 850 °C.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^\ominus = -906\ kJ\ mol^{-1}$$

(a) Write the expression for the equilibrium constant, K_p, stating the units.

K_p =

units .... [2]

(b) What will be the effect on the yield of NO of **each** of the following? In each case, explain your answer.

(i) increasing the temperature

....

....

....

(ii) decreasing the applied pressure

....

....

.... [4]

Topic **Chem 7 Q# 161/** ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 A sample of a fertiliser was known to contain ammonium sulfate, $(NH_4)_2SO_4$, and sand only.

A 2.96 g sample of the solid fertiliser was heated with 40.0 cm^3 of NaOH(aq), an excess, and all of the ammonia produced was boiled away.

After cooling, the remaining NaOH(aq) was exactly neutralised by 29.5 cm^3 of 2.00 mol dm^{-3} HCl.

In a separate experiment, 40.0 cm^3 of the original NaOH(aq) was exactly neutralised by 39.2 cm^3 of the 2.00 mol dm^{-3} HCl.

(a) **(i)** Write balanced equations for the following reactions.

NaOH with HCl

....

$(NH_4)_2SO_4$ with NaOH

....

(ii) Calculate the amount, in moles, of NaOH present in the 40.0 cm^3 of the original NaOH(aq) that was neutralised by 39.2 cm^3 of 2.00 mol dm^{-3} HCl.

(iii) Calculate the amount, in moles, of NaOH present in the 40.0 cm^3 of NaOH(aq) that remained after boiling the $(NH_4)_2SO_4$.

(iv) Use your answers to **(ii)** and **(iii)** to calculate the amount, in moles, of NaOH that reacted with the $(NH_4)_2SO_4$.

(v) Use your answers to **(i)** and **(iv)** to calculate the amount, in moles, of $(NH_4)_2SO_4$ that reacted with the NaOH.

(vi) Hence calculate the mass of $(NH_4)_2SO_4$ that reacted.

(vii) Use your answer to **(vi)** to calculate the percentage, by mass, of $(NH_4)_2SO_4$ present in the fertiliser.
Write your answer to a suitable number of significant figures.

[9]

Topic **Chem 7 Q# 162/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Ammonia is an important industrial chemical which is manufactured on a large scale by using the Haber process.

(a) **(i)** Write a balanced equation, with state symbols, for the reaction occurring in the Haber process.

....

(ii) Give **three** essential operating conditions that are used in the Haber process.

....

....

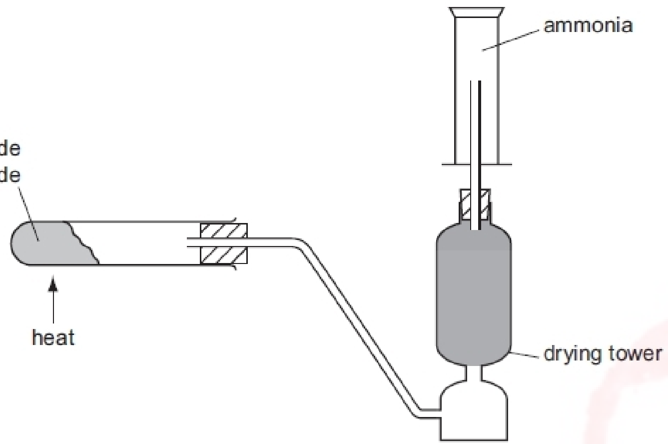
....

(iii) State **one** large scale use of ammonia.

....

[5]

(b) Ammonia may be prepared in a school or college laboratory by using the apparatus below.



The reaction involves the displacement of ammonia from one of its compounds.

(i) Give the formulae of the two reactants that are heated together to produce ammonia.

.... and ....

(ii) Construct a balanced equation for the reaction between your two reagents.

....

(iii) Common drying agents include calcium oxide, concentrated sulfuric acid and phosphorus(V) oxide.
Which **one** of these would be used in the drying tower in this experiment? Explain your answer.

....

....

[5]

Topic **Chem 7 Q# 163/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Each of the Group VII elements chlorine, bromine and iodine forms a hydride.

Hydrogen iodide can be made by heating together hydrogen gas and iodine vapour. The reaction is incomplete.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

(b) Write an expression for K_c and state the units.

K_c = ... units .... [2]

(c) For this equilibrium, the numerical value of the equilibrium constant K_c is 140 at 500 K and 59 at 650 K.

Use this information to state and explain the effect of the following changes on the equilibrium position.

(i) increasing the pressure applied to the equilibrium

....

....

(ii) decreasing the temperature of the equilibrium

....

....

[4]

(d) A mixture of 0.02 mol of hydrogen and 0.02 mol of iodine was placed in a 1 dm^3 flask and allowed to come to equilibrium at 650 K.

Calculate the amount, in moles, of each substance present in the equilibrium mixture at 650 K.

	$H_2(g)$	+	$I_2(g)$	$\rightleftharpoons$	$2HI(g)$
initial moles	0.02		0.02		0

[4]

[Total: 13]

Topic **Chem 7 Q# 164/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org
NOT with 2012/s/TZ 1/Paper 4/Q# 3(b)

3 Methanol, CH_3OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H^{\circ}_{reaction} = -49\ kJ\ mol^{-1}$$

(c) The synthesis of methanol is carried out at about 500 K with a pressure of between 40 and 100 atmospheres (between 4×10^6 Pa and 10×10^7 Pa) and using a catalyst. The use of such conditions will affect both the rate of reaction and the equilibrium yield.

In the spaces below, explain the effects of higher temperature, higher pressure, and the use of a catalyst on the **equilibrium yield** of methanol.

higher temperature

effect ....

explanation ....

....

higher pressure

effect ....

explanation ....

....

use of catalyst

effect ....

explanation ....

.... [6]

[Total: 14]

Topic **Chem 7 Q# 165/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

Sulfur-containing compounds are removed from oil products at the refinery. The sulfur is recovered and converted into SO_2, which is then used in the Contact process.

(e) State the main operating details of the formation of SO_3 in the Contact process.

....

....

....

....

.... [3]

[Total: 15]

Topic **Chem 7 Q# 166/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Nitrogen makes up about 79% of the Earth's atmosphere. As a constituent element of proteins, it is present in living organisms.

Atmospheric nitrogen is used in the Haber process for the manufacture of ammonia.

(a) Write an equation for the formation of ammonia in the Haber process.

.... [1]

(b) The Haber process is usually carried out at a high pressure of between 60 and 200 atmospheres (between 60 □ 10^5 Pa and 200 □ 10^5 Pa).
State **two further** important operating conditions that are used in the Haber process.
For **each** of your conditions, explain why it is used.

condition 1 ....

reason ....

condition 2 ....

reason .... [4]

(c) State **one** large-scale use for ammonia, other than in the production of nitrogenous fertilisers.

.... [1]

Topic **Chem 7 Q# 167/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

The reaction between nitrogen and hydrogen to produce ammonia in the Haber process is an example of a large-scale gaseous reaction that is catalysed.

(c) **(i)** State the catalyst used and give the operating temperature and pressure of the Haber process.

catalyst ....

temperature ....

pressure .... [2]

Topic **Chem 7 Q# 168/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Concern over the ever-increasing use of fossil fuels has led to many suggestions for alternative sources of energy. One of these, suggested by Professor George Olah, winner of a Nobel Prize in chemistry, is to use methanol, CH_3OH, which can be obtained in a number of different ways.

Methanol could be used instead of petrol in a conventional internal combustion engine or used to produce electricity in a fuel cell.

Methanol may be manufactured catalytically from *synthesis gas*, a mixture of CO, CO_2 and H_2. The CO is reacted with H_2 to form methanol, CH_3OH.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \qquad \Delta H = -91 \text{ kJ mol}^{-1}$$

(c) From your understanding of Le Chatelier's principle, state **two** conditions that could be used in order to produce a high yield of methanol.

In **each** case, explain why the yield would increase.

condition 1 ....

explanation ....

....

condition 2 ....

explanation ....

.... [4]

Carbon monoxide, which can be used to make methanol, may be formed by reacting carbon dioxide with hydrogen.

$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g) \qquad K_c = 1.44 \text{ at } 1200 \text{ K}$$

(d)

(ii) A mixture containing 0.50 mol of CO_2, 0.50 mol of H_2, 0.20 mol of CO and 0.20 mol of H_2O was placed in a 1.0 dm^3 flask and allowed to come to equilibrium at 1200 K.

Calculate the amount, in moles, of each substance present in the equilibrium mixture at 1200 K.

	CO_2	+	H_2	$\rightleftharpoons$	CO	+	H_2O
initial moles	0.50		0.50		0.20		0.20

[5]

[Total: 13]

Topic Chem 8 Q# 169**/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

(g) Cold water reacts slowly with a piece of Mg to produce bubbles of $H_2(g)$.
Cold water reacts rapidly with burning Mg to produce $H_2(g)$ in an explosive mixture.

$$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$$

Explain why the rate of reaction of cold water with burning magnesium is greater.

....

.... [2]

[Total: 17]

Topic **Chem 8 Q# 170/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O $\quad Al_2O_3$ $\quad P_4O_6$ $\quad P_4O_{10}$ $\quad SO_2$ $\quad SO_3$

(b)

(iii) Al_2O_3 is used as a catalyst in the dehydration of alcohols.

State the effect of using Al_2O_3 as a catalyst in the dehydration of alcohols. Use the Boltzmann distribution in Fig. 2.1 to help explain your answer.

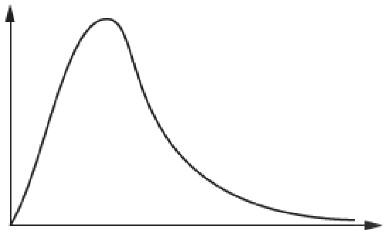


Fig. 2.1

....

....

.... [3]

Topic **Chem 8 Q# 171/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(iv) H_2SO_4 acts as a homogeneous catalyst in reaction 3.

Explain why H_2SO_4 is described as *homogeneous*.

....

.... [1]

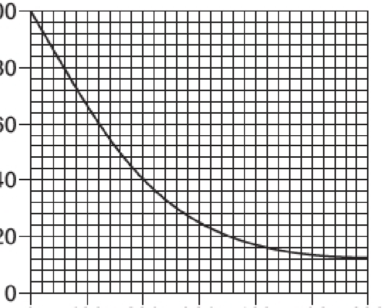
Topic **Chem 8 Q# 172/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Aqueous bromine reacts with methanoic acid to form hydrogen bromide and carbon dioxide gas.

$$Br_2(aq) + HCO_2H(aq) \rightarrow 2HBr(aq) + CO_2(g)$$

(c) This reaction can be followed by measuring the concentration of bromine present in the mixture at regular time intervals.

The graph shows the change in concentration of bromine against time in a reaction carried out at 20 °C.



(i) Use the graph to calculate the average rate of reaction at 20 °C during the first 600 s. State the units of this rate of reaction.

average rate of reaction .... units ....
[2]

The experiment is repeated at a temperature of 40 °C. This relatively small increase in temperature produces a large increase in reaction rate.

(ii) Sketch a graph, on the same axes, to show the expected results when repeating the experiment at 40 °C. [1]

(iii) The rate of reaction increases when the frequency of successful collisions between reactant particles increases.

Explain why an increase in temperature produces this effect.

....

....

.... [2]

1 The rate of chemical reactions is affected by changes in temperature and pressure.

(a) (i) Draw a curve on the axes to show the Boltzmann distribution of energy of particles in a sample of gaseous krypton atoms at a given temperature.

Label the curve **T1** and label the axes.

[2]

(ii) On the diagram in **(a)(i)**, draw a second curve to show the distribution of energies of the krypton atoms at a higher temperature.

Label the second curve **T2**. [1]

(b) The Boltzmann distribution assumes that the particles behave as an ideal gas.

(i) State **two** assumptions of the kinetic theory as applied to an ideal gas.

1 ....

....

2 ....

....

[2]

(ii) Explain, in terms of activation energy, E_a, and the collision of particles, how an increase in temperature affects the rate of a chemical reaction.

....

....

....

.... [2]

[Total: 14]

(e) Lucas's reagent is a mixture of HCl and $ZnCl_2$. Primary, secondary and tertiary alcohols can be distinguished by their reaction with Lucas's reagent.

Alcohols react with the HCl in Lucas's reagent to form halogenoalkanes.

$ZnCl_2$ acts as a homogeneous catalyst for these reactions.

(i) Explain the meaning of the term *homogeneous*.

....

.... [1]

3 Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(ii) An important reaction of $CHCl_3(g)$ is the manufacture of $CHClF_2(g)$, using the following reversible reaction.

$$CHCl_3(g) + 2HF(g) \rightleftharpoons CHClF_2(g) + 2HCl(g)$$

(iii) The reaction in **(ii)** is carried out using a heterogeneous catalyst.

Explain fully the meaning of the terms *heterogeneous* and *catalyst*.

heterogeneous ....

....

....

catalyst ....

....

....

....

[3]

Topic **Chem 8 Q# 176/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2O{=}\overset{\displaystyle O}{\overset{\|}{S}}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) **(i)** State the effect of a catalyst on a reaction.
Explain how a catalyst causes this effect.

....

....

....

.... [2]

(ii) State the meaning of the term *heterogeneous* as applied to catalysts.

....

....

.... [1]

Topic **Chem 8 Q# 177/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

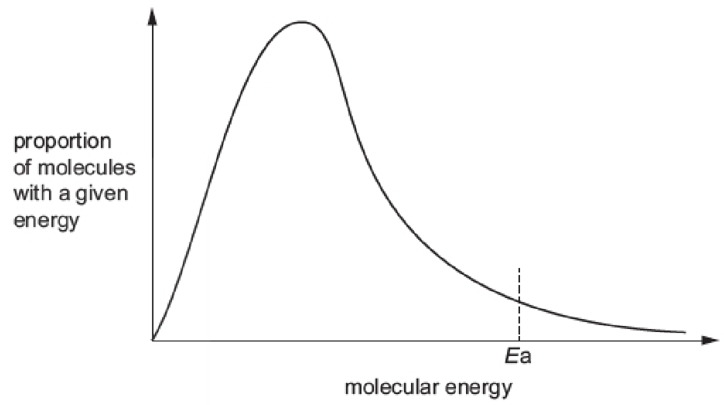
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

N≡N = 944 $kJ\,mol^{-1}$
H–H = 436 $kJ\,mol^{-1}$

(b) The Haber process is usually carried out at a temperature of approximately 400 °C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400 °C is shown.
Ea represents the activation energy for the reaction.



(i) Using the same axes, sketch a second curve to indicate the Boltzmann distribution at a higher temperature. [2]

(ii) **With reference to the Boltzmann distribution**, state and explain the effect of increasing temperature on the rate of production of ammonia.

....

....

....

.... [3]

Topic **Chem 8 Q# 178/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(c) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(ii) State the **type** of catalyst used in this reaction. Explain how a catalyst is able to increase the rate of a chemical reaction.

....

....

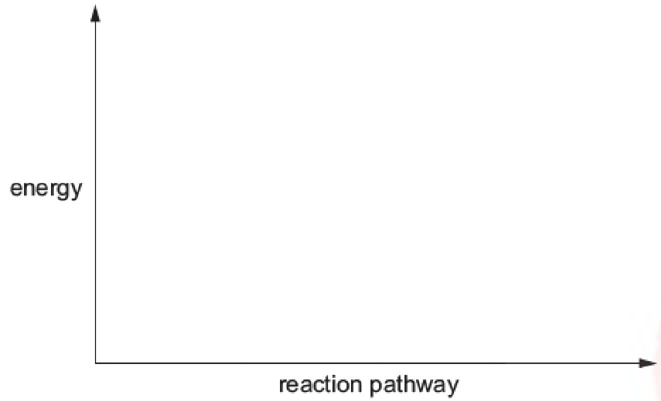
....

.... [2]

Topic **Chem 8 Q# 179/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) Magnesium oxide can be formed by the reaction of magnesium and oxygen in the air.

(i) Draw a **fully labelled** reaction pathway diagram for the reaction between magnesium and oxygen.



[2]

(ii) Explain why there is no visible reaction when a piece of magnesium ribbon is exposed to the air.

....

....

.... [2]

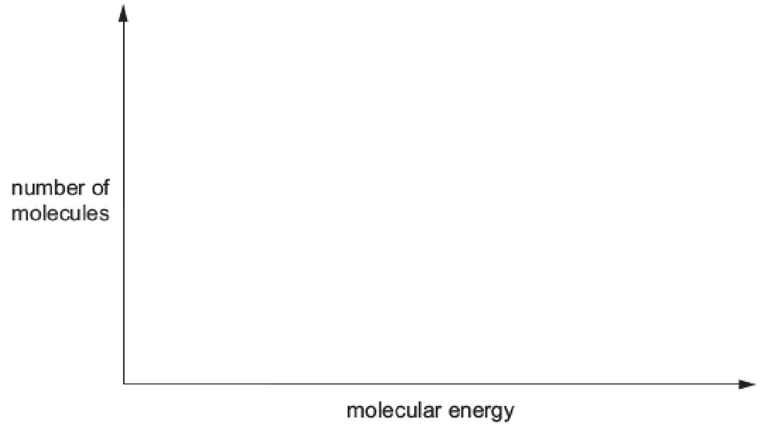
Topic **Chem 8 Q# 180/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(c) The process uses a platinum catalyst, which increases the rate of reaction.

Sketch a Boltzmann distribution on the axes given below and use your diagram to explain how the platinum catalyst increases the rate of the reaction.



....

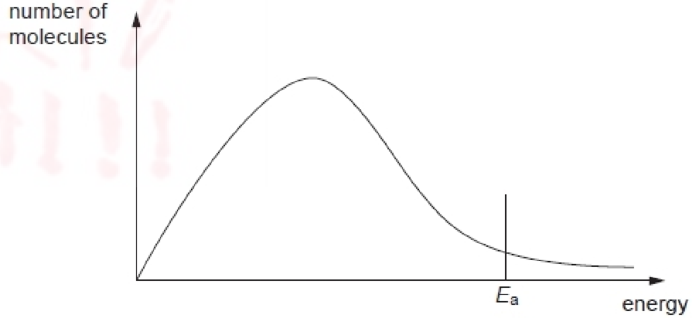
....

....

.... [3]

Topic **Chem 8 Q# 181/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The diagram below shows, for a given temperature T, a Boltzmann distribution of the kinetic energy of the molecules of a mixture of two gases that will react together, such as nitrogen and hydrogen.
The activation energy for the reaction, E_a, is marked.



(a) **On the graph above,**

(i) draw a new distribution curve, **clearly labelled T′**, for the same mixture of gases at a higher temperature, **T′**;

(ii) **mark clearly, as H**, the position of the activation energy of the reaction at the higher temperature, **T′**. [3]

(b) Explain the meaning of the term *activation energy*.

....

....

....

.... [2]

The reaction between nitrogen and hydrogen to produce ammonia in the Haber process is an example of a large-scale gaseous reaction that is catalysed.

(ii) **On the energy axis of the graph opposite**, mark the position, **clearly labelled C**, of the activation energy of the reaction when a catalyst is used.

(iii) Use your answer to **(ii)** to explain how the use of a catalyst results in reactions occurring at a faster rate.

....

....

.... [2]

(d) Two reactions involving aqueous NaOH are given below.

$CH_3CHBrCH_3 + NaOH \rightarrow CH_3CH(OH)CH_3 + NaBr$ **reaction 1**

$HCl + NaOH \rightarrow NaCl + H_2O$ **reaction 2**

In order for **reaction 1** to occur, the reagents must be heated together for some time. On the other hand, **reaction 2** is almost instantaneous at room temperature.

Suggest brief explanations why the rates of these two reactions are very different.

reaction 1 ....

....

....

reaction 2 ....

....

.... [4]

Topic Chem 9 Q# 182/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chlorides of Period 3 elements are shown in the list.

$NaCl$ $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(a) From this list, identify:

(ii) all the chlorides that react vigorously with water to form strongly acidic solutions

.... [1]

(iii) the chloride that dissolves in water to form a neutral solution

.... [1]

(iv) the chloride formed from the **element** with the highest melting point.

.... [1]

(d) Sulfur, S_8, reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2. SCl_2 forms when sulfur reacts with an excess of chlorine.

reaction **1** $S_8(s) + 4Cl_2(g) \rightarrow 4S_2Cl_2(l)$ $\Delta H_r = -58.2\,kJ\,mol^{-1}$

reaction **2** $S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l)$ $\Delta H_r = -40.6\,kJ\,mol^{-1}$

(i) SCl_2 is a cherry-red liquid that reacts vigorously with water to form an acidic solution.

Use this information to deduce the bonding and structure shown by SCl_2.
Explain your answer.

....

....

.... [2]

Topic **Chem 9 Q# 183/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(d) Separate samples of **Q** and **R** are added to separate test-tubes containing acidified $K_2Cr_2O_7(aq)$ and heated.

Q **R**

Fig. 3.3

(ii) When $PCl_5(s)$ is added to separate samples of **Q** and **R** at room temperature, both react vigorously.

(iii) Suggest why samples of **Q** and **R** must be dried before PCl_5 is added. Include a relevant equation to support your answer.

....

....

.... [2]

[Total: 17]

Topic **Chem 9 Q# 184/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

(f) Magnesium, Mg, burns in oxygen, O_2.
The activation energy, E_a, for this reaction is $+148\,kJ\,mol^{-1}$.

(i) State **one** observation when magnesium burns in oxygen.
Do **not** refer to temperature changes in your answer.

.... [1]

Topic **Chem 9 Q# 185/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 The hydrogen halides HCl, HBr and HI are all colourless gases at room temperature.

(b) HCl is a product of several different reactions. Some of these are shown in Fig. 3.1.

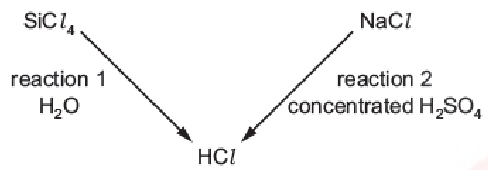


Fig. 3.1

(i) Write an equation for reaction 1.

.... [1]

Topic **Chem 9 Q# 186/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O $\quad Al_2O_3$ $\quad P_4O_6$ $\quad P_4O_{10}$ $\quad SO_2$ $\quad SO_3$

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(ii) Write an equation for the reaction of Na_2O with water.

.... [1]

(b) Al_2O_3 is an amphoteric oxide found in bauxite.

(i) State what is meant by amphoteric.

....

.... [1]

(ii) Al_2O_3 is purified from bauxite in several steps. The first step involves heating Al_2O_3 with an excess of NaOH(aq). A colourless solution forms.

Write an equation for this reaction.

.... [1]

(c) P_4O_6 is a white solid that has a melting point of 24 °C. Solid P_4O_6 reacts with water to form H_3PO_3.

(i) Deduce the type of structure and bonding shown by P_4O_6. Explain your answer.

....

....

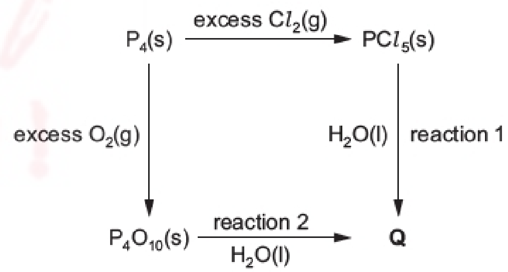
.... [2]

(iv) Write an equation for the reaction of P_4O_{10} with water.

.... [1]

Topic **Chem 9 Q# 187/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) Some reactions of $P_4(s)$ are shown in the reaction scheme.



(ii) Deduce the identity of **Q** and hence construct chemical equations for reactions 1 and 2.

reaction 1 $\quad PCl_5$ + ...H_2O → ....

reaction 2 $\quad P_4O_{10}$ + ...H_2O → ....

[2]

Topic **Chem 9 Q# 188/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(e) Aluminium reacts with chlorine to form aluminium chloride.

Aluminium chloride can exist as the gaseous molecule Al_2Cl_6(g). This molecule contains coordinate bonds.

(ii) Describe what you would see when solid aluminium chloride reacts with water.

Name the type of reaction that occurs.

....

....

.... [2]

(f) 0.020 mol of element **Z** reacts with excess Cl_2 to form 0.020 mol of a liquid chloride.

The liquid chloride has formula $\mathbf{Z}Cl_n$, where *n* is an integer.

$\mathbf{Z}Cl_n$ reacts vigorously with water at room temperature to give an acidic solution and a white solid.

When excess $AgNO_3$(aq) is added to the solution, 11.54 g of $AgCl$(s) forms.

(i) Suggest the type of bonding and structure shown by $\mathbf{Z}Cl_n$.

.... [1]

(ii) Calculate the value of *n* in $\mathbf{Z}Cl_n$.

n = ... [2]

Topic **Chem 9 Q# 189/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

(b) $LiAlH_4$ cannot be used in aqueous solution because it reacts with water to produce LiOH(aq), H_2(g) and a white precipitate which is soluble in excess sodium hydroxide.

Identify the white precipitate.

.... [1]

Topic **Chem 9 Q# 190/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Phosphorus, sulfur and chlorine can all react with oxygen to form oxides.

(a) Phosphorus reacts with an excess of oxygen to form phosphorus(V) oxide.

(i) Write an equation to show the reaction of phosphorus with excess oxygen.

.... [1]

(ii) Describe the reaction of phosphorus(V) oxide with water.

....

....

.... [2]

(b)

(ii) Write the equation for the reaction of SO_2 with water.

.... [1]

(e) Element **E** is a Period 5 element.

E reacts with oxygen to form an insoluble white oxide that has a melting point of 1910 °C. The oxide of **E** conducts electricity only when liquid.

E also reacts readily with Cl_2(g) to form a white solid that reacts exothermically with water. The resulting solution reacts with aqueous silver nitrate to form a white precipitate that dissolves in dilute ammonia.

(i) Suggest the type of bonding shown by the **oxide** of **E**. Explain your answer.

....

....

.... [2]

(ii) Suggest the type of bonding shown by the **chloride** of **E**. Explain your answer.

....

....

.... [2]

[Total: 21]

Topic **Chem 9 Q# 191/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Gallium is a metal in Group 13 of the Periodic Table.

(a) There are two stable isotopes of gallium, ^{69}Ga and ^{71}Ga.

(c) Gallium metal reacts rapidly when exposed to air. A white solid layer is formed on its surface.

(i) Suggest an equation to describe the reaction occurring when gallium metal is exposed to air.

.... [2]

(ii) The table gives the formula of each gallium-containing product formed when gallium oxide reacts separately with hot aqueous hydrochloric acid and hot aqueous sodium hydroxide.

	formula of gallium-containing product
hot aqueous hydrochloric acid	$GaCl_3$
hot aqueous sodium hydroxide	$NaGa(OH)_4$

Give the name of the type of behaviour shown by gallium oxide in these reactions.

.... [1]

[Total: 8]

Topic **Chem 9 Q# 192/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(e) Unlike the other oxides of Group 2 metals, beryllium oxide is amphoteric.

(i) Give the meaning of the term *amphoteric*.

....

.... [1]

(ii) Beryllium oxide and aluminium oxide have similar chemical properties.

The $Be(OH)_4^{2-}$ anion is a product of the reaction between beryllium oxide and excess concentrated $OH^-(aq)$.

Construct an equation for this reaction.

.... [1]

Topic **Chem 9 Q# 193/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

	Na_2O	MgO	Al_2O_3	SiO_2	SO_3
boiling point / °C	1275	3670	2977	2950	45
nature of oxide	basic	basic	amphoteric	acidic	acidic

(b)

(ii) Al_2O_3 is an amphoteric oxide.

Explain what is meant by the term *amphoteric*. Use chemical equations to illustrate your answer.

....

....

.... [3]

(iii) State what you would observe when a small sample of Na_2O is placed in water.

.... [1]

(c)

(iii) SeO_2 shows similar chemical reactions to SO_2.

Suggest an equation to show the reaction of SeO_2 with aqueous sodium hydroxide, NaOH.

.... [1]

[Total: 13]

Topic **Chem 9 Q# 194/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(f) Silicon dioxide reacts with hot, concentrated sodium hydroxide.

(i) Identify the **two** products formed during this reaction.

....

.... [2]

(ii) Describe the behaviour of the silicon dioxide during this reaction.

.... [1]

[Total: 15]

Topic **Chem 9 Q# 195/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) The elements in the third period, from sodium to silicon, can react with chlorine to form chlorides.

(i) State and explain the pattern of change of oxidation number which occurs to both chlorine and the different Period 3 elements when they react together.

....

....

....

.... [3]

(ii) Give the equations to show the reactions of sodium chloride and silicon(IV) chloride when separately added to water.

sodium chloride ....

silicon(IV) chloride .... [2]

(iii) Complete the table to describe the structure and bonding in sodium chloride and silicon(IV) chloride.

	structure	bonding
sodium chloride		
silicon(IV) chloride		

[2]

[Total: 16]

Topic **Chem 9 Q# 196/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The elements in the third period, and their compounds, show trends in their physical and chemical properties.

(b) The chlorides of the elements in the third period behave in different ways when added to water, depending on their structure and bonding.

L and **M** are each a chloride of an element in Period 3. A student investigated **L** and **M** and their results are given.

L is a white crystalline solid with a melting point of 987 K. **L** dissolves in water to form an approximately neutral solution. Addition of NaOH(aq) to an aqueous solution of **L** produces a white precipitate.

M is a liquid with a boiling point of 331 K. **M** is hydrolysed rapidly by cold water to form a strongly acidic solution, a white solid and white fumes.

Identify **L** and **M**.
Explain any properties and observations described.
Give equations where appropriate.

(i) **L** is ....

....

....

....

.... [3]

(ii) **M** is ....

....

....

....

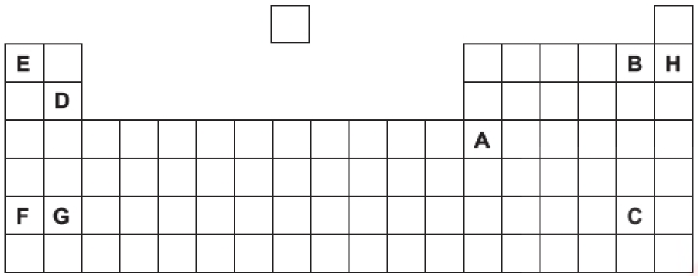
.... [3]

[Total: 14]

Topic **Chem 9 Q# 197/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The properties of elements and their compounds show similarities, differences and trends depending on the positions of the elements in the Periodic Table.

(a) The positions of some elements are indicated. The letters used are **not** the symbols of the elements.



From the elements labelled, give the letter for;

(i) the element that forms an amphoteric oxide, ... [1]

(ii) the element with the highest first ionisation energy, ... [1]

(iii) the element that forms a soluble hydroxide and an insoluble sulfate, ... [1]

(iv) the most volatile element in a group that contains elements in all three states of matter at room temperature and pressure,

.... [1]

(v) the element that forms the largest cation. .... [1]

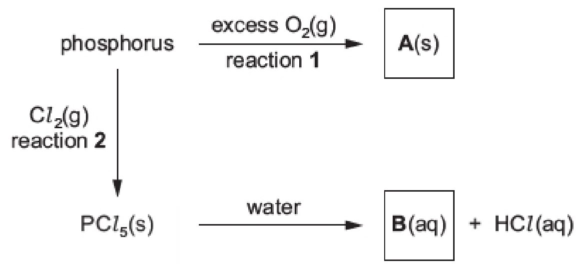
Topic **Chem 9 Q# 198/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** The table shows information about some of the elements in the third period.

element	Na	Mg	Al	P	S	Cl
atomic radius / nm	0.186	0.160	0.143	0.110	0.104	0.099
radius of most common ion / nm	0.095	0.065	0.050	0.212	0.184	0.181
maximum oxidation number of the element in its compounds	+1					+7

(b) Phosphorus is a non-metal in the third period. It reacts vigorously with excess oxygen but slowly with chlorine.

Some reactions of phosphorus are shown.



(i) Write an equation to represent reaction **1**, the formation of compound **A**.

.... [1]

(ii) Give **two** observations you could make in reaction **2**.

1. ....

2. ....

[2]

(iii) Name compound **B**.

.... [1]

Topic **Chem 9 Q# 199/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 **D**, **E**, **F**, and **G** are four consecutive elements in the **fourth** period of the Periodic Table. (The letters are **not** the actual symbols of the elements.)

D is a soft, silvery metal with a melting point just above room temperature. Its amphoteric oxide, D_2O_3, has a melting point of 1900 °C and can be formed by heating **D** in oxygen.

G is a solid that can exist as several different allotropes, most of which contain G_8 molecules. **G** burns in air to form GO_2 which dissolves in water to form an acidic solution. This solution reacts with sodium hydroxide to form the salt Na_2GO_3.

(a) Suggest the identities of **D** and **G**.

D .... **G** ....

[1]

(b) Write equations for the reactions of D_2O_3 with

(i) hydrochloric acid,

.... [2]

(ii) sodium hydroxide.

.... [2]

(c) Suggest the type of bonding and structure in $\mathbf{D}_2O_3$.

.... [1]

(d) Write an equation for the formation of an acidic solution when $\mathbf{G}O_2$ dissolves in water.

.... [1]

[Total: 7]

Topic **Chem 9 Q# 200/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) The element tellurium, Te, reacts with chlorine to form a single solid product, with a relative formula mass of 270. The product contains 52.6% chlorine by mass.

(ii) This chloride melts at 224 °C and reacts vigorously with water.

State the type of bonding **and** structure present in this chloride and explain your reasoning.

....

....

....

.... [2]

(iii) Suggest an equation for the reaction of this chloride with water.

.... [1]

(d) Sodium and silicon also react directly with chlorine to produce the chlorides shown.

chloride	melting point/°C	difference between the electronegativities of the elements
$NaCl$	801	2.2
$SiCl_4$	–69	1.3

(i) Describe what you would **see** during the reaction between sodium and chlorine.

....

....

.... [2]

(ii) Explain the differences between the melting points of these two chlorides in terms of their structure **and** bonding. You should refer to the difference between the electronegativities of the elements in your answer.

$NaCl$ structure **and** bonding ....

....

$SiCl_4$ structure **and** bonding ....

....

explanation ....

....

....

....

....

.... [4]

[Total: 20]

Topic **Chem 9 Q# 201/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) The chlorides of elements in Period 3 of the Periodic Table show different behaviours on addition to water, depending on their structure and bonding.

(i) Write equations to show the behaviour of sodium chloride, $NaCl$, and silicon chloride, $SiCl_4$, when separately added to an excess of water.

$NaCl$ ....

$SiCl_4$ ....

[2]

(ii) State and explain the differences in behaviour of these two chlorides when added to water, in terms of their structure and the bonding found in the compounds.

....

....

....

....

....

.... [4]

(b) Chlorine is very reactive and will form compounds by direct combination with many elements.

Describe what you would see when chlorine is passed over separate heated samples of sodium and phosphorus.
In **each** case write an equation for the reaction.

sodium

....

....

....

phosphorus

....

....

.... [4]

(d) Magnesium chloride, $MgCl_2$, and silicon tetrachloride, $SiCl_4$, each dissolve in or react with water.

Suggest the approximate pH of the solution formed in **each** case.

$MgCl_2$ .... $SiCl_4$ ....

Explain, with the aid of an equation, the difference between the two values.

....

....

....

.... [5]

[Total: 16]

3 This question refers to the elements in the section of the Periodic Table shown below.

		H						He
Li	Be		B	C	N	O	F	Ne
Na	Mg		Al	Si	P	S	Cl	Ar
K	Ca	.... transition elements	Ga	Ge	As	Se	Br	Kr

(a) From this list of elements, identify in **each** case **one** element that has the property described. Give the **symbol** of the element.

(i) An element that floats on cold water and reacts readily with it.

....

(ii) An element that forms an oxide that is a reducing agent.

....

(iii) The element that has the smallest first ionisation energy.

....

(iv) The element which has a giant molecular structure **and** forms an oxide which has a simple molecular structure.

....

(v) The element in Period 3 (Na to Ar) that has the smallest anion.

....

(vi) The element in Period 3 (Na to Ar) which forms a chloride with a low melting point and an oxide with a very high melting point.

....

[6]

(b) Use the elements in Period 3 (Na to Ar) in the section of the Periodic Table opposite to identify the oxide(s) referred to below.
In **each** case, give the **formula** of the oxide(s).

(i) An oxide which when placed in water for a long time has no reaction with it.

....

(ii) An oxide which dissolves readily in water to give a strongly alkaline solution.

....

(iii) Two acidic oxides formed by the same element.

.... and ....

(iv) An oxide which is amphoteric.

....

[5]

Topic **Chem 9 Q# 204/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Zinc is an essential trace element which is necessary for the healthy growth of animals and plants. Zinc deficiency in humans can be easily treated by using zinc salts as dietary supplements.

(a) One salt which is used as a dietary supplement is a hydrated zinc sulfate, $ZnSO_4.xH_2O$, which is a colourless crystalline solid.

Crystals of zinc sulfate may be prepared in a school or college laboratory by reacting dilute sulfuric acid with a suitable compound of zinc.

Give the formulae of **two** simple compounds of zinc that could **each** react with dilute sulfuric acid to produce zinc sulfate.

.... and .... [2]

Topic **Chem 9 Q# 205/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Oxides are compounds which usually contain oxygen combined with one other element.

Oxides are classified as follows.

acidic alkaline amphoteric basic

(a) **Using these terms only**, complete the table to describe the oxides of the elements of the third period of the Periodic Table sodium to sulfur.

Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2	Cl_2O_7
						acidic

[4]

(b) Give the names of **two** elements from sodium to chlorine which form more than one oxide.

.... and .... [1]

(c) Sodium reacts with water.

(i) Describe, as fully as you can, what you would see when a piece of sodium is reacted with water.

....

....

....

(ii) Write an equation for the reaction of sodium with water.

....

[4]

Topic **Chem 9 Q# 206/** ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

The table below refers to the elements of the third Period sodium to sulfur and is incomplete.

element	Na	Mg	Al	Si	P	S
conductivity			high			
melting point			high			

(d) **(i)** Complete the 'conductivity' row by using **only** the words 'high', 'moderate' or 'low'.

(ii) Complete the 'melting point' row by using **only** the words 'high' or 'low'. [5]

When Mendeleev published his first Periodic Table, he left gaps for elements that had yet to be discovered. He also predicted some of the physical and chemical properties of these undiscovered elements.

For one element, **E**, he correctly predicted the following properties.

melting point of the element	high
melting point of the oxide	high
boiling point of the chloride	low

The element **E** was in the fourth Period and was one of the elements from gallium, proton number 31, to bromine, proton number 35.

(e) By considering the properties of the third Period elements aluminium to chlorine, suggest the identity of the fourth Period element **E**.

.... [1]

[Total: 15]

Topic **Chem 9 Q# 207/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 This question refers to the elements shown in the portion of the Periodic Table given below.

							H										He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr

(a) From this table, identify in **each** case **one** element that has the property described. Give the **symbol** of the element in each case.

(i) The element that has a molecule which contains exactly eight atoms.

....

(ii) The element that forms the largest cation.

....

(iii) An element that floats on water and reacts with it.

....

(iv) An element that reacts with water to give a solution that can behave as an oxidising agent.

....

(v) An element whose nitrate gives a brown gas on thermal decomposition.

....

[5]

(b) **(i)** Give the formula of the oxide of the most electronegative element.

....

(ii) Several of these elements form more than one acidic oxide.
Give the formulae of **two** such oxides formed by the **same** element.

.... and ....

[3]

Topic **Chem 9 Q# 208/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, Al, is in the third period of the Periodic Table; copper and titanium are both transition elements.

Aluminium reacts with chlorine.

Copper forms two chlorides, CuCl and $CuCl_2$.

(e) At room temperature, the chloride of titanium, **A**, is a liquid which does not conduct electricity.

What does this information suggest about the bonding and structure in **A**?

....

....

.... [2]

[Total: 14]

Topic **Chem 9 Q# 209/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, Al, is in the third period of the Periodic Table; copper and titanium are both transition elements.

Aluminium reacts with chlorine.

(b) (i) Outline how, starting from aluminium powder, this reaction could be carried out in a school or college laboratory to give a small sample of aluminium chloride. A diagram is not necessary.

....

....

....

(ii) Describe what you would see during this reaction.

....

.... [4]

Topic Chem 10 Q# 210/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium shows reactions typical of a Group 2 metal.

(b) Fig. 2.1 shows some reactions of magnesium and its compounds.

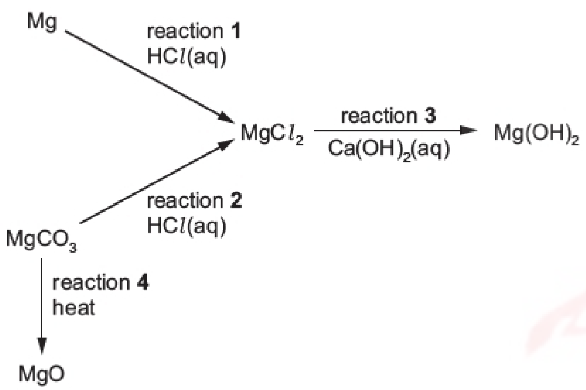


Fig. 2.1

(i) Identify the other products of reactions **1** and **2**.

reaction **1** ....

reaction **2** ....
[2]

(ii) Reaction **3** is used to form a precipitate of $Mg(OH)_2$ from $MgCl_2(aq)$.

State why $Ca(OH)_2(aq)$ would **not** form a precipitate of $Ba(OH)_2$ from $BaCl_2(aq)$.

....

.... [1]

(iii) State the type of reaction that occurs in reaction **4**.

.... [1]

Topic **Chem 10 Q# 211/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Calcium, magnesium and radium are Group 2 elements. Radium follows the same trends as the other members of Group 2.

(b) (i) Write the equation for the thermal decomposition of calcium nitrate.

.... [1]

(ii) Suggest which of the Group 2 nitrates, calcium, magnesium or radium, requires the highest temperature to decompose. Explain your answer.

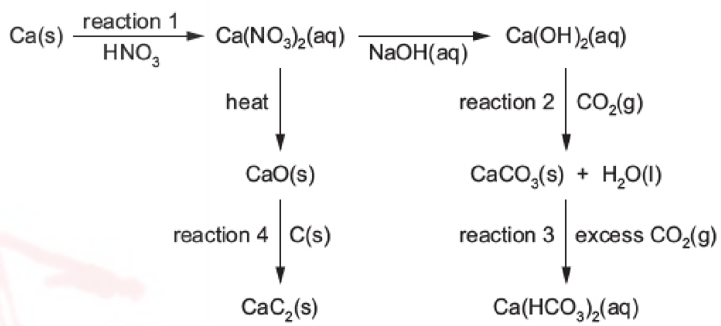
....

....

.... [1]

Topic **Chem 10 Q# 212/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The reaction scheme shows some reactions of calcium.



(a) (i) Reaction 1 produces $Ca(NO_3)_2$ and one other product.

Identify the other product.

.... [1]

(ii) Construct an equation for the thermal decomposition of $Ca(NO_3)_2(s)$.

.... [1]

(iii) State the trend in the thermal stability of the Group 2 nitrates down the group.

.... [1]

(iv) In reaction 3, excess CO_2 is bubbled through water containing $CaCO_3$. A solution of $Ca(HCO_3)_2(aq)$ forms.

Construct an equation for reaction 3.

.... [1]

Topic **Chem 10 Q# 213/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Ethanedioic acid, HO_2CCO_2H, has a relative molecular mass of 90.0.

(b) Solid ethanedioic acid reacts with aqueous calcium ions to make a precipitate of calcium ethanedioate, CaC_2O_4.

CaC_2O_4 breaks down when heated to form calcium oxide, carbon dioxide and carbon monoxide.

(i) Construct an equation to represent the reaction of CaC_2O_4 when heated. Include state symbols.

.... [2]

(ii) Identify the type of reaction which occurs when CaC_2O_4 is heated.

.... [1]

(iii) Identify another compound containing calcium ions which will also produce carbon dioxide and calcium oxide when it is heated.

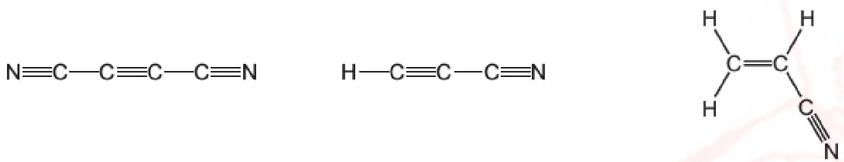
.... [1]

[Total: 10]

Topic **Chem 10 Q# 214/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.

P **Q** **R**



(ii) One of the products of the complete combustion of **P** is nitrogen gas, $N_2(g)$.

Explain the lack of reactivity of nitrogen.

.... [1]

Topic **Chem 10 Q# 215/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 Group 2 metals form alkaline solutions in water.

(a) (i) Write the equation for the reaction of calcium oxide with water.

.... [1]

(ii) Identify the ion that causes an aqueous solution to be alkaline.

.... [1]

(b) The table shows the melting points of some Group 2 metal oxides.

compound	melting point/°C
MgO	2825
CaO	2613
SrO	2531
BaO	1923

Explain the trend in the melting points of the oxides down Group 2.

....

....

.... [2]

(c) Oxygen reacts readily with some metals, but each Group 2 metal requires strong heating to start the reaction with oxygen.

Suggest why strong heating is required to start these reactions.

....

.... [1]

Topic **Chem 10 Q# 216/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Group 2 elements share common chemical properties.

(i) Calcium reacts in cold water more quickly than magnesium because more energy is required to remove the outer electrons in magnesium. This occurs even though calcium atoms have a greater nuclear charge.

Explain why more energy is required to remove the outer electrons in magnesium than in calcium.

....

....

.... [2]

Topic **Chem 10 Q# 217/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Group 2 elements share common chemical properties.

(i) Calcium reacts in cold water more quickly than magnesium because more energy is required to remove the outer electrons in magnesium. This occurs even though calcium atoms have a greater nuclear charge.

(ii) 0.001 mol of strontium reacts with an excess of cold water. When the reaction is complete a colourless solution is seen.

Construct the equation for the reaction of strontium with cold water. Include state symbols.

.... [2]

(iii) 0.005 mol of calcium and 0.005 mol of strontium are added separately to two beakers. Each beaker contains 100 cm^3 of cold water.
At the end of each reaction a white solid and a colourless solution are seen in both beakers.

Predict which element, calcium or strontium, produces the more alkaline solution. Explain your answer.

....

....

.... [2]

(iv) Describe one observation when magnesium carbonate is added to excess dilute sulfuric acid.

....

.... [1]

(b) Element **X** is a metal. **X** reacts with oxygen to form a black solid oxide. The oxidation state of **X** in this oxide is +2. The carbonate of **X**, **X**CO_3, is a green solid. It decomposes on heating to form the oxide and a colourless gas.

(i) From the information given, state two similarities and one difference that metal **X** and its compounds have with Group 2 metals and their compounds.

similarity 1 ....

....

similarity 2 ....

....

difference 1 ....

....

[3]

(ii) Write the formula of the oxide of **X**.

.... [1]

(iii) Write an equation for the reaction of **X**CO_3 when it is heated.

.... [1]

[Total: 12]

Topic **Chem 10 Q# 218/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(iii) Another fertiliser, calcium ammonium nitrate, is formed when solid calcium carbonate is added to a mixture of aqueous ammonium nitrate and dilute nitric acid.

Suggest what would be **observed** in this reaction.

....

....

.... [2]

(iv) Calcium nitrate decomposes at a higher temperature than calcium ammonium nitrate.

Write an equation for the thermal decomposition of calcium nitrate.

.... [1]

[Total: 15]

Topic **Chem 10 Q# 219/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium and its compounds have a large variety of applications.

(ii) When calcium metal is placed in dilute sulfuric acid, it reacts vigorously at first.

After a short time, a crust of calcium sulfate forms on the calcium metal and the reaction stops. Some of the calcium metal and dilute sulfuric acid remain unreacted.

Suggest an explanation for these observations.

....

....

....

.... [2]

(b) The elements in Group 2 all react with oxygen and with water.

(i) State and explain the conditions needed for magnesium to react with oxygen.

....

.... [2]

(ii) State what would be seen during the reaction in **(b)(i)**.

....

.... [1]

(iii) Write an equation for the reaction of magnesium with cold water.
Include state symbols.

.... [2]

(c) The carbonates and nitrates of the elements in Group 2 can all be decomposed by heating.

(i) Write an equation for the thermal decomposition of magnesium nitrate.

.... [1]

(ii) The thermal decomposition of calcium carbonate forms a solid product that is industrially important. This solid product reacts with water to form a compound commonly known as slaked lime.

Write equations for the thermal decomposition of calcium carbonate and the reaction of the solid product to form slaked lime.

thermal decomposition ....

formation of slaked lime ....

[2]

(d) Calcium carbonate and calcium hydroxide both have an important use in agriculture.

(i) Describe this use and explain what makes these two compounds suitable for it.

....

....

.... [2]

(ii) Write an ionic equation to illustrate this use of calcium carbonate.

.... [1]

[Total: 16]

3 The elements in Group 2 and their compounds show various trends in their physical and chemical properties.

(b) **L** is a salt of a Group 2 element **M**.
When **L** is heated strongly a brown gas is observed and a white solid remains.

The white solid dissolves in water to form a colourless solution of the metal hydroxide **M**$(OH)_2$.

Addition of dilute sulfuric acid to this colourless solution produces a dense white precipitate.

(i) Identify the anion in salt **L**.

.... [1]

(ii) Identify the element **M** and write an **ionic** equation for the formation of the white precipitate with sulfuric acid.

M = ...

equation ....

[1]

(iii) Give the formula of salt **L** and use it to write an equation for the thermal decomposition of salt **L**.

formula of salt **L** ....

equation ....

[2]

(c) Calcium carbonate and calcium hydroxide can both be used in agriculture to neutralise acidic soils.

(i) Write **ionic** equations for the neutralisation of acid by each of calcium hydroxide and calcium carbonate.

calcium hydroxide ....

calcium carbonate ....

[2]

(ii) Suggest and explain why calcium carbonate is a better choice than calcium hydroxide for this purpose in areas of high rainfall.

....

....

.... [2]

(d) Magnesium reacts with both cold water and steam.

Give the formula of the magnesium-containing product of each of these reactions.

with cold water ....

with steam ....
[2]

[Total: 14]

Topic **Chem 10 Q# 222/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The elements in Group 2, and their compounds, show many similarities and trends in their properties.

(a) Magnesium, calcium, strontium and barium all react with cold water.

(i) Describe what you would **see** when some calcium is added to cold water.

....

....

.... [3]

(ii) Write an equation for the reaction taking place in **(i)**.

.... [1]

(iii) Describe how the reaction of barium with cold water would differ from the reaction of calcium in **(i)** in terms of what you would **see**.

....

.... [1]

(c) The nitrates and carbonates of the Group 2 elements, from magnesium to barium, decompose when heated.

(i) State the trend in the temperature of thermal decomposition of these Group 2 nitrates and carbonates.

....

.... [1]

(ii) Give the equation for the thermal decomposition of magnesium carbonate.

.... [1]

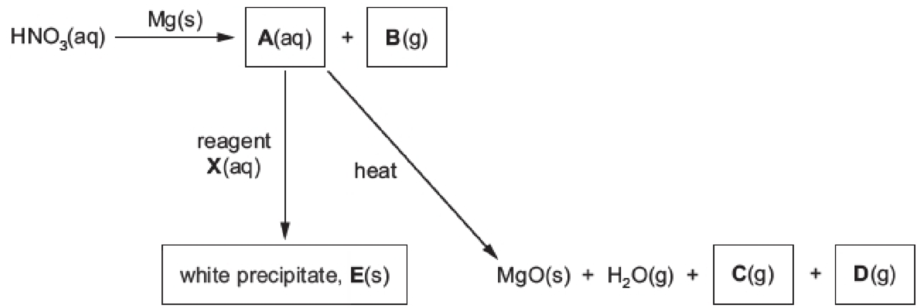
(iii) Give the equation for the thermal decomposition of calcium nitrate.

.... [1]

[Total: 15]

Topic **Chem 10 Q# 223/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(b) The flow chart below shows a series of reactions.



(i) Give the **formula** of each of the compounds **A** to **D**.

A .... **B** ....

C .... **D** ....
[4]

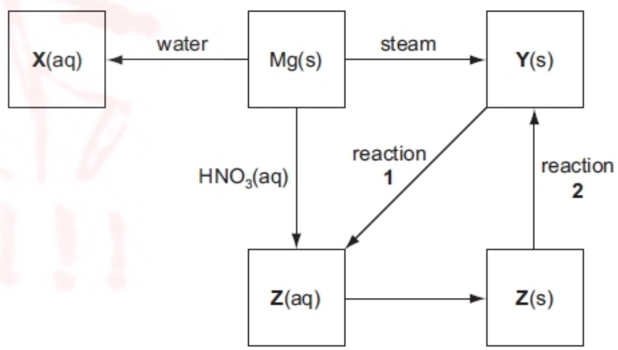
(ii) **E** reacts with dilute aqueous acid to produce a gas that turns limewater cloudy.

Suggest the identity of reagent **X**.

.... [1]

Topic **Chem 10 Q# 224/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) Some reactions involving magnesium and its compounds are shown in the reaction scheme below.



(i) Give the **formulae** of the compounds **X**, Y and **Z**.

X ....

Y ....

Z ....
[3]

(ii) Name the reagent needed to convert Y(s) into **Z**(aq) in reaction **1** and write an equation for the reaction.

reagent ....

equation .... [2]

(iii) How would you convert a sample of **Z**(s) into Y(s) in reaction **2**?

.... [1]

(iv) Give equations for the conversions of Mg into **X**, and **Z**(s) into Y.

Mg to **X** ....

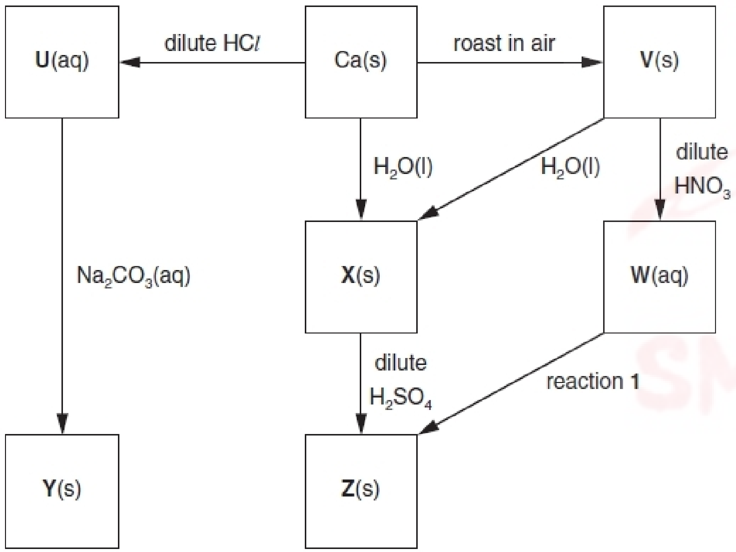
Z to Y .... [2]

[Total: 21]

Topic **Chem 10 Q# 225/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium is the fifth most common element in the Earth's crust.
Calcium compounds occur in bones and teeth and also in many minerals.

Some reactions of calcium and its compounds are shown in the reaction scheme below.



(a) State the formula of **each** of the calcium compounds **U** to **Y**.

U ....

V ....

W ....

X ....

Y .... [5]

(b) Compound **Y** may be converted into compound **V**.
Outline how this reaction would be carried out in a school or college laboratory using a small sample of **Y**.

....

....[1]

(c) (i) Construct balanced equations for the following reactions.

calcium to compound **U**

....

compound **V** to compound **W**

....

compound **U** to compound **Y**

....

(ii) Construct a balanced equation for the effect of heat on solid compound **W**.

....
[4]

(d) Suggest the formula of an aqueous reagent, other than an acid, for reaction **1**.

.... [1]

(e) What would be observed when **each** of the following reactions is carried out in a test-tube?

the formation of **X** from Ca(s)

....

the formation of **X** from **V**

....
[2]

Topic **Chem 10 Q# 226/** ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Radium was discovered in the ore pitchblende by Marie and Pierre Curie in 1898, and the metal was first isolated by them in 1910.

The metal was obtained by first reacting the radium present in the pitchblende to form insoluble radium sulfate which was converted into aqueous radium bromide. This solution was then electrolysed using a mercury cathode and a carbon anode.

(a) Radium has chemical reactions that are typical of Group II metals and forms ionic compounds.

(i) What is the characteristic feature of the electronic configurations of all Group II metals?

....

(ii) Radium sulfate is extremely insoluble. From your knowledge of the simple salts of Group II metals, suggest another very insoluble radium salt.

....

[2]

(c) **(i)** Describe what you would see when magnesium reacts with

cold water, ...

....

steam. ....

....

(ii) Write an equation for the reaction with steam.

....

[5]

(d) Radium reacts vigorously when added to water.

(i) Write an equation, with state symbols, for this reaction.

....

(ii) State **two** observations that could be made during this reaction.

....

....

(iii) Suggest the approximate pH of the resulting solution.

....

(iv) Will the reaction be more or less vigorous than the reaction of barium with water?

Explain your answer.

....

....

[6]

[Total: 15]

Topic **Chem 10 Q# 227/** ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Magnesium, Mg, and radium, Ra, are elements in Group II of the Periodic Table.

Magnesium has three isotopes.

(d) Radium, like other Group II elements, forms a number of ionic compounds.

(i) What is the formula of the radium cation?

....

(ii) Use the *Data Booklet* to suggest a value for the energy required to form one mole of the gaseous radium cation you have given in **(i)** from one mole of gaseous radium atoms. Explain your answer.

....

....

.... [3]

[Total: 10]

Topic **Chem 10 Q# 228/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium will react on heating with chlorine, or oxygen, or nitrogen to give the chloride, or oxide, or nitride respectively. Each of these compounds is ionic and in them magnesium has the same +2 oxidation state.

(b) Separate samples of magnesium chloride and magnesium oxide are shaken with water. In **each** case, describe what you would see when this is done, and state the approximate pH of the water after the solid has been shaken with it.

(i) magnesium chloride

observation ....

approximate pH of the water ....

(ii) magnesium oxide

observation ....

approximate pH of the water .... [4]

Topic Chem 11 Q# 229/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chlorides of Period 3 elements are shown in the list.

$NaCl$ $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(b) $NaCl$ is one product of the reaction of chlorine gas and cold aqueous sodium hydroxide.

Identify the other products.

.... [1]

Topic **Chem 11 Q# 230/** ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Magnesium shows reactions typical of a Group 2 metal.

(c) 1 cm^3 of $MgCl_2$(aq) is placed in a test-tube. A few drops of $AgNO_3$(aq) are added, followed by 1 cm^3 of dilute NH_3(aq).

State in full what is observed in this experiment.

....

.... [2]

(d) When 1 cm^3 of $MgCl_2$(aq) is added to 1 cm^3 of Br_2(aq) in a test-tube, the solution remains orange.

Explain this observation.

....

....

.... [1]

[Total: 9]

Topic **Chem 11 Q# 231/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 The hydrogen halides HCl, HBr and HI are all colourless gases at room temperature.

(a) The hydrogen halides can be formed by reacting the halogens with hydrogen.

Describe and explain the relative reactivity of the halogens down the group when they react with hydrogen to form HCl, HBr and HI.

....

....

.... [2]

(ii) In reaction 2, $NaCl$ reacts with concentrated H_2SO_4 to form HCl and $NaHSO_4$. When NaBr reacts with concentrated H_2SO_4, the products include Br_2 and SO_2.

Identify the type(s) of reaction that occur in each case by completing Table 3.1. Explain the difference in these reactions.

Table 3.1

reactants	type(s) of reaction
$NaCl$ and concentrated H_2SO_4	
NaBr and concentrated H_2SO_4	

explanation ....

.... [3]

(c) When heated with a Bunsen burner, HCl does not decompose, whereas HI forms H_2 and I_2.

Explain the difference in the effect of heating on HCl and HI.

....

.... [1]

Topic **Chem 11 Q# 232/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Sulfides are compounds that contain sulfur but not oxygen.

(a) Carbon disulfide, CS_2, is a volatile liquid at room temperature and pressure.

(i) State the meaning of *volatile*.

.... [1]

Topic **Chem 11 Q# 233/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Aqueous bromine reacts with methanoic acid to form hydrogen bromide and carbon dioxide gas.

$$Br_2(aq) + HCO_2H(aq) \rightarrow 2HBr(aq) + CO_2(g)$$

The table shows the oxidation numbers of bromine and carbon in the species involved in this reaction.

	Br in Br_2	C in HCO_2H	Br in HBr	C in CO_2
oxidation number	0	+2	–1	+4

(a) Identify the oxidising agent in this reaction. Explain your reasoning with reference to oxidation numbers.

....

.... [1]

(b) Suggest one change you would observe, ignoring temperature changes, when bromine reacts with methanoic acid.

.... [1]

Topic **Chem 11 Q# 234/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Sodium halide salts react with concentrated sulfuric acid at room temperature.

(a) (i) Write an equation to represent the reaction of NaC*l*(s) with concentrated sulfuric acid.

.... [1]

(ii) Name this type of reaction.

.... [1]

(b) NaI(s) reacts with concentrated sulfuric acid, at room temperature, to form steamy fumes.

(i) Identify the chemical responsible for the steamy fumes.

.... [1]

(ii) The reaction of NaI(s) with concentrated sulfuric acid continues, forming several other products, including a dark grey solid.

Identify the chemical responsible for the dark grey solid and **one** other product of this further reaction.

dark grey solid ....

other product .... [2]

(c) Explain the differences in observations, at room temperature, when NaI(s) reacts with concentrated sulfuric acid compared to those for NaC*l*(s).

....

....

.... [2]

(d) Complete the equation for the reaction of Br^- with excess concentrated H_2SO_4 at room temperature.

......Br^- + ...H^+ + ...H_2SO_4 → ....

[1]

[Total: 8]

Topic **Chem 11 Q# 235/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Chlorine, Cl_2, is a reactive yellow-green gas. It is a strong oxidising agent.

(a) State how Cl_2 is used in water purification.

....

.... [1]

(c) The halide ions, X^- (where X = C*l*, Br, I), show clear trends in their physical and chemical properties.

(i) State and explain the relative thermal stabilities of the hydrogen halides, HX.

....

....

.... [2]

The halide ions react easily with concentrated H_2SO_4.

The main sulfur-containing product of each reaction is shown in the table.

halide ion	Cl^-	Br^-	I^-
main sulfur-containing product of reaction with concentrated H_2SO_4	HSO_4^-	SO_2	H_2S
oxidation number of sulfur			

(ii) Complete the table to show the oxidation number of sulfur in each of the sulfur-containing products. [1]

(iii) Explain why different sulfur-containing products are produced when each of these halide ions reacts with concentrated H_2SO_4.

....

.... [1]

(d) Cl_2 reacts with aqueous sodium hydroxide in a disproportionation reaction.

(i) State what is meant by *disproportionation*.

....

.... [1]

(ii) Write an equation for the reaction of Cl_2 with cold aqueous sodium hydroxide.

.... [1]

Topic **Chem 11 Q# 236/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Iodine is used in many inorganic and organic reactions.

(a) (i) State and explain the trend in volatility of the halogens, from chlorine to iodine.

....

....

....

.... [2]

(ii) Explain why HI is the **least** thermally stable of HCl, HBr and HI.

....

.... [1]

(iii) The table shows the electronegativity values for hydrogen, fluorine and iodine.

element	electronegativity value
H	2.1
F	4.0
I	2.5

Explain, in terms of intermolecular forces, why HI has a lower boiling point than HF.

....

....

....

.... [2]

(iv) Iodine reacts with hot concentrated aqueous sodium hydroxide in the same way as chlorine.

Write an equation for the reaction of iodine and hot aqueous sodium hydroxide.

.... [1]

Topic **Chem 11 Q# 237/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(d) Chlorine forms several oxides, including Cl_2O, ClO_2 and Cl_2O_6.

(ii) ClO_2 can be prepared by reacting $NaClO_2$ with Cl_2.

Write the oxidation state of chlorine in each species in the boxes provided.

$$2NaClO_2 + Cl_2 \rightarrow 2ClO_2 + 2NaCl$$

oxidation state of chlorine: [+3] [ ] [ ] [ ] [1]

Topic **Chem 11 Q# 238/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 The Group 17 elements, chlorine, bromine and iodine, are non-metals that show trends in their physical and chemical properties.

(a) Describe the trend in the colour of the Group 17 elements down the group.

....

.... [1]

(b) The Group 17 elements can oxidise many metals to form halides.

(i) Describe the relative reactivity of the elements in Group 17 as oxidising agents.

....

.... [1]

(ii) Chlorine reacts with hot tin metal to form tin(IV) chloride, $SnCl_4$.

$SnCl_4$ is a colourless liquid at room temperature that reacts vigorously with water to form an acidic solution.

Suggest the type of structure and bonding shown by $SnCl_4$. Explain your answer.

....

....

....

....

.... [2]

(c) The Group 17 elements form soluble halides with sodium.

(i) Describe what is seen when dilute $AgNO_3(aq)$ is added to NaBr(aq) followed by aqueous ammonia.

....

....

.... [2]

(ii) NaCl reacts with concentrated H_2SO_4 to form HCl and $NaHSO_4$.

Explain the difference between the reactions of concentrated H_2SO_4 with NaCl and with NaI. Your answer should refer to the role of the sulfuric acid in each reaction.

....

....

....

....

....

.... [3]

(d) The hydrogen halides are useful reagents in organic and inorganic reactions.

(i) Describe and explain the trend in the boiling points of the hydrogen halides, HCl, HBr and HI.

....

....

....

.... [2]

(ii) Describe and explain the trend in the thermal stabilities of the hydrogen halides, HCl, HBr and HI.

....

....

....

.... [2]

Topic **Chem 11 Q# 239/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** Chlorine can be prepared using the following reaction.

$$MnO_2(s) + 4HCl(aq) \rightarrow MnCl_2(aq) + 2H_2O(l) + Cl_2(g)$$

(ii) State what you would observe during this reaction.

.... [1]

(b) The halogens chlorine, bromine and iodine are all volatile elements.

State and explain the trend in volatility down Group 17.

....

....

.... [3]

(c) Chlorine undergoes disproportionation during many chemical reactions.

(i) Write an equation for the reaction of chlorine with cold aqueous sodium hydroxide, NaOH.

Explain why it is a disproportionation reaction.

equation ....

explanation ....

.... [2]

(ii) One of the products of the reaction of chlorine with **hot** aqueous sodium hydroxide differs from those in **(c)(i)**.

Identify the compound that is formed in this reaction that is different from that formed in the reaction in **(c)(i)**.

.... [1]

(d) State and explain the use of chlorine in water purification.

....

....

.... [2]

(e) Under certain conditions, chlorine undergoes a free-radical substitution reaction with ethane.

(i) State the conditions required to initiate this reaction.

.... [1]

(ii) Write the overall equation for this free-radical substitution reaction.

.... [1]

[Total: 12]

Topic **Chem 11 Q# 240/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(c) HOF is the only known molecule that contains only the elements hydrogen, oxygen and fluorine.

(ii) HOF can be made by the reaction of F_2 with ice at –40 °C. The reaction is similar to the reaction of Cl_2 with cold water.

Suggest an equation for the reaction of F_2 with ice.

.... [1]

Topic **Chem 11 Q# 241/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 The elements in Group 17 of the Periodic Table are called the halogens. They form stable compounds with both metals and non-metals.

The table gives some data about F_2, HCl and CaF_2.

	F_2	HCl	CaF_2
boiling point / K	85	188	2773
relative formula mass	38.0	36.5	78.1

(ii) When Cl_2 is passed over hot iron, $FeCl_3$ is formed.

However, when I_2(g) is passed over hot iron, the following reaction occurs.

$$Fe(s) + I_2(g) \rightarrow FeI_2(s)$$

State what you would observe during the reaction between Fe and I_2. Explain why FeI_2(s) is formed rather than FeI_3(s).

observation ....

....

explanation ....

....

.... [2]

(iii) FeI_2 is soluble in water.

A student carries out a chemical test to confirm that a solution of FeI_2 contains aqueous iodide ions, I^-(aq). The student adds a single reagent and a precipitate forms.

Identify the reagent the student uses. State the colour of the precipitate that forms.

reagent ....

colour of precipitate .... [2]

(iv) Compounds containing I^- are often contaminated by bromide ions, Br^-.

Identify a further reagent that the student could use to show that the precipitate formed in **(iii)** contained iodide ions.

.... [1]

Topic **Chem 11 Q# 242/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium and its compounds have a large variety of applications.

(c) Calcium chlorate(I), $Ca(ClO)_2$, is used as an alternative to sodium chlorate(I), NaClO, in some household products.

(i) Suggest a use for calcium chlorate(I).

.... [1]

(ii) The chlorate(I) ion is formed when cold aqueous sodium hydroxide reacts with chlorine.

Write an **ionic** equation for this reaction. State symbols are **not** required.

.... [1]

(iii) The chlorate(I) ion is unstable and decomposes when heated as shown.

Deduce the oxidation number of chlorine in each species. Complete the boxes.

$$3ClO^- \rightarrow 2Cl^- + ClO_3^-$$

oxidation number of chlorine: [+1] [ ] [ ]

[1]

(iv) In terms of electron transfer, state what happens to the chlorine in the reaction in **(iii)**.

.... [1]

Topic **Chem 11 Q# 243/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

hydrogen halide	HF	HCl	HBr	HI
boiling point / °C	19	–85	–67	–35
H–X bond energy / kJ mol⁻¹	562	431	366	299

(iii) Describe and explain the relative thermal stabilities of the hydrogen halides.

....

....

....

....

....

.... [3]

(b) The equation for the preparation of hydrogen chloride using concentrated sulfuric acid is shown.

$$H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl$$

(ii) Explain why the reaction of concentrated sulfuric acid and sodium iodide is **not** suitable for the preparation of hydrogen iodide.

....

....

....

.... [2]

Topic **Chem 11 Q# 244/** ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 A 0.17 g sample of a Group 14 chloride, $\mathbf{X}Cl_4$, reacted with water to produce an oxide, $\mathbf{X}O_2$, and HCl.

equation 1 $$\mathbf{X}Cl_4(s) + 2H_2O(l) \rightarrow \mathbf{X}O_2(s) + 4HCl(aq)$$

The HCl produced was absorbed in 100 cm^3 of 0.10 mol dm^{-3} sodium hydroxide solution (an excess).

In a titration, the unreacted sodium hydroxide solution required 30.0 cm^3 of 0.20 mol dm^{-3} hydrochloric acid for complete neutralisation.

(a) Calculate the amount, in moles, of hydrochloric acid used in the titration to neutralise the unreacted sodium hydroxide solution.

amount = ... mol [1]

(b) Write the equation for the reaction between hydrochloric acid and sodium hydroxide.

.... [1]

(c) Calculate the amount, in moles, of sodium hydroxide neutralised in the titration.

amount = ... mol [1]

(d) Calculate the amount, in moles, of sodium hydroxide that reacted with the HCl produced by the reaction in equation 1.

amount = ... mol [1]

(e) Calculate the amount, in moles, of HCl produced by the reaction in equation 1.

amount = ... mol [1]

(f) Calculate the amount, in moles, of $\mathbf{X}Cl_4$ in the original 0.17 g sample.

amount = ... mol [1]

(g) Calculate the molecular mass, M_r, of $\mathbf{X}Cl_4$.

M_r = ... [1]

(h) Calculate the relative atomic mass, A_r, of **X** and suggest its identity.

A_r of **X** = ...

identity of **X** ....

[2]

[Total: 9]

3 **(a)** In this question, **K**, **L** and **M** refer to a halogen atom or halide ion.
For each part question, read the information and complete the answer lines below.

(i) When concentrated sulfuric acid is added to solid Na**K**, white fumes are produced that turn damp blue litmus paper red. No other colour changes are observed.

identity of **K** = ...

equation for reaction ....

explanation of observation ....

.... [3]

(ii) When silver nitrate solution is added to an aqueous solution of Na**L**, a precipitate forms that remains after the addition of concentrated ammonia solution.

identity of **L** = ...

colour of precipitate ....

equation for reaction .... [3]

(iii) $\mathbf{M}_2$ is a liquid at room temperature with a boiling point higher than that of chlorine but lower than that of iodine.

identity of **M** = ...

explanation ....

....

....

....

.... [2]

Topic **Chem 11 Q# 246/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) Chlorine reacts with aqueous sodium hydroxide in two different ways, depending on the conditions used. In each case, water, sodium chloride and one other chlorine-containing compound are formed.

For **each** condition below, give the formula of the **other** chlorine-containing compound and state the oxidation number of chlorine in it.

condition	formula of **other** chlorine-containing compound	oxidation number of chlorine in this compound
cold dilute NaOH(aq)		
hot concentrated NaOH(aq)		

[4]

Topic **Chem 11 Q# 247/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Each of the Group VII elements chlorine, bromine and iodine forms a hydride.

(a) **(i)** Outline how the relative thermal stabilities of these hydrides change from HCl to HI.

....

....

(ii) Explain the variation you have outlined in **(i)**.

....

....

.... [3]

Topic **Chem 11 Q# 248/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 The gaseous hydrogen halides HCl, HBr and HI, may be prepared by reacting the corresponding sodium salt with anhydrous phosphoric(V) acid, H_3PO_4.

When the sodium halide Na*X* was used, the following reaction occurred and a sample of gaseous H*X* was collected in a gas jar.

$$NaX + H_3PO_4 \rightarrow NaH_2PO_4 + HX$$

A hot glass rod was placed in the sample of H*X* and immediately a red/orange colour was observed.

(a) What is the identity of Na*X*?

.... [1]

(b) What gas, other than H*X*, would be formed if concentrated sulfuric acid were used with Na*X* instead of phosphoric(V) acid?

.... [1]

(c) Suggest why phosphoric(V) acid rather than concentrated sulfuric acid is used to make samples of H*X* from the corresponding sodium salt.
Explain your answer.

....

.... [1]

[Total: 3]

Topic **Chem 11 Q# 249/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Copper and titanium are each used with aluminium to make alloys which are light, strong and resistant to corrosion.

Aluminium, Al, is in the third period of the Periodic Table; copper and titanium are both transition elements.

Aluminium reacts with chlorine.

Copper forms two chlorides, $CuCl$ and $CuCl_2$.

(c) When copper is reacted directly with chlorine, only $CuCl_2$ is formed.
Suggest an explanation for this observation.

....

.... [1]

Topic Chem 12 Q# 250/ ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Nitrogen molecules, $N_2(g)$, contain two atoms attracted to each other by a triple covalent bond.

(b) Nitrogen oxides, NO_2 and NO, are produced in internal combustion engines. Release of these gases into the atmosphere leads to the formation of photochemical smog.

(i) Outline how nitrogen oxides are involved in the formation of photochemical smog.

....

....

.... [2]

(ii) Construct an equation to demonstrate how a catalytic converter reduces the amount of nitrogen oxide gases released into the atmosphere.

.... [1]

(c) $N_2(g)$ is very unreactive. It is difficult to make ammonia, $NH_3(g)$, directly from its elements but it can be made from $NH_4Cl(s)$.

Identify a reagent and the conditions required to make $NH_3(g)$ from $NH_4Cl(s)$.

.... [1]

Topic Chem 12 Q# 251/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O Al_2O_3 P_4O_6 P_4O_{10} SO_2 SO_3

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(d) SO_2 and SO_3 are found in the atmosphere.
The oxidation of SO_2 to SO_3 in the atmosphere is catalysed by NO_2.
The first step of the catalytic oxidation is shown in equation 1.

equation 1 $SO_2(g) + NO_2(g) \rightleftharpoons SO_3(g) + NO(g)$

(i) Construct an equation to show how NO_2 is regenerated in the catalytic oxidation of SO_2.

.... [1]

(ii) NO_2 can also react with unburned hydrocarbons to form photochemical smog.

State the product of this reaction that contributes to photochemical smog.

.... [1]

Topic Chem 12 Q# 252/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(ii) State the environmental consequences of releasing $SO_2(g)$ into the atmosphere.

.... [1]

(iii) $SO_2(g)$ can be removed from the air by reacting it with NaOH(aq).

Construct an equation for the reaction of $SO_2(g)$ with NaOH(aq). Include state symbols.

.... [2]

[Total: 21]

Topic Chem 12 Q# 253/ ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Carbon monoxide gas, CO(g), and nitrogen gas, $N_2(g)$, are both diatomic molecules.

(b) $N_2(g)$ is less reactive than CO(g) even though $N_2(g)$ has a lower bond energy than CO(g).

Suggest why CO(g) is more reactive than $N_2(g)$.

....

.... [1]

Topic Chem 12 Q# 254/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(iii) SO_2 reacts with NO_2 in the atmosphere to form SO_3 and NO.

NO is then oxidised in air to form NO_2.

$$SO_2 + NO_2 \rightarrow SO_3 + NO$$

$$2NO + O_2 \rightarrow 2NO_2$$

State the role of NO_2 in this two-stage process.

.... [1]

Topic Chem 12 Q# 255/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Nitric acid, HNO_3, can be made by reacting nitrogen dioxide with water.

The enthalpy change for the reaction can be measured indirectly using a Hess' cycle.

$$3NO_2(g) + H_2O(l) \xrightarrow{\Delta H_r} 2HNO_3(l) + NO(g)$$

(c) Nitrogen and oxygen do not react at normal atmospheric temperatures.

Explain why.

....

....

....

.... [2]

Nitrogen oxides can be formed naturally in the Earth's atmosphere from nitrogen and oxygen in the air.

(d) State **one** way that nitrogen oxides are produced naturally.

.... [1]

(e) Nitrogen dioxide, NO_2, acts as a homogeneous catalyst in the oxidation of atmospheric sulfur dioxide.

(i) Explain why NO_2 is described as a homogeneous catalyst.

....

....

....

.... [3]

(ii) Write equations which describe the two reactions occurring when NO_2 acts as a catalyst in the formation of sulfur trioxide from sulfur dioxide.

....

.... [2]

[Total: 13]

Topic **Chem 12 Q# 256/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Crude oil is a natural source of hydrocarbons that are used as fuels.

(b) Thiophene, $C_4H_4S(l)$, is an organic compound that is found as a contaminant in crude oil.

(i) Construct the equation for the complete combustion of thiophene, $C_4H_4S(l)$.

Include state symbols in your answer.

.... [2]

Topic **Chem 12 Q# 257/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 Nitrogen, N_2, is the most abundant gas in the Earth's atmosphere and is very unreactive.

(a) State why N_2 is very unreactive.

.... [1]

(c) **(i)** State the industrial importance of ammonia.

.... [1]

(ii) One method of producing NH_3 is by heating ammonium chloride, NH_4Cl, with CaO.

$$2NH_4Cl + CaO \rightarrow 2NH_3 + CaCl_2 + H_2O$$

Explain why the reaction of NH_4Cl with CaO produces ammonia.

....

....

.... [2]

(d) Three oxides of nitrogen, NO, NO_2 and N_2O, can be formed under different conditions.

(i) Complete the table to give the oxidation numbers of nitrogen in NO and NO_2.

compound	NO	NO_2
oxidation number of N		

[1]

(ii) NO_2 can be formed by different chemical reactions.

Write equations for the formation of NO_2 by:

- the reaction of N_2 with O_2

....

- the thermal decomposition of magnesium nitrate.

....

[2]

Topic **Chem 12 Q# 258/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 **(a)** Nitrogen, N_2, is an inert gas that makes up 78% of the Earth's atmosphere.

(i) Explain why nitrogen is inert.

....

....

.... [2]

(b) Nitrogen, N_2, and oxygen, O_2, react together in the air during lightning strikes to form nitrogen monoxide, NO.

(i) Explain why the reaction of N_2 and O_2 occurs during lightning strikes.

....

.... [1]

(ii) Write two equations to suggest how the NO formed reacts further to create nitric acid, HNO_3.

1 ....

2 ....

[2]

(d) Some soils have compounds such as ammonium nitrate, calcium carbonate and calcium hydroxide added to them.

(ii) When calcium hydroxide reacts with compounds containing the ammonium ion, NH_4^+, a gas is produced.

State the identity of this gas and explain why the reaction occurs.

gas ....

explanation ....

....

....

[2]

Topic **Chem 12 Q# 259/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Iron pyrite, FeS_2, has a yellow colour that makes it look like gold metal. The compound contains the ions Fe^{2+} and S_2^{2-}.

(c) Iron pyrite is often called *fool's gold* because of its appearance. Impure samples of iron pyrite often contain a small amount of gold.

The gold can be obtained from impure iron pyrite. The impure iron pyrite is roasted in oxygen, to produce iron(III) oxide and sulfur dioxide. Gold does not react with oxygen.

(i) The sulfur dioxide produced during roasting would cause environmental consequences if released into the atmosphere.

State and explain **one** of these environmental consequences.

....

....

.... [2]

(ii) Complete the equation to show the roasting of iron pyrite in oxygen.

$4FeS_2$ + ... → $2Fe_2O_3$ + ...

[2]

(iii) A sample of impure iron pyrite was roasted in oxygen. The composition of the mixture of solid products is shown.

solid product	mass / g
Fe_2O_3	33.18
Au	0.37

Calculate the mass of FeS_2 present in the sample of impure iron pyrite.
Assume that all the FeS_2 was converted to Fe_2O_3 during the roasting process.

(M_r: FeS_2, 120.0; Fe_2O_3, 159.6)

mass of FeS_2 = ... g [2]

(iv) Use your answer to **(iii)** to calculate the percentage by mass of gold in this sample of impure iron pyrite. Assume that gold is the only impurity in this sample of impure iron pyrite.

Give your answer to **two** significant figures.

(If you were unable to calculate an answer to **(iii)**, use 55.00 g as the mass of FeS_2 in this calculation. This is **not** the correct answer.)

percentage by mass of gold = ... % [1]

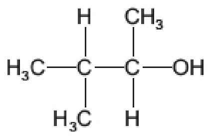
[Total: 11]

Topic **Chem 12 Q# 260/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 The following compounds were all found to be components of a sample of petrol.

$CH_3(CH_2)_2CH_3$ — **G**

$(CH_3)_3CCH_2CH(CH_3)_2$ — **H**



J

(c) Fossil fuels are often contaminated with sulfur.

State and explain why supplies of fossil fuels that contain sulfur pose a problem to the environment.

....

....

.... [2]

Topic **Chem 12 Q# 261/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Heptane, C_7H_{16}, is an undesirable component of petrol as it burns explosively causing 'knocking' in an engine.

(iii) Incomplete combustion can also lead to emission of unburnt hydrocarbons.

State one environmental consequence of this.

.... [1]

Topic **Chem 12 Q# 262/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(d) The use of nitrate fertilisers can give rise to environmental consequences in terms of effects on both rivers and the atmosphere.

(ii) Oxides of nitrogen are produced by the action of bacteria on nitrate fertilisers.

Explain the problems associated with the release of oxides of nitrogen into the atmosphere. Include an equation in your answer.

....

....

.... [2]

[Total: 21]

Topic **Chem 12 Q# 263/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) Although nitrogen gas makes up about 79% of the atmosphere it does not easily form compounds.

(i) Explain why nitrogen is so unreactive.

....

.... [1]

(ii) Explain why the conditions in a car engine lead to the production of oxides of nitrogen.

....

.... [1]

(iii) Give an equation for a reaction involved in the removal of nitrogen monoxide, NO, from a car's exhaust gases, in the catalytic converter.

.... [1]

One of the main reasons for reducing the amounts of oxides of nitrogen in the atmosphere is their contribution to the formation of acid rain.

(iv) Write an equation for the formation of nitric acid from nitrogen dioxide, NO_2, in the atmosphere.

.... [1]

(v) Write equations showing the catalytic role of nitrogen monoxide, NO, in the oxidation of atmospheric sulfur dioxide, SO_2.

....

.... [2]

[Total: 15]

Topic **Chem 12 Q# 264/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 The Contact process for the manufacture of sulfuric acid was originally patented in the 19th century and is still in use today.

The key step in the overall process is the reversible conversion of sulfur dioxide to sulfur trioxide in the presence of a vanadium(V) oxide catalyst.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(a) One way in which the sulfur dioxide for this reaction is produced is by heating the sulfide ore iron pyrites, FeS_2, in air. Iron(III) oxide is also produced. Write an equation for this reaction.

.... [2]

(b) The sulfur trioxide produced in the Contact process is reacted with 98% sulfuric acid. The resulting compound is **then** reacted with water to produce sulfuric acid.

(i) Explain why the sulfur trioxide is not first mixed directly with water.

....

.... [1]

(ii) Write equations for the two steps involved in the conversion of sulfur trioxide into sulfuric acid.

....

.... [2]

(d) The conversion of sulfur dioxide into sulfur trioxide is carried out at a temperature of 400 °C.

(i) With reference to Le Chatelier's Principle and reaction kinetics, state and explain one advantage and one disadvantage of using a higher temperature.

....

....

....

....

....

.... [4]

(ii) State the expression for the equilibrium constant, K_p, for the formation of sulfur trioxide from sulfur dioxide.

K_p =

[1]

(iii) 2.00 moles of sulfur dioxide and 2.00 moles of oxygen were put in a flask and left to reach equilibrium.
At equilibrium, the pressure in the flask was 2.00×10^5 Pa and the mixture contained 1.80 moles of sulfur trioxide.

Calculate K_p. Include the units.

K_p = ...

units = ... [5]

[Total: 19]

Topic **Chem 12 Q# 265/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Propane, C_3H_8, and butane, C_4H_{10}, are components of Liquefied Petroleum Gas (LPG) which is widely used as a fuel for domestic cooking and heating.

(b) When propane or butane is used in cooking, the saucepan may become covered by a solid black deposit.

(i) What is the chemical name for this black solid?

....

(ii) Write a balanced equation for its formation from butane.

.... [2]

Topic **Chem 12 Q# 266/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) Ammonia is a weak base which forms salts containing the ammonium ion.

Describe, with the aid of an equation, the formation and structure of the ammonium ion.
You should use displayed formulae in your answer.

[3]

[Total: 13]

Topic **Chem 12 Q# 267/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Ammonium sulfate, $(NH_4)_2SO_4$, is widely used as a fertiliser.

In order to determine its percentage purity, a sample of ammonium sulfate fertiliser was analysed by reacting a known amount with an excess of NaOH(aq) and then titrating the unreacted NaOH with dilute HC*l*.

(a) Ammonium sulfate reacts with NaOH in a 1 : 2 ratio.
Complete and balance the equation for this reaction.

$(NH_4)_2SO_4$ + 2NaOH → ....NH_3 + ... + ...

[2]

(b) A 5.00 g sample of a fertiliser containing $(NH_4)_2SO_4$ was warmed with 50.0 cm^3 (an excess) of 2.00 mol dm^{-3} NaOH.

When all of the ammonia had been driven off, the solution was cooled.

The remaining NaOH was then titrated with 1.00 mol dm^{-3} HC*l* and 31.2 cm^3 were required for neutralisation.

(i) Write a balanced equation for the reaction between NaOH and HC*l*.

....

(ii) Calculate the amount, in moles, of HC*l* in 31.2 cm^3 of 1.00 mol dm^{-3} HC*l*.

(iii) Calculate the amount, in moles, of NaOH in 50.0 cm^3 of 2.00 mol dm^{-3} NaOH.

(iv) Use your answers to **(i)**, **(ii)** and **(iii)** to calculate the amount, in moles, of NaOH used up in the reaction with $(NH_4)_2SO_4$.

(v) Use your answer to **(iv)** and the equation in **(a)** to calculate the amount, in moles, of $(NH_4)_2SO_4$ that reacted with NaOH.

(vi) Use your answer to **(v)** to calculate the mass of $(NH_4)_2SO_4$ that reacted with NaOH.

(vii) Hence, calculate the percentage purity of the ammonium sulfate fertiliser.

[7]

[Total: 9]

Topic **Chem 12 Q# 268/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) Sulfur dioxide is present in small, but significant, amounts in the Earth's atmosphere.

(i) State **one** way by which sulfur dioxide enters the atmosphere.

....

(ii) Give the formula of another sulfur compound which is formed in the atmosphere from sulfur dioxide.

....

(iii) What are the environmental consequences of the compound you have identified in **(ii)**?

....

[3]

Topic **Chem 12 Q# 269/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Crude oil contains a mixture of hydrocarbons together with other organic compounds which may contain nitrogen, oxygen or sulfur in their molecules.

At an oil refinery, after the fractional distillation of crude oil, a number of other processes may be used including 'cracking', 'isomerisation', and 'reforming'.

One of the sulfur-containing compounds present in crude oil is ethanethiol, C_2H_5SH, the sulfur-containing equivalent of ethanol. Ethanethiol is toxic and is regarded as one of the smelliest compounds in existence.

When ethanethiol is burned in an excess of air, three oxides of different elements are formed.

(c)

When ethanethiol is burned in an excess of air, three oxides of different elements are formed.

(c) (i) Construct a balanced equation for this rection.

....

(ii) **Two** of the oxides formed cause serious environmental damage.

One oxide is CO2 which leads to enhanced greenhouse effect causing global warming.

For the other oxide, identify the type of pollution caused and describe one consequence of this pollution.

....

....

.... [4]

(d) A small amount of ethanethiol is added to liquefied gases such as butane that are widely used in portable cooking stoves.

Suggest a reason for this.

.... [1]

Topic **Chem 12 Q# 270/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

In many countries, new cars have to comply with regulations which are intended to reduce the pollutants coming from their internal combustion engines.

Two pollutants that may be formed in an internal combustion engine are carbon monoxide, CO, and nitrogen monoxide, NO.

(e) (i) Outline how **each** of these pollutants may be formed in an internal combustion engine.

CO ....

....

NO ....

....

(ii) State the main hazard associated with **each** of these pollutants.

CO ....

NO .... [4]

Pollutants such as CO and NO are removed from the exhaust gases of internal combustion engines by catalytic converters which are placed in the exhaust system of a car.

(f) (i) What metal is most commonly used as the catalyst in a catalytic converter?

....

(ii) Construct **one** balanced equation for the reaction in which **both** CO **and** NO are removed from the exhaust gases by a catalytic converter.

.... [2]

[Total: 14]

Topic **Chem 12 Q# 271/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) Hydrogen cyanide, HCN, is a gas which is also isoelectronic with N_2 and with CO. Each molecule contains a strong triple bond with the following bond energies.

bond	bond energy / $kJ\,mol^{-1}$
$-C\equiv N$ in HCN	890
$N\equiv N$	994
$C\equiv O$	1078

Although each compound contains the same number of electrons and a strong triple bond in its molecule, CO and HCN are both very reactive whereas N_2 is not.

Suggest a reason for this.

....

.... [1]

3 Concern over the ever-increasing use of fossil fuels has led to many suggestions for alternative sources of energy. One of these, suggested by Professor George Olah, winner of a Nobel Prize in chemistry, is to use methanol, CH_3OH, which can be obtained in a number of different ways.

Methanol could be used instead of petrol in a conventional internal combustion engine or used to produce electricity in a fuel cell.

(a) Construct a balanced equation for the **complete** combustion of methanol.

.... [1]

When hydrocarbon fuels are completely burned in an internal combustion engine, several toxic pollutants may be formed.

(b) State **two toxic** pollutants that can be produced after **complete** combustion of a hydrocarbon fuel in an internal combustion engine.

....

.... [2]

C1	C2
	

(b) **C1** has melting point –94 °C and boiling point +49 °C.

Explain these properties by referring to the type of van der Waals' forces between molecules.

....

....

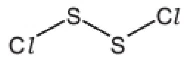
.... [2]

(c) Draw the structure of the cis isomer of **C2**.

[1]

Fig. 3.1 shows the two structural isomers of S_2Cl_2.

isomer **I**



isomer **II**

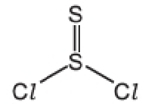


Fig. 3.1

(iv) Define the term structural isomer.

....

.... [2]

3 Liquids that contain molecules of **T** smell like lemons.

T

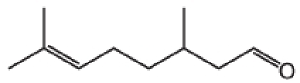


Fig. 3.1

(a) Molecules of **T** exist as a pair of stereoisomers.

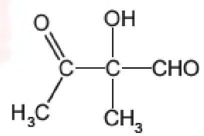
Name the type of stereoisomerism shown by molecules of **T**. Explain your answer.

....

.... [2]

4 Compounds **J** and **K** are found in plant oils.

J



K

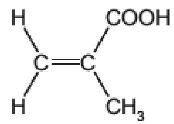


Fig. 4.1

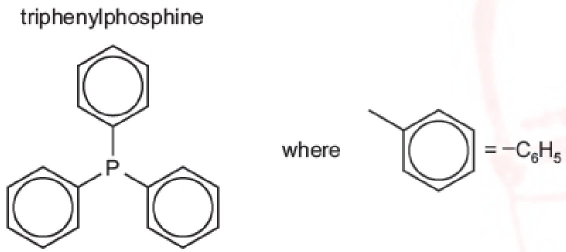
(ii) **J** has **two** optical isomers.

Draw the three-dimensional structures of the **two** optical isomers of **J**.

[2]

Topic **Chem 13 Q# 277/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) Triphenylphosphine is used in a type of reaction known as a *Wittig reaction*.

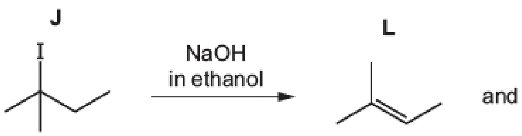


(i) Give the empirical formula of triphenylphosphine.

.... [1]

Topic **Chem 13 Q# 278/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(iii) **J** reacts with NaOH dissolved in ethanol to form a mixture of two alkenes, **L** and **M**. Alkene **L** is shown.



M

(iv) Explain why **L** does **not** show geometrical (cis-trans) isomerism.

....

....

.... [1]

Topic **Chem 13 Q# 279/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

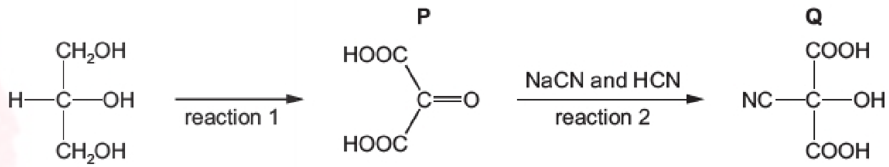
(a) Draw the skeletal formula of 2-methylbut-1-ene.

[1]

Topic **Chem 13 Q# 280/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Glycerol, $CH_2(OH)CH(OH)CH_2OH$, is widely used in the food industry and in pharmaceuticals.

(a) A series of reactions starting from glycerol is shown.



(iv) **Q** does **not** show optical isomerism.

Explain why.

....

....

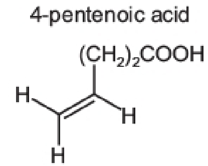
....

.... [1]

Topic **Chem 13 Q# 281/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(c) Fats are compounds made from glycerol and unsaturated carboxylic acids.

4-pentenoic acid is an example of an unsaturated carboxylic acid.



(i) Give the molecular formula of 4-pentenoic acid.

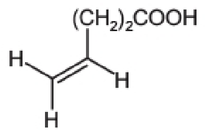
.... [1]

Topic **Chem 13 Q# 282/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

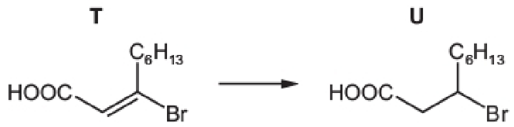
(c) Fats are compounds made from glycerol and unsaturated carboxylic acids.

4-pentenoic acid is an example of an unsaturated carboxylic acid.

4-pentenoic acid



(d) A reaction of another unsaturated carboxylic acid, **T**, is shown.



(i) **T** is one of a pair of geometrical (*cis-trans*) isomers.

Draw the other geometrical isomer of **T** and explain why the molecules exhibit this form of isomerism.

....

....

.... [3]

Topic **Chem 13 Q# 283/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Ethanal reacts with a mixture of HCN and NaCN to make 2-hydroxypropanenitrile, $CH_3CH(OH)CN$.

The reaction mechanism is nucleophilic addition.

(b) $CH_3CH(OH)CN$ exists as a pair of stereoisomers.

(i) Name the type of stereoisomerism shown by $CH_3CH(OH)CN$.

.... [1]

(ii) Draw three-dimensional diagrams of this pair of stereoisomers.

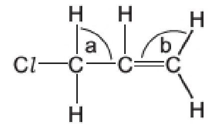
Indicate with an asterisk (*) the chiral centre on one of the structures drawn.

[3]

Topic **Chem 13 Q# 284/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 The structure of compound **Y** is shown.

Y



(a) Give the systematic name for **Y**.

.... [1]

(b) Predict the values for the bond angles a and b shown in the diagram.

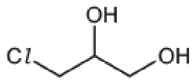
a ....

b ....

[2]

(c) When **Y** reacts with cold, dilute, acidified manganate(VII) ions, compound **Z** is produced.

Z



(i) State the molecular formula of **Z**.

.... [1]

Topic **Chem 13 Q# 285/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 Allyl chloride is an important chemical used in the manufacture of plastics, pharmaceuticals and pesticides.

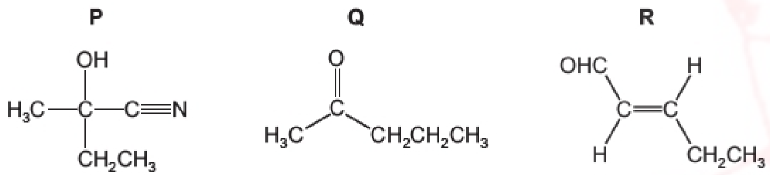
allyl chloride

(a) Give the systematic name of allyl chloride.

.... [1]

Topic **Chem 13 Q# 286/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **P**, **Q** and **R** all contain five carbon atoms.



(c) **R** exists as a pair of stereoisomers.

Identify the type of stereoisomerism shown by **R** and draw the structure of the other stereoisomer.

type of stereoisomerism ....

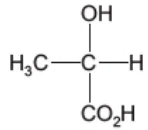
stereoisomer of **R**

[2]

Topic **Chem 13 Q# 287/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium and its compounds have a large variety of applications.

(d) Calcium lactate is used in some medicines. It forms when lactic acid (2-hydroxypropanoic acid) reacts with calcium carbonate.



lactic acid

(v) Lactic acid has a chiral centre.

State what is meant by the term *chiral centre*.

....

....

.... [1]

[Total: 18]

Topic **Chem 13 Q# 288/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) 2-bromo-2-methylpropane is a tertiary halogenoalkane that is a structural isomer of 1-bromobutane.

(i) Define the term *structural isomer* and name the three different types of structural isomerism.

definition ....

....

....

....

types of structural isomerism

1 ....

2 ....

3 ....

[4]

(d) The product of reaction 2, but-1-ene, does **not** show stereoisomerism. However, but-1-ene reacts with HC*l* to form a mixture of structural isomers **X** and **Y**.

but-1-ene + HC*l* → **X** (exists as a pair of stereoisomers and is produced in higher yield than **Y**)

but-1-ene + HC*l* → **Y** (does not show stereoisomerism)

(i) Explain the meaning of the term *stereoisomers*.

....

....

.... [2]

Topic **Chem 13 Q# 289/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(d) **P** and **Q** each react with hydrogen cyanide to form a single product.
The product formed from **P** exists as a pair of optical isomers.
The product formed from **Q** does not exhibit optical isomerism.

(i) Explain the meaning of the term *optical isomers*.

....

....

....

.... [2]

Topic **Chem 13 Q# 290/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 **P**, **Q** and **R** all have the molecular formula C_3H_8O. They are all structural isomers of each other.

P and **Q** each contain an oxygen atom bonded directly to a carbon atom that is sp^2 hybridised. **R** contains an oxygen atom bonded directly to a carbon atom that is sp^3 hybridised.

(a) **(i)** Explain the meaning of the term *structural isomers*.

....

....

....

.... [2]

(ii) Explain how sp^2 and sp^3 hybridisation can occur in carbon atoms.

sp^2 hybridisation ....

....

sp^3 hybridisation ....

.... [2]

(iii) State the bond angles normally associated with each type of hybridisation in carbon atoms.

sp^2 ....

sp^3 .... [2]

Topic **Chem 13 Q# 291/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Combustion data can be used to calculate the empirical formula, molecular formula and relative molecular mass of many organic compounds.

(b) **T** is an alcohol, C_xH_yO. A gaseous sample of **T** occupied a volume of $20\,cm^3$ at 120°C and 100 kPa.

The sample was completely burned in $200\,cm^3$ of oxygen (an excess). The final volume, measured under the same conditions as the gaseous sample, was $250\,cm^3$.

Under these conditions, all water present is vaporised. Removal of the water vapour from the gaseous mixture decreased the volume to $170\,cm^3$.

Treating the remaining gaseous mixture with concentrated alkali, to absorb carbon dioxide, decreased the volume to $110\,cm^3$.

The equation for the complete combustion of **T** can be represented as shown.

$$C_xH_yO + zO_2 \rightarrow xCO_2 + \frac{y}{2}H_2O$$

(i) Use the data given to calculate the value of *x*.

x = ... [1]

(ii) Use the data given to calculate the value of *y*.

y = ... [1]

If you were unable to calculate values for x and y then use $x = 4$ and $y = 10$ for the remaining parts of this question. These are **not** the correct values.

(iii) Complete the equation for the complete combustion of the alcohol, **T**.

.... + ...O_2 → ....CO_2 + ...H_2O [1]

(iv) Give the skeletal formulae for two possible structures of **T**.

Name each alcohol.

.... [2]

(v) Use the general gas equation to calculate the mass of **T** present in the original 20 cm^3 gaseous sample, which was measured at 120 °C and 100 kPa.

Give your answer to **three** significant figures. Show your working.

mass = ... g [3]

[Total: 10]

4 This question is about molecules with molecular formula C_4H_8.

(a) Give the structures of a pair of **positional** isomers with the formula C_4H_8.

[1]

(b) Give the structures of a pair of **chain** isomers with the formula C_4H_8, that do **not** exhibit stereoisomerism.

[1]

(c) Give the structures and full names of a pair of **stereoisomers** with the formula C_4H_8.

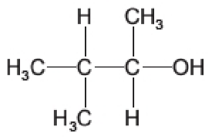
.... [2]

Topic **Chem 13 Q# 293/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 The following compounds were all found to be components of a sample of petrol.

$CH_3(CH_2)_2CH_3$ — **G**

$(CH_3)_3CCH_2CH(CH_3)_2$ — **H**



J

(a) (i) Give the **molecular** formula of compound **G**.

.... [1]

(ii) Give the **empirical** formula of compound **H**.

.... [1]

(iii) Draw the **skeletal** formula of compound **J**.

[1]

Topic **Chem 13 Q# 294/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Heptane, C_7H_{16}, is an undesirable component of petrol as it burns explosively causing 'knocking' in an engine.

(a) There are nine structural isomers with the formula C_7H_{16}, only two of which contain chiral centres.

(i) Explain the meanings of the terms *structural isomers* and *chiral*.

structural isomers ....

....

....

chiral ....

....

.... [2]

Topic **Chem 13 Q# 295/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Ethanal reacts with hydrogen cyanide, in the presence of a small amount of NaCN, as shown.

$$CH_3CHO + HCN \rightarrow CH_3CH(OH)CN$$

(b) The product of this reaction shows stereoisomerism as it contains a chiral centre. This reaction produces an equimolar mixture of two optical isomers.

(i) Explain the meanings of the terms *stereoisomerism* and *chiral centre*.

stereoisomerism ....

....

....

chiral centre ....

.... [2]

Topic **Chem 13 Q# 296/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) (i) Explain what is meant by the term *stereoisomerism*.

....

....

.... [2]

Topic **Chem 13 Q# 297/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(e) The boiling points of methane, ethane, propane, and butane are given below.

compound	CH_4	CH_3CH_3	$CH_3CH_2CH_3$	$CH_3(CH_2)_2CH_3$
boiling point / K	112	185	231	273

(i) Suggest an explanation for the increase in boiling points from methane to butane.

....

....

....

(ii) The isomer of butane, 2-methylpropane, $(CH_3)_3CH$, has a boiling point of 261 K. Suggest an explanation for the difference between this value and that for butane in the table above.

....

....

.... [4]

[Total: 15]

Topic **Chem 13 Q# 298/** ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Crotonaldehyde, $CH_3CH{=}CHCHO$, occurs in soybean oils.

(b) Crotonaldehyde exists in more than one stereoisomeric form.
Draw the **displayed formulae** of the **stereoisomers** of crotonaldehyde.
Label **each** isomer.

[3]

(c) Draw the **skeletal formula** of crotonaldehyde.

[1]

Topic **Chem 13 Q# 299/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Isomerism occurs in many organic compounds. The two main forms of isomerism are structural isomerism and stereoisomerism. Many organic compounds that occur naturally have molecules that can show stereoisomerism, that is *cis-trans* or optical isomerism.

(a) (i) Explain what is meant by *structural isomerism*.

....

....

(ii) State **two** different features of molecules that can give rise to **stereoisomerism**.

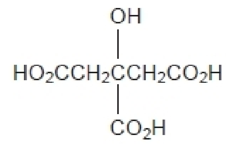
....

.... [3]

Unripe fruit often contains polycarboxylic acids, that is acids with more than one carboxylic acid group in their molecule.

One of these acids is commonly known as tartaric acid, $HO_2CCH(OH)CH(OH)CO_2H$.

Another acid present in unripe fruit is citric acid,



(c) Does citric acid show optical isomerism? Explain your answer.

....

....

.... [1]

Topic Chem 14 Q# 300/ ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Liquids that contain molecules of **T** smell like lemons.

T

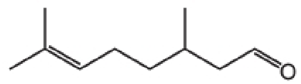


Fig. 3.1

(b) Two organic products are produced when a sample of **T** is heated under reflux with excess acidified concentrated $KMnO_4$.

Draw the structure of the two organic products, from this reaction, in the boxes.

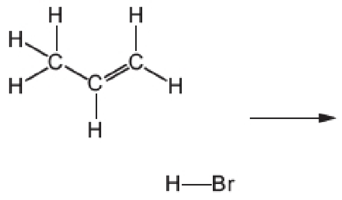
organic product 1	organic product 2

[2]

3 The hydrogen halides HC*l*, HBr and HI are all colourless gases at room temperature.

(e) HBr reacts with propene to form two bromoalkanes, $CH_3CH_2CH_2Br$ and $(CH_3)_2CHBr$.

(i) Complete the diagram to show the mechanism of the reaction of HBr and propene to form the major organic product.
Include charges, dipoles, lone pairs of electrons and curly arrows, as appropriate.
Draw the structures of the intermediate and the major organic product.



[4]

(ii) Explain why the two bromoalkanes are **not** produced in equal amounts by this reaction.

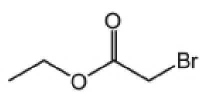
....

....

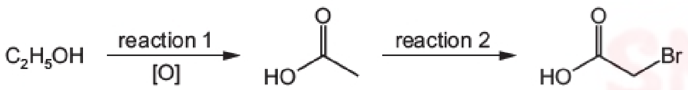
.... [2]

4 Compound **B** is a liquid with a fruity smell.

B



The reaction scheme shows how **B** can be made from ethanol, C_2H_5OH.



(iii) Suggest the type of reaction that occurs in reaction 2.

.... [1]

6 Propene, C_3H_6, reacts with H_2O in the presence of an acid catalyst to form an alcohol with molecular formula C_3H_8O.

(a) Name this type of reaction.

.... [1]

(b) Name the catalyst used and state the conditions needed for this reaction to occur.

catalyst ....

conditions .... [2]

(c) Complete the table to show the numbers of sigma (σ) bonds and pi (π) bonds present in propene, C_3H_6, and C_3H_8O.

	σ	π
C_3H_6		
C_3H_8O		

[2]

(d) The reaction of propene, C_3H_6, with H_2O occurs in a two-step mechanism. In step 1 C_3H_6 reacts with the catalyst, H^+, to form a carbocation.

(i) Draw structures to identify the more stable and less stable carbocations which can form in step 1. Explain your answer.

more stable carbocation	**less** stable carbocation

explanation ....

....

....

....

.... [3]

(ii) Name the major organic product formed from the reaction of propene, C_3H_6, with H_2O.

.... [1]

Topic **Chem 14 Q# 304/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(e) Polymer **Z** is useful because it absorbs large amounts of water. However, there are problems associated with the disposal of products containing polymer **Z**.

Combustion is not an appropriate method to dispose of pure **Z** because the process releases harmful gases. Some of these gases contribute to the enhanced greenhouse effect.

(ii) Identify another gas which could be produced during the combustion of pure **Z**. Describe a consequence, other than the enhanced greenhouse effect, of its release into the atmosphere.

gas ....

consequence ....

[1]

[Total: 10]

Topic **Chem 14 Q# 305/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 **(a)** Naphtha is a mixture which contains only hydrocarbon molecules.

(i) What is meant by the term *hydrocarbon*?

....

.... [1]

(ii) Name the raw material that is used to produce a sample of naphtha.

.... [1]

(b) Compound **V** is found in naphtha. It has a molecular formula $C_{10}H_{22}$.

When **V** is heated at high pressure in the absence of air, an equal number of moles of ethene, propene and **W** are made. **W** is a compound made of straight chain, saturated molecules.

(i) Name the process that describes this reaction.

.... [1]

(ii) Deduce the structure of **W**. Draw its structure below.

[1]

Topic **Chem 14 Q# 306/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(c) Propene is separated from the mixture and heated in air in the presence of a catalyst. Propene is oxidised to **X**, which contains two functional groups.

(i) Effervescence is seen when Na_2CO_3(aq) is added to **X**.

Identify the functional group present in **X** which is responsible for this observation.

.... [1]

(ii) Identify a reagent which could be used to show that **X** contains a C=C. Include relevant observations.

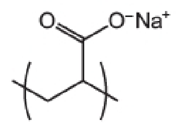
....

.... [2]

(d) **X** reacts with another reagent to form **Y**.

Molecules of **Y** react together to form addition polymer **Z**. The diagram shows the repeat unit of polymer **Z**.

repeat unit of polymer **Z**

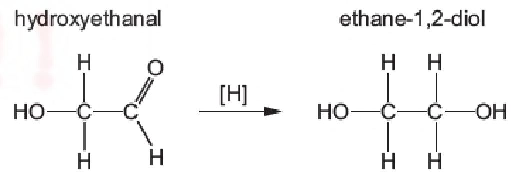


Draw the structural formula of monomer **Y**.

[1]

Topic **Chem 14 Q# 307/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(d) Hydroxyethanal can be reduced to ethane-1,2-diol, $(CH_2OH)_2$, as shown.



(iii) $(CH_2OH)_2$ also forms when an alkene **A** reacts with cold, dilute, acidified manganate(VII) ions.

Name **A**.

.... [1]

[Total: 10]

Topic **Chem 14 Q# 308/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(g) Dichloromethane, CH_2Cl_2, is widely used as an organic solvent.

CH_2Cl_2 can be prepared by reacting CH_3Cl and Cl_2 at room temperature.

The reaction proceeds via several steps, as shown.

$$Cl_2 \xrightarrow{\text{initiation}} 2Cl\bullet$$

$$Cl\bullet + CH_3Cl \xrightarrow{\text{propagation 1}} HCl + \bullet CH_2Cl$$

$$Cl_2 + \bullet CH_2Cl \xrightarrow{\text{propagation 2}} \text{products}$$

$$Cl\bullet + \bullet CH_2Cl \xrightarrow{\text{final step}} CH_2Cl_2$$

(i) Give the name of the mechanism of this reaction.

.... [1]

(ii) State the essential condition required for the initiation step to take place.

.... [1]

(iii) Give the electronic configuration of $Cl\bullet$.

$1s^2$ .... [1]

(iv) Identify the products of the step labelled propagation 2.

.... [1]

(v) Name the type of reaction shown in the final step.

.... [1]

(vi) Suggest the identity of another organic molecule that is a product of the reaction of CH_3Cl and Cl_2 under the same conditions.

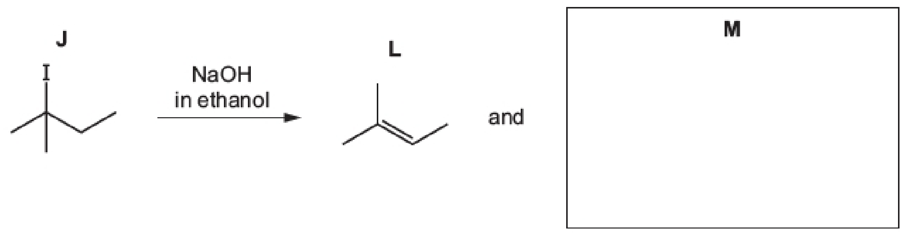
.... [1]

[Total: 23]

Topic **Chem 14 Q# 309/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Iodine is used in many inorganic and organic reactions.

(iii) **J** reacts with NaOH dissolved in ethanol to form a mixture of two alkenes, **L** and **M**. Alkene **L** is shown.



(v) **L** reacts with hot concentrated acidified $KMnO_4(aq)$ to form propanone and one other organic product.

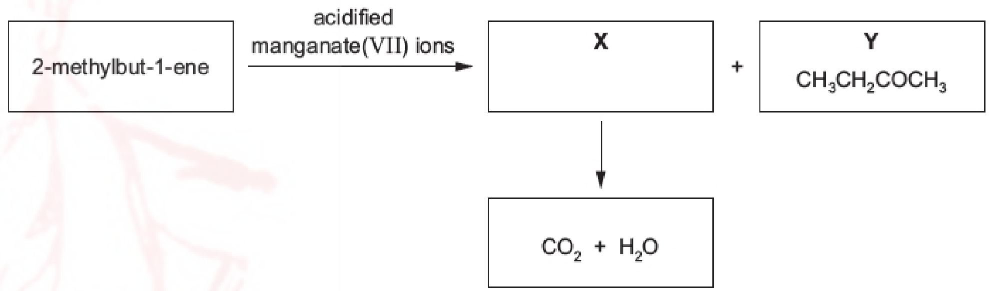
Identify the other organic product.

.... [1]

Topic **Chem 14 Q# 310/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6 2-methylbut-1-ene reacts with acidified manganate(VII) ions, under specific conditions, to produce two organic compounds **X** and **Y**.

X immediately reacts with the acidified manganate(VII) ions to form carbon dioxide and water. **Y** has the structural formula $CH_3CH_2COCH_3$.



(b) (i) State the specific conditions required for the acidified manganate(VII) ions to react with 2-methylbut-1-ene in this way.

.... [1]

(ii) Name the type of reaction occurring to the functional group in 2-methylbut-1-ene in the reaction in **(b)(i)**.

.... [1]

(c) Draw the structural formula of **X**.

.... [1]

(d) Describe a chemical test and the expected observation(s) to confirm the presence of the carbonyl functional group in **Y**.

....

.... [2]

Topic **Chem 14 Q# 311/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) Below is a list of species which can react with organic compounds.

CN^- HCl Cl H_2O CO_3^{2-}

(i) From the list, identify a species which can react with ethane.

.... [1]

(b) Cl(g) can be made from Cl_2(g).

(i) Describe the conditions required for this process.

.... [1]

(ii) Name this process.

.... [1]

Topic **Chem 14 Q# 312/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) Below is a list of species which can react with organic compounds.

CN^- HCl Cl H_2O CO_3^{2-}

(d) But-1-ene reacts with steam in the presence of concentrated phosphoric acid to form two isomers of molecular formula $C_4H_{10}O$.

Each reaction occurs via a different intermediate ion.

(i) Draw the structure of both intermediate ions.

[2]

(ii) Circle the more stable intermediate ion drawn in **(d)(i)**. Explain your answer.

....

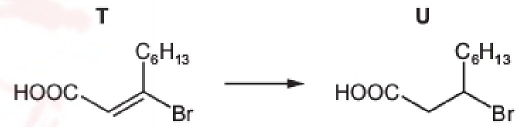
....

.... [2]

[Total: 12]

Topic **Chem 14 Q# 313/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(d) A reaction of another unsaturated carboxylic acid, **T**, is shown.



(ii) Identify the reagent used to convert **T** to **U**.

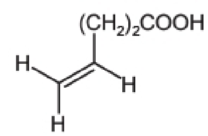
.... [1]

Topic **Chem 14 Q# 314/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

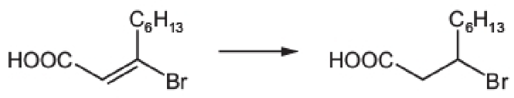
(c) Fats are compounds made from glycerol and unsaturated carboxylic acids.

4-pentenoic acid is an example of an unsaturated carboxylic acid.

4-pentenoic acid



(d) A reaction of another unsaturated carboxylic acid, **T**, is shown.



(i) **T** is one of a pair of geometrical (*cis-trans*) isomers.

Draw the other geometrical isomer of **T** and explain why the molecules exhibit this form of isomerism.

....

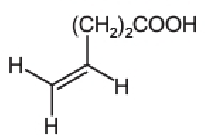
....

.... [3]

Topic **Chem 14 Q# 315/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(c) Fats are compounds made from glycerol and unsaturated carboxylic acids.

4-pentenoic acid is an example of an unsaturated carboxylic acid.

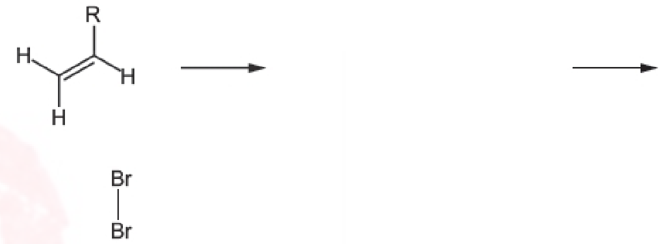


(iii) Unsaturated acids are often brominated before being added to soft drinks.

Complete the mechanism for the addition of Br_2 to 4-pentenoic acid.

- Include the structures of the intermediate and the product of the reaction.
- Include all charges, partial charges, lone pairs and curly arrows.

In the mechanism, R has been used to represent $(CH_2)_2COOH$.



[4]

Topic **Chem 14 Q# 316/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Crude oil is a natural source of hydrocarbons that are used as fuels.

(a) Hydrocarbons with low relative molecular mass, M_r, are used as fuels in industry, in the home and for transport.

There is a high demand for the hydrocarbons with low M_r.

(i) Name the process by which long-chain hydrocarbons are broken down into shorter-chain hydrocarbons.

.... [1]

(ii) Give one reason why hydrocarbons with low M_r are suitable for use as fuels.

.... [1]

(iii) Incomplete combustion of hydrocarbons can release carbon monoxide, CO, into the atmosphere.

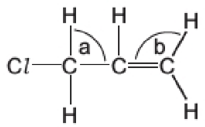
Write an equation for the formation of CO from the incomplete combustion of butene, C_4H_8.

.... [1]

Topic **Chem 14 Q# 317/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

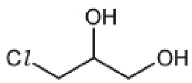
4 The structure of compound **Y** is shown.

Y



(c) When **Y** reacts with cold, dilute, acidified manganate(VII) ions, compound **Z** is produced.

Z



(ii) Name the type of reaction occurring when **Y** is converted into **Z**.

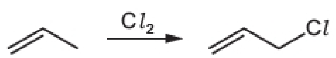
.... [1]

Topic **Chem 14 Q# 318/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 Allyl chloride is an important chemical used in the manufacture of plastics, pharmaceuticals and pesticides.

allyl chloride

(b) Allyl chloride can be produced by many different methods. The most common method is chlorination of propene which proceeds via a free-radical substitution mechanism.



(i) The initiation step in this reaction is the formation of chlorine radicals ($Cl\bullet$) from Cl_2 molecules.

State the conditions required to initiate this reaction.

.... [1]

(ii) The propenyl radical, $CH_2{=}CHCH_2\bullet$, is formed in the first propagation step of the reaction.

Write an equation to show the formation of $CH_2{=}CHCH_2\bullet$ in this propagation step.

.... [1]

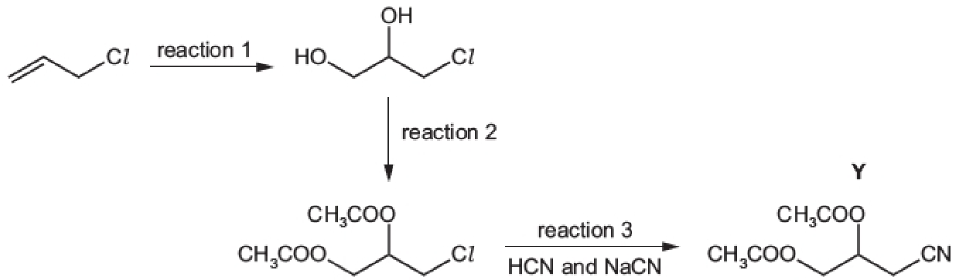
(iii) Explain why the free-radical substitution reaction gives a low yield of allyl chloride.

....

.... [1]

Topic **Chem 14 Q# 319/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

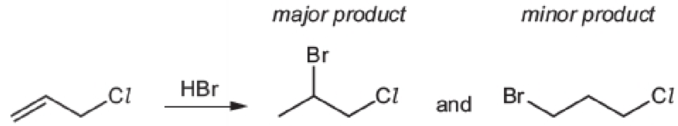
(c) A series of reactions starting from allyl chloride is shown.



(i) Suggest a reagent that can be used in reaction 1.

.... [1]

(d) 2-bromo-1-chloropropane, $CH_3CHBrCH_2Cl$, is the major product of the reaction of allyl chloride with HBr.



Explain why 2-bromo-1-chloropropane is the major product of this reaction.

....

....

....

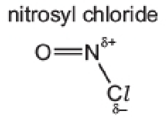
.... [2]

[Total: 13]

Topic **Chem 14 Q# 320/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 Nitrogen, N_2, is the most abundant gas in the Earth's atmosphere and is very unreactive.

(e) Nitrosyl chloride, NOC*l*, is a reactive gas that is sometimes formed when NO reacts with C*l*$_2$.



NOC*l* is a strong electrophile and readily undergoes an addition reaction with alkenes.

Complete the diagram to show the mechanism of the electrophilic addition reaction of NOC*l* with ethene.

Include all necessary charges, lone pairs and curly arrows, and the structure of the organic intermediate.

[2]

[Total: 13]

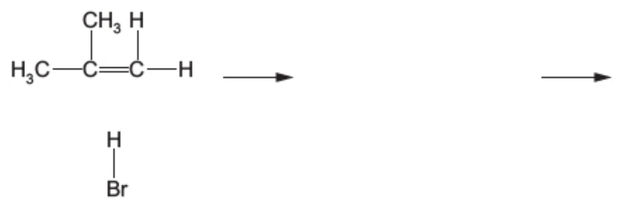
Topic **Chem 14 Q# 321/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(d) The reaction of methylpropene, $(CH_3)_2CCH_2$, with hydrogen bromide, HBr, produces a mixture of two halogenoalkanes.

One of the halogenoalkanes, 2-bromo-2-methylpropane, is formed as the major product while 1-bromo-2-methylpropane is formed in small quantities.

(i) Complete the mechanism to show the reaction of methylpropene with HBr to form the **major** product.

Include the structure of the intermediate and all necessary charges, dipoles, lone pairs and curly arrows. The structure of 2-bromo-2-methylpropane is not required.



[4]

(ii) Explain why 2-bromo-2-methylpropane is the major product of this reaction.

....

....

....

.... [2]

[Total: 15]

Topic **Chem 14 Q# 322/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Crude oil is a complex mixture of hydrocarbon molecules.

The hydrocarbon molecules in crude oil are separated by fractional distillation. Fractional distillation is used because the different hydrocarbon molecules in crude oil have different boiling points.

(a) Explain why the hydrocarbon molecules in crude oil have different boiling points.

....

....

....

....

....

....

.... [2]

(b) Some of the hydrocarbon molecules obtained from crude oil are processed further by cracking.

Suggest why some hydrocarbon molecules are processed further by cracking.

....

....

.... [1]

(c) Cracking one mole of dodecane, $C_{12}H_{26}$, produces two moles of ethene and one mole of another hydrocarbon molecule.

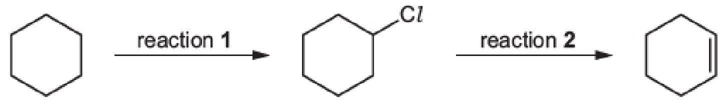
(i) Write the equation for this cracking reaction.

.... [1]

Topic **Chem 14 Q# 323/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 Cyclohexane is a colourless liquid used in industry to produce synthetic fibres.

A reaction scheme involving cyclohexane is shown.



(c) The product of reaction **2** is cyclohexene.

Cyclohexene can be converted into adipic acid (hexanedioic acid), $HO_2C(CH_2)_4CO_2H$.

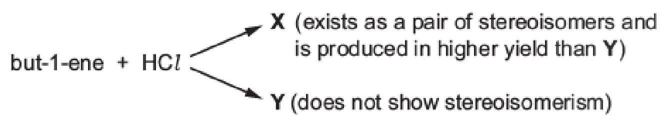
(i) Identify the reagents and conditions for the conversion of cyclohexene into adipic acid.

....

.... [2]

Topic **Chem 14 Q# 324/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(d) The product of reaction 2, but-1-ene, does **not** show stereoisomerism. However, but-1-ene reacts with HC*l* to form a mixture of structural isomers **X** and **Y**.



(ii) Give **two** reasons why but-1-ene does **not** show stereoisomerism.

....

....

.... [2]

(iii) Name **X** and **Y**.

X ....

Y ....
[2]

(iv) Name the type of stereoisomerism shown by **X**.

.... [1]

(v) Use the conventional representation to draw the two stereoisomers of **X**.

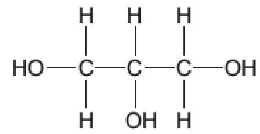
[2]

[Total: 24]

Topic **Chem 14 Q# 325/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 **P**, **Q** and **R** all have the molecular formula C_3H_6O. They are all structural isomers of each other.

(b) **R** contains two different functional groups, one of which is an alkene group.
R reacts with cold, dilute, acidified manganate(VII) ions to form propane-1,2,3-triol.



propane-1,2,3-triol

(i) Give the displayed formula of **R**.

[1]

(ii) State the type of reaction and what you would observe when **R** reacts with bromine water.

....

.... [2]

(iii) Draw the structure of the product formed when **R** reacts with bromine water.

[1]

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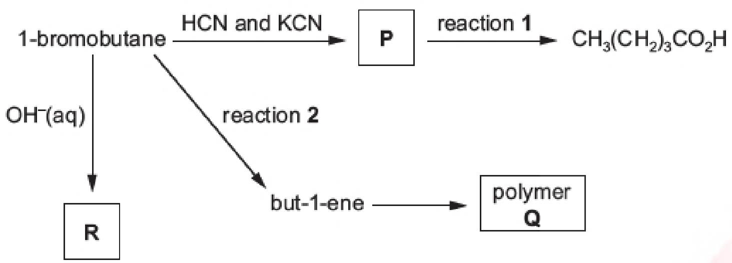
(iv) Identify the gaseous product formed when **R** reacts with hot, concentrated, acidified manganate(VII) ions.

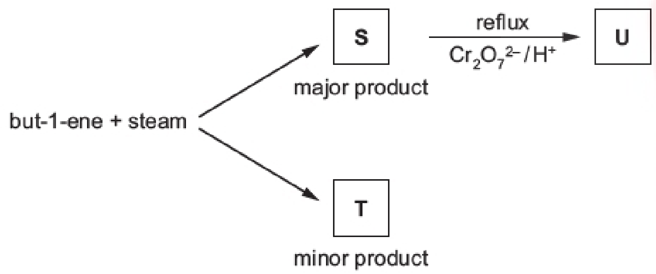
.... [1]

Topic **Chem 14 Q# 326/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** A series of reactions starting from 1-bromobutane is shown.



(c) But-1-ene reacts with steam as shown to form a mixture of two structural isomers, **S** and **T**.



S can be oxidised with acidified potassium dichromate(VI) to form compound **U**.
S and **U** both react with alkaline aqueous iodine.

(i) Identify the *type of reaction* that occurs when but-1-ene reacts with steam.

.... [1]

(iii) Explain why **S** is the major product of the reaction of but-1-ene with steam.

....

....

....

....

.... [2]

Topic **Chem 14 Q# 327/** ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 In each section of this question an organic compound is shown. For each compound give its name and answer the questions about it.

(a) $CH_3CH_2CH(CH_3)CH{=}CHCH_3$

(i) name .... [1]

(ii) This compound shows stereoisomerism.

Define *stereoisomerism*.

....

....

.... [1]

(iii) State and explain how many stereoisomers of this structure there are.

....

....

....

....

....

.... [4]

(b) $(CH_3)_2C{=}C(CH_3)_2$

(i) name .... [1]

(ii) Draw the **skeletal** formula of the organic product of the reaction of this compound with cold, dilute, acidified manganate(VII) ions.

[1]

(iii) Name the organic product of the reaction of this compound with hot, concentrated, acidified manganate(VII) ions.

.... [1]

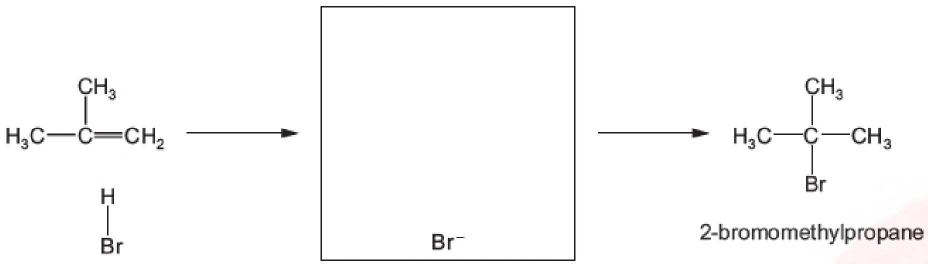
(iv) Draw the structure of part of a molecule of the addition polymer formed from this compound, showing exactly **three** repeat units.

[1]

(c) $(CH_3)_2C{=}CH_2$

(i) name .... [1]

(ii) Complete the mechanism for the reaction of this compound with hydrogen bromide. Include all necessary curly arrows, lone pairs, charges and partial charges.



[4]

(iii) Explain fully why 2-bromomethylpropane is the major product of this reaction while only relatively small amounts of 1-bromomethylpropane are produced.

....

....

....

....

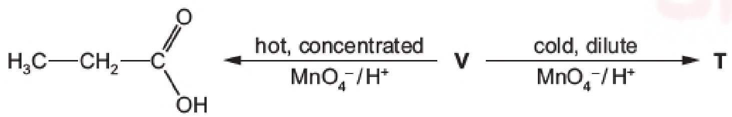
....

.... [3]

[Total: 18]

Topic **Chem 14 Q# 328/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(e) **V** reacts with acidified manganate(VII) ions in two different ways depending on the conditions, as shown in the reaction sequence below.



propanoic acid

V decolourises bromine water.

When the acidified manganate(VII) is hot and concentrated, propanoic acid is the only organic product.

When the acidified manganate(VII) is cold and dilute, the organic product is **T** which has two chiral centres.

(i) Give the structural formulae of **V** and **T**.

V .... **T** ....

[2]

(ii) Identify the types of stereoisomerism shown by **V** and **T**.

V .... **T** ....

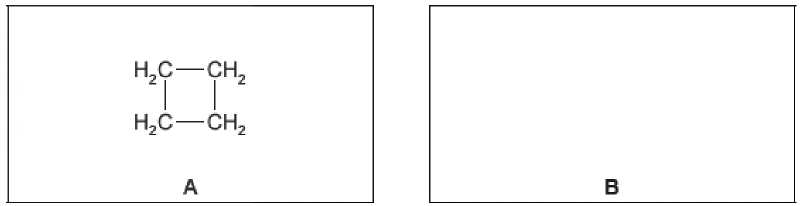
[2]

[Total: 15]

Topic **Chem 14 Q# 329/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(d) The structure of a molecule, **A**, of formula C_4H_8 is shown.

Draw a functional group isomer of molecule **A** in box **B**. Explain how molecules **A** and **B** could be distinguished by a chemical test.



....

....

.... [3]

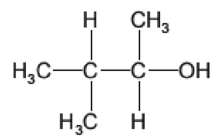
[Total: 7]

Topic **Chem 14 Q# 330/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 The following compounds were all found to be components of a sample of petrol.

$CH_3(CH_2)_2CH_3$ — **G**

$(CH_3)_3CCH_2CH(CH_3)_2$ — **H**



J

(b) Write an equation to represent the complete combustion of compound **H**.

.... [1]

Topic **Chem 14 Q# 331/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Heptane, C_7H_{16}, is an undesirable component of petrol as it burns explosively causing 'knocking' in an engine.

(ii) Give the structures and names of the two structural isomers of C_7H_{16} which contain a chiral centre.

[4]

(b) (i) Write an equation for the complete combustion of heptane.

.... [1]

(ii) Write an equation for the incomplete combustion of heptane leading to the production of a solid pollutant.

.... [1]

(c) The reaction of heptane with chlorine in the presence of UV light produces a wide variety of products.

Formation of the monochloroheptanes can be represented by the following equation.

$$C_7H_{16} + Cl_2 \rightarrow C_7H_{15}Cl + HCl$$

(i) Name the mechanism of the reaction between heptane and chlorine in the presence of UV light.

.... [1]

(ii) Describe this mechanism, using suitable equations and including the names of each stage in the process.

....

....

....

....

....

....

....

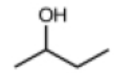
....

.... [5]

[Total: 15]

Topic **Chem 14 Q# 332/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org
NOT WITH 2015/s/TZ 1/Paper 4/Q# 4 (a)

B =



(b) (i) Give the names of the two structural isomers produced by the reaction of **B** with hot, concentrated sulfuric acid

.... [2]

(ii) State which of these two isomers shows stereoisomerism. Explain why this molecule is capable of showing stereoisomerism.

....

....

....

.... [2]

(iii) Draw **displayed** formulae to show the two stereoisomers.

stereoisomer 1	stereoisomer 2

[2]

[Total: 13]

Topic **Chem 14 Q# 333/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Alkanes and alkenes both react with bromine.

(a) Explain how and why bromine can be used to distinguish between an alkene and an alkane.

....

....

.... [2]

(c) The reaction of ethene with bromine forms a single product.

(i) Give the full name of the mechanism of this reaction.

.... [2]

(ii) Complete the diagram below to illustrate this mechanism.
Include all relevant charges, partial charges, curly arrows and lone pairs.

[4]

(d) Chloroethene can be polymerised to form a polymer commonly known as PVC.
Draw a diagram of the structure of PVC including **three** repeat units.

[2]

Topic **Chem 14 Q# 334/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Alkanes and alkenes both react with bromine.

(b) The reaction of ethane with bromine forms a mixture of products.

(i) State the essential conditions for this reaction to occur.

.... [1]

(ii) Give the full name of the mechanism of this reaction.

.... [2]

(iii) Give the equation for a **termination** step that could occur, producing a **hydrocarbon**.

.... [1]

(iv) Give the equation for one **propagation** step involved in the formation of dibromoethane from bromoethane during this reaction.

.... [1]

Topic **Chem 14 Q# 335/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Propane, C_3H_8, and butane, C_4H_{10}, are components of Liquefied Petroleum Gas (LPG) which is widely used as a fuel for domestic cooking and heating.

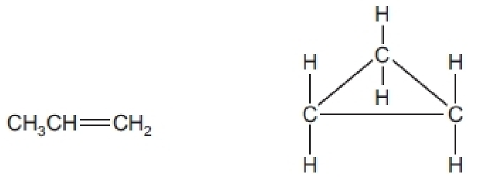
(a) **(i)** To which class of compounds do these two hydrocarbons belong?

....

(ii) Write a balanced equation for the complete combustion of butane.

.... [2]

2 The molecular formula C_3H_6 represents the compounds propene and cyclopropane.



propene cyclopropane

(a) What is the H–C–H bond angle at the terminal $=CH_2$ group in propene?

.... [1]

(b) Under suitable conditions, propene and cyclopropane each react with chlorine.

(i) With propene, 1,2-dichloropropane, $CH_3CHClCH_2Cl$ is formed.

State fully what type of reaction this is.

.... [1]

(ii) When cyclopropane reacts with chlorine, three different compounds with the molecular formula $C_3H_4Cl_2$ can be formed.

Draw displayed structures of **each** of these three compounds.

[3]

[Total: 5]

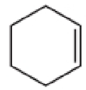
(b) Ethene is bubbled into two separate test-tubes, one containing aqueous hydrogen bromide and the other containing cold, dilute acidified potassium manganate(VII).

In **each** case, describe any colour changes you would see and give the structural formula of the organic product.

	aqueous hydrogen bromide	cold, dilute acidified potassium manganate(VII)
colour at start		
colour after reaction		
structural formula of organic product		

[4]

(c) Cyclohexene has the following structural formula.



(i) What is the molecular formula of cyclohexene?

....

(ii) Draw the structural formula of the compound formed when cyclohexene is reacted with bromine.

(iii) State as fully as you can what *type of reaction* this is.

....

(iv) Draw the structural formula of the compound formed when cyclohexene is reacted with hot concentrated acidified potassium manganate(VII).

[5]

[Total: 12]

Topic **Chem 14 Q# 338/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Crude oil contains a mixture of hydrocarbons together with other organic compounds which may contain nitrogen, oxygen or sulfur in their molecules.

At an oil refinery, after the fractional distillation of crude oil, a number of other processes may be used including 'cracking', 'isomerisation', and 'reforming'.

(a) (i) What is meant by the term '*cracking*' and why is it carried out?

....

....

....

....

(ii) Outline briefly how the cracking of hydrocarbons would be carried out.

....

....

(iii) Construct a balanced equation for the formation of heptane, C_7H_{16}, by cracking tetradecane, $C_{14}H_{30}$.

.... [4]

Topic **Chem 14 Q# 339/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Some intercontinental jet airliners use kerosene as fuel. The formula of kerosene may be taken as $C_{14}H_{30}$.

(a) To which homologous series of compounds does kerosene belong?

.... [1]

(b) When kerosene burns in an excess of air, carbon dioxide and water form. Balance the following equation for the complete combustion of kerosene.

$$......C_{14}H_{30}(l) + ...O_2(g) \rightarrow ......CO_2(g) + ...H_2O(g)$$ [1]

(c) In this section, give your answers to <u>one</u> decimal place.

The flight path from Beijing to Paris is approximately 8195 km.
A typical intercontinental jet airliner burns 10.8 kg of kerosene for each kilometre covered.

(i) Calculate the mass, in tonnes, of $C_{14}H_{30}$ burnt on a flight from Beijing to Paris.
[1 tonne = 1 000 kg]

(ii) Use your equation in **(b)** to calculate the mass, in tonnes, of CO_2 produced during this flight.

[4]

Topic **Chem 14 Q# 340/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Crude oil is a naturally occurring flammable liquid which consists of a complex mixture of hydrocarbons. In order to separate the hydrocarbons the crude oil is subjected to fractional distillation.

(a) Explain what is meant by the following terms.

(i) *hydrocarbon* ....

....

(ii) *fractional distillation* ....

.... [2]

(b) Undecane, $C_{11}H_{24}$, is a long chain hydrocarbon which is present in crude oil.
Such long chain hydrocarbons are 'cracked' to produce alkanes and alkenes which have smaller molecules.

(i) Give the conditions for **two different** processes by which long chain molecules may be cracked.

process 1 ....

....

process 2 ....

....

(ii) Undecane, $C_{11}H_{24}$, can be cracked to form pentane, C_5H_{12}, and an alkene.
Construct a balanced equation for this reaction.

.... [3]

Pentane, C_5H_{12}, exhibits structural isomerism.

(c) **(i)** Draw the three structural isomers of pentane.

isomer **B**	isomer **C**	isomer **D**

(ii) The three isomers of pentane have different boiling points.

Which of your isomers has the highest boiling point?

isomer ....

Suggest an explanation for your answer.

....

....

.... [6]

Topic **Chem 14 Q# 341/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

The unsaturated hydrocarbon, **E**, is obtained by cracking hexane and is important in the chemical industry.

The standard enthalpy change of combustion of **E** is –2059 kJ mol^{-1}.

When 0.47 g of **E** was completely burnt in air, the heat produced raised the temperature of 200 g of water by 27.5 °C. Assume no heat losses occurred during this experiment.

(e) **(i)** Use relevant data from the *Data Booklet* to calculate the amount of heat released in this experiment.

(ii) Use the data above and your answer to **(i)** to calculate the relative molecular mass, M_r, of **E**.

[4]

(f) Deduce the molecular formula of **E**.

[1]

[Total: 18]

Topic **Chem 14 Q# 342/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 In 1814, Sir Humphrey Davy and Michael Faraday collected samples of a flammable gas, **A**, from the ground near Florence in Italy.
They analysed **A** which they found to be a hydrocarbon. Further experiments were then carried out to determine the molecular formula of **A**.

Davy and Faraday deduced the formula of **A** by exploding it with an excess of oxygen and analysing the products of combustion.

(b) Complete and balance the following equation for the complete combustion of a hydrocarbon with the formula C_xH_y.

$$C_xH_y + \left(x + \frac{y}{4}\right)O_2 \rightarrow \text{.................} + \text{.................}$$

[2]

(c) When 10 cm^3 of **A** was mixed at room temperature with 50 cm^3 of oxygen (an excess) and exploded, 40 cm^3 of gas remained after cooling the apparatus to room temperature and pressure.
When this 40 cm^3 of gas was shaken with an excess of aqueous potassium hydroxide, KOH, 30 cm^3 of gas still remained.

(i) What is the identity of the 30 cm^3 of gas that remained at the end of the experiment?

....

(ii) The combustion of **A** produced a gas that reacted with the KOH(aq).

What is the identity of this gas?

....

(iii) What volume of the gas you have identified in **(ii)** was produced by the combustion of **A**?

.... cm^3

(iv) What volume of oxygen was used up in the combustion of **A**?

.... cm^3 [4]

(d) Use your equation in **(b)** and your results from **(c)(iii)** and **(c)(iv)** to calculate the molecular formula of **A**.
Show all of your working.

[3]

[Total: 11]

Topic **Chem 14 Q# 343/** ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Alkanes such as methane, CH_4, undergo few chemical reactions. Methane will, however, react with chlorine but not with iodine.

(i) Answer

(b) (i) By using equations, describe the mechanism of the reaction between chlorine and methane to form chloromethane, CH_3Cl.

Identify, by name, the separate steps of the overall reaction.

....

....

....

....

....

....

(ii) What is the intermediate organic species in this reaction?

.... [7]

Topic Chem 15 Q# 344/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 The hydrogen halides HC*l*, HBr and HI are all colourless gases at room temperature.

(e) HBr reacts with propene to form two bromoalkanes, $CH_3CH_2CH_2Br$ and $(CH_3)_2CHBr$.

(iii) The reaction of $CH_3CH_2CH_2Br$ and NaOH is different depending on whether water or ethanol is used as a solvent.

Complete Table 3.2 to identify the organic and inorganic products of the reaction of $CH_3CH_2CH_2Br$ and NaOH in each solvent.

Table 3.2

solvent	organic product(s)	inorganic product(s)
water		
ethanol		

[2]

[Total: 20]

Topic **Chem 15 Q# 345/** ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

(e) 2-bromopropane reacts to form propene, hydrogen bromide and water under certain conditions.

(i) Name this type of reaction.

.... [1]

(ii) Describe the reagents and conditions needed to favour this reaction.

reagents ....

conditions ....
[2]

[Total: 12]

Topic **Chem 15 Q# 346/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Iodine is used in many inorganic and organic reactions.

(b) Iodoalkanes contain carbon-iodine bonds.

The simplest iodoalkane is CH_3I.

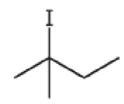
(i) CH_3I can be made from methanol, CH_3OH.

Identify a reagent that can convert CH_3OH to CH_3I.

.... [1]

(c) **J** reacts with NaOH, forming different products dependent on the conditions used.

J

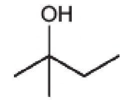


(i) Name **J**.

.... [1]

(ii) **J** reacts with NaOH(aq) to form **K**.

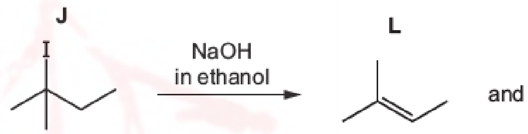
K



Fully name the mechanism of the reaction of **J** with NaOH(aq) to form **K**.

.... [1]

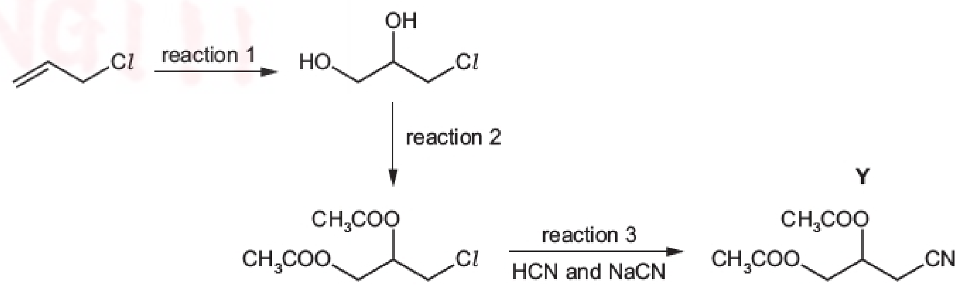
(iii) **J** reacts with NaOH dissolved in ethanol to form a mixture of two alkenes, **L** and **M**. Alkene **L** is shown.



M

In the box provided, draw the structure of **M**. [1]

Topic **Chem 15 Q# 347/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org



(iii) State the name of the mechanism that occurs in reaction 3.

.... [1]

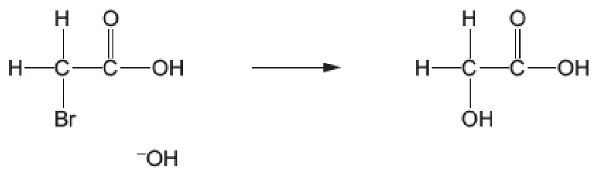
Topic **Chem 15 Q# 348/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

sequence B $CH_3CO_2H \xrightarrow[\text{reaction 3}]{Br_2} CH_2BrCO_2H \xrightarrow[\text{reaction 4}]{} CH_2(OH)CO_2H$

(v) Reaction **4** occurs via an S_N2 mechanism.

Complete the diagram for the mechanism for reaction **4**.

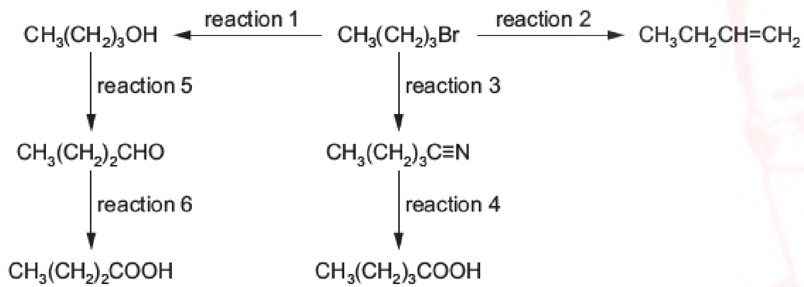
Include all relevant charges, partial charges, curly arrows and lone pairs.



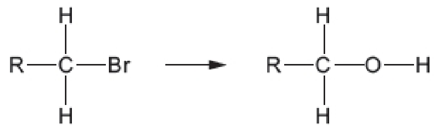
[2]

Topic **Chem 15 Q# 349/** ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some reactions based on 1-bromobutane, $CH_3(CH_2)_3Br$, are shown.



(b) Complete the diagram to show the S_N2 mechanism of reaction 1. R represents the $CH_3(CH_2)_2$ group.
Include all necessary charges, dipoles, lone pairs and curly arrows.



[2]

(c)

(ii) 2-bromo-2-methylpropane is treated with the same reagents as in reaction 1. Methylpropan-2-ol is formed.

Identify the mechanism for this reaction.
Explain why this reaction proceeds via a different mechanism from that of reaction 1.

mechanism ....

explanation ....

....

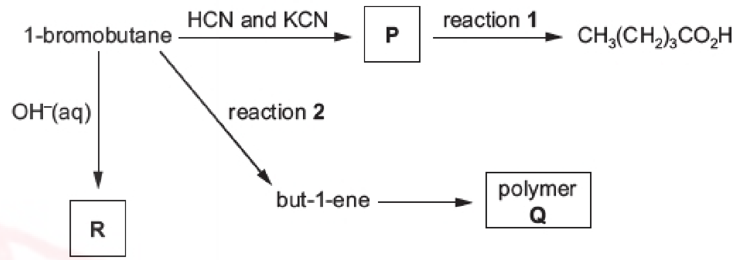
....

....

.... [3]

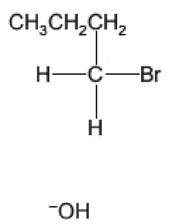
Topic **Chem 15 Q# 350/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** A series of reactions starting from 1-bromobutane is shown.



(b) Complete the reaction scheme to show the mechanism of the reaction of 1-bromobutane with OH^-(aq) to produce **R**.

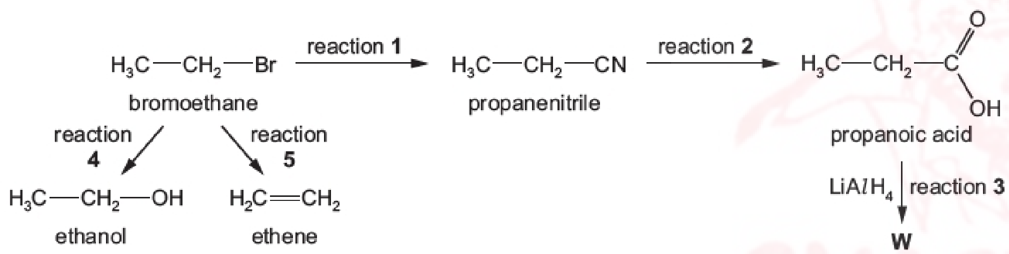
Include all necessary charges, dipoles, lone pairs and curly arrows and the structure of **R**.



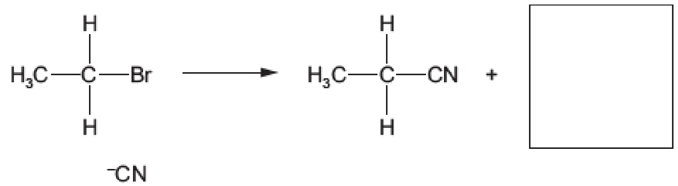
[3]

Topic **Chem 15 Q# 351/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 A reaction sequence is shown.



(a) Complete the diagram to show the mechanism of reaction **1**. Include all necessary charges, partial charges, lone pairs and curly arrows.



[2]

(c) (i) Reactions **4** and **5** use the same reagent.

Give the reagent and conditions needed for reaction **4**.

reagent ....

conditions .... [2]

(ii) Give the conditions needed for reaction **5**.

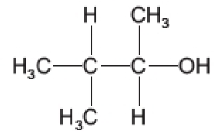
.... [1]

Topic **Chem 15 Q# 352/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 The following compounds were all found to be components of a sample of petrol.

$CH_3(CH_2)_2CH_3$ — **G**

$(CH_3)_3CCH_2CH(CH_3)_2$ — **H**



J

(e) Compound **J** can be produced from 2-chloro-3-methylbutane, $C_5H_{11}Cl$.

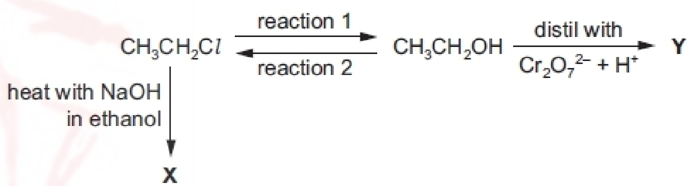
Give the reagent(s) and conditions for this reaction.

.... [1]

[Total: 11]

Topic **Chem 15 Q# 353/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Some reactions involving ethanol are shown.



(ii) State the reagent and conditions required for reaction 1.

.... [2]

(b) (i) Identify the organic product **X**.

.... [1]

(ii) Nitric acid is added to the products of reaction of CH_3CH_2Cl with NaOH in ethanol. Silver nitrate solution is then added to this mixture.

State what you would observe.

.... [1]

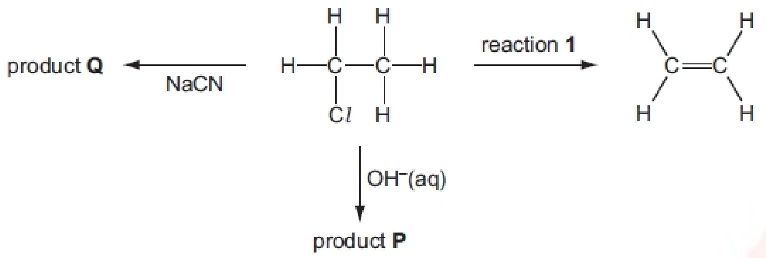
(iii) Write an ionic equation, including state symbols, for the reaction responsible for the observation in **(ii)**.

.... [1]

Topic **Chem 15 Q# 354/** ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Alkanes and alkenes both react with bromine.

(e) Chloroethane undergoes a series of reactions as shown in the diagram below.



(i) Give the reagent and conditions necessary for reaction 1.

....

.... [2]

(ii) Give the **skeletal** formula of product **P**.

[1]

(iii) Give the **displayed** formula and the name of product **Q**.

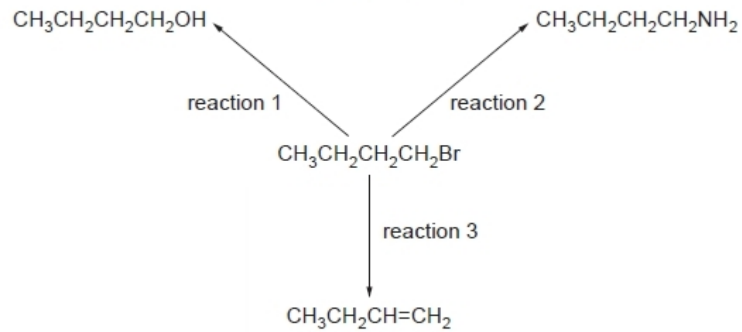
.... [2]

[Total: 20]

Topic **Chem 15 Q# 355/** ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Halogenoalkanes have many chemical uses, particularly as intermediates in organic reactions.

Three reactions of 1-bromobutane, $CH_3CH_2CH_2CH_2Br$, are shown below.



(a) For **each** reaction, state the reagent and solvent used.

reaction 1 reagent ....

solvent ....

reaction 2 reagent ....

solvent ....

reaction 3 reagent ....

solvent .... [6]

(b) When 1-iodobutane, $CH_3CH_2CH_2CH_2I$, is reacted under the same conditions as those used in reaction 1, butan-1-ol is formed.

What difference, if any, would there be in the rate of this reaction compared to the reaction of 1-bromobutane?

Use appropriate data from the *Data Booklet* to explain your answer.

....

....

....

.... [3]

Topic Chem 16 Q# 356/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chloride of Period 3 elements are shown in the list.

$NaCl$ $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(c) PCl_5 reacts with alcohols to form chloroalkanes.

(i) Identify this type of reaction.

.... [1]

(ii) Draw the structure of the organic product formed in the reaction of an excess of PCl_5 with butane-1,3-diol.

[1]

Topic **Chem 16 Q# 357/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) Fig. 3.2 shows two reactions of **T**.

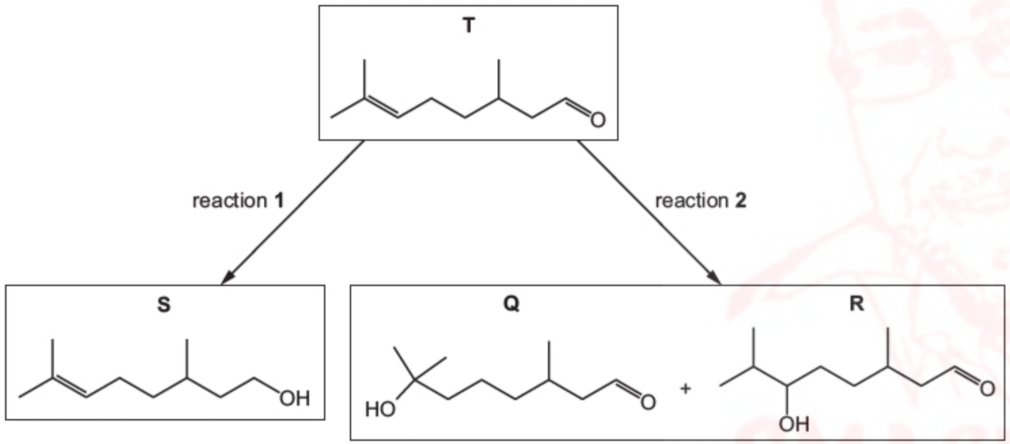


Fig. 3.2

(i) Identify a suitable reagent for reaction **1**.

.... [1]

(ii) Identify the reagent and conditions needed for reaction **2**.

....

.... [2]

(iii) Suggest which product formed in reaction **2** has a higher yield. Explain your answer.

....

....

.... [3]

(d) Separate samples of **Q** and **R** are added to separate test-tubes containing acidified $K_2Cr_2O_7(aq)$ and heated.

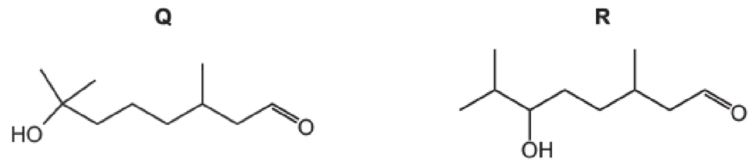


Fig. 3.3

(i) Predict the observations for each test-tube. Explain your answer in terms of the functional groups present in **Q** and **R**.

....

....

....

.... [3]

(ii) When $PCl_5(s)$ is added to separate samples of **Q** and **R** at room temperature, both react vigorously.

Complete the equation shown in Fig. 3.4 to describe the reaction that occurs when **R** reacts with $PCl_5(s)$.

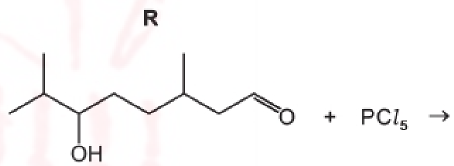


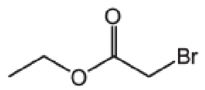
Fig. 3.4

[2]

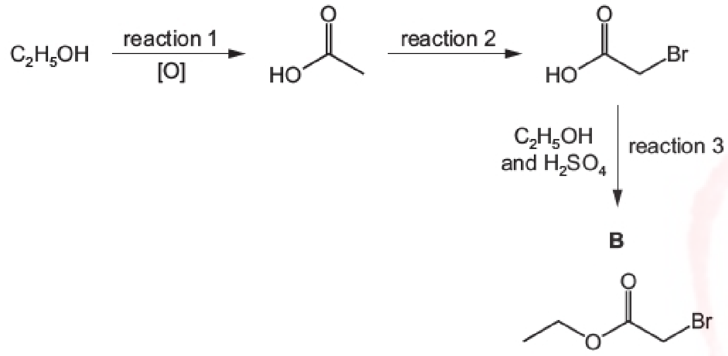
Topic **Chem 16 Q# 358/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Compound **B** is a liquid with a fruity smell.

B



The reaction scheme shows how **B** can be made from ethanol, C_2H_5OH.



(a) (i) Reaction 1 is an oxidation reaction.

Give the reagent(s) and conditions required for reaction 1.

reagent(s) ....

conditions ....

.... [2]

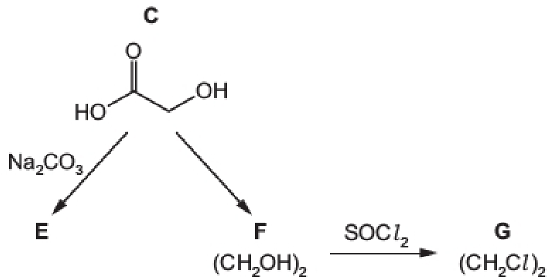
(ii) Construct an equation to represent reaction 1.

Use [O] to represent an oxygen atom from the oxidising agent in this reaction.

.... [1]

Topic **Chem 16 Q# 359/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) Some other reactions of **C** are shown.



(iii) Construct an equation for the reaction of $(CH_2OH)_2$ with $SOCl_2$ to form **G**, $(CH_2Cl)_2$.

.... [1]

(d) Explain why **C** is very soluble in water.

....

....

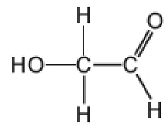
.... [1]

[Total: 12]

Topic **Chem 16 Q# 360/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 Hydroxyethanal, $HOCH_2CHO$, has been observed in dust clouds near the centre of our galaxy.

hydroxyethanal



(c) Hydroxyethanal is converted to ethanedioic acid, $(CO_2H)_2$, when it reacts with excess acidified dichromate(VI) ions, $Cr_2O_7^{2-}$.

(i) State the role of acidified $Cr_2O_7^{2-}$ in this reaction.

.... [1]

(ii) State and explain any other necessary conditions for this reaction to be successful.

....

....

.... [2]

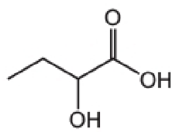
Topic **Chem 16 Q# 361/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

(a) (i) At 200 °C, aluminium chloride exists as Al_2Cl_6(g).

(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.

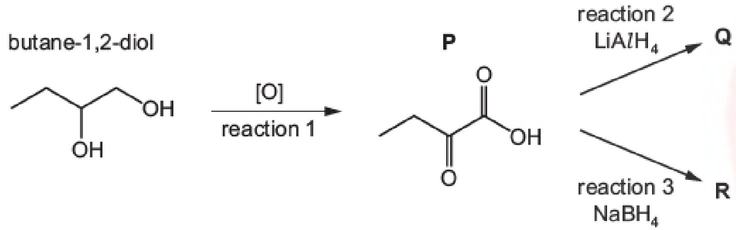
2-hydroxybutanoic acid



Both students oxidise butane-1,2-diol to form **P** in reaction 1.

One student then reduces **P** using $LiAlH_4$. **Q** is formed.

The other student reduces **P** using $NaBH_4$. **R** is formed.



(i) State the reagents and conditions required for reaction 1.

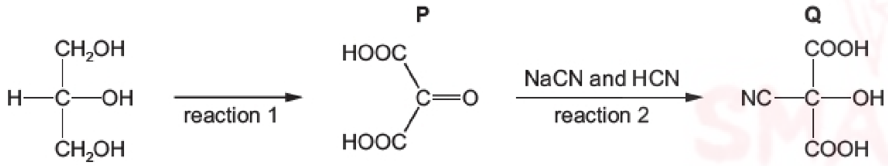
....

.... [2]

Topic **Chem 16 Q# 362/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Glycerol, $CH_2(OH)CH(OH)CH_2OH$, is widely used in the food industry and in pharmaceuticals.

(a) A series of reactions starting from glycerol is shown.



(i) Suggest the reagent(s) and conditions for reaction 1.

....

.... [2]

Topic **Chem 16 Q# 363/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

(e) Lucas's reagent is a mixture of HC*l* and $ZnCl_2$. Primary, secondary and tertiary alcohols can be distinguished by their reaction with Lucas's reagent.

Alcohols react with the HC*l* in Lucas's reagent to form halogenoalkanes.

$ZnCl_2$ acts as a homogeneous catalyst for these reactions.

(ii) Pentan-3-ol, $C_2H_5CH(OH)C_2H_5$, reacts slowly with HC*l* to form a secondary halogenoalkane.

Complete the equation for this reaction using structural formulae.

$C_2H_5CH(OH)C_2H_5$ + ... [1]

(iii) The fastest reaction shown by Lucas's reagent is with a tertiary alcohol.

Draw the structure of the tertiary alcohol that is an isomer of pentan-3-ol.

[1]

(iv) Tertiary alcohols tend to react with Lucas's reagent using the same mechanism as in their reaction with HC*l*.

Suggest the type of reaction shown by tertiary alcohols with Lucas's reagent.

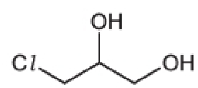
.... [1]

[Total: 17]

Topic **Chem 16 Q# 364/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) When **Y** reacts with cold, dilute, acidified manganate(VII) ions, compound **Z** is produced.

Z



(iii) Alcohols can be classified as primary, secondary or tertiary.

Identify with a tick (✓) the alcohol group(s) present in **Z**.

	alcohol group present in **Z**
primary	
secondary	
tertiary	

[1]

Topic **Chem 16 Q# 365/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(iv) Allyl chloride can also be formed by the following substitution reaction.

Suggest the identity of reagent **X**.

.... [1]

Topic **Chem 16 Q# 366/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 **X** is $CH_3CH(OH)CH_2CH_3$.

(a) The reaction between **X** and alkaline aqueous iodine produces a yellow precipitate.

(i) Give the name of the compound formed as a yellow precipitate in this reaction.

.... [1]

(ii) Give the name of **X**.

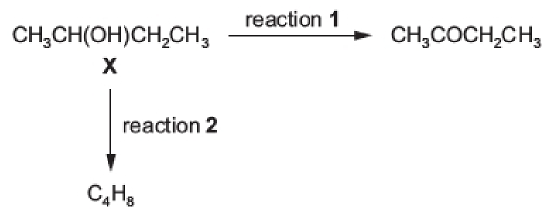
.... [1]

(b) There are three structural isomers of **X** that are alcohols.

Draw the structures of these three isomers of **X**.

[2]

(c) Two reactions of **X** are shown.



(i) Identify the type of reaction involved in reaction **1**.

.... [1]

(ii) Identify the reagents for reaction **1**.

.... [1]

(iii) Reaction **2** can be carried out by passing the vapour of **X** over hot aluminium oxide.

The product of reaction **2**, C_4H_8, is actually a mixture of three isomers.

Give the full names of the three isomers formed by reaction **2**.

1 ....

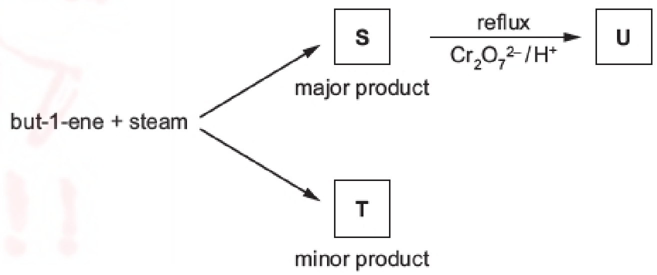
2 ....

3 ....

[3]

Topic **Chem 16 Q# 367/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(c) But-1-ene reacts with steam as shown to form a mixture of two structural isomers, **S** and **T**.



S can be oxidised with acidified potassium dichromate(VI) to form compound **U**.
S and **U** both react with alkaline aqueous iodine.

(ii) State what can be deduced about the structure of **S** from its reaction with alkaline aqueous iodine.

.... [1]

(iv) Draw the **skeletal** formulae of **S**, **T** and **U**.

S

T

U

[3]

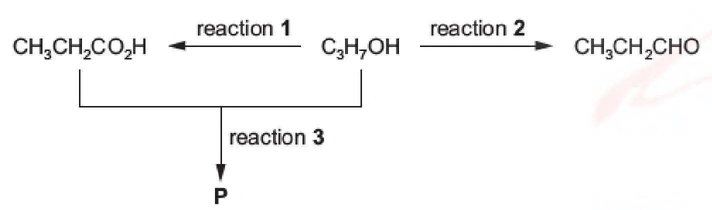
(v) Write an equation to represent the oxidation of **S** to **U** by acidified potassium dichromate(VI).

You should use [O] to represent the oxidising agent.

.... [1]

Topic **Chem 16 Q# 368/** ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 A sequence of reactions is shown starting with an alcohol, C_3H_7OH.



(a) Draw the skeletal formula of the alcohol C_3H_7OH.

[1]

(b) State the reagents and conditions needed for reaction **1**.

....

.... [2]

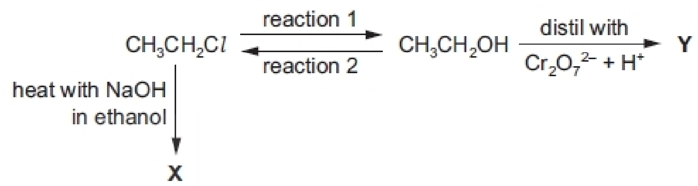
(c) State the reagents and conditions needed for reaction **2**.

....

.... [2]

Topic **Chem 16 Q# 369/** ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Some reactions involving ethanol are shown.



(a) **(i)** Give an equation for reaction 2 including the reagent needed for the conversion.

.... [2]

(c) **(i)** Identify the organic product **Y** which is distilled out of the reaction mixture.

.... [1]

(ii) Explain, in terms of the properties of and intermolecular forces in CH_3CH_2OH and **Y**, why the chosen conditions for the reaction ensure that **Y** is the product.

....

....

.... [3]

[Total: 11]

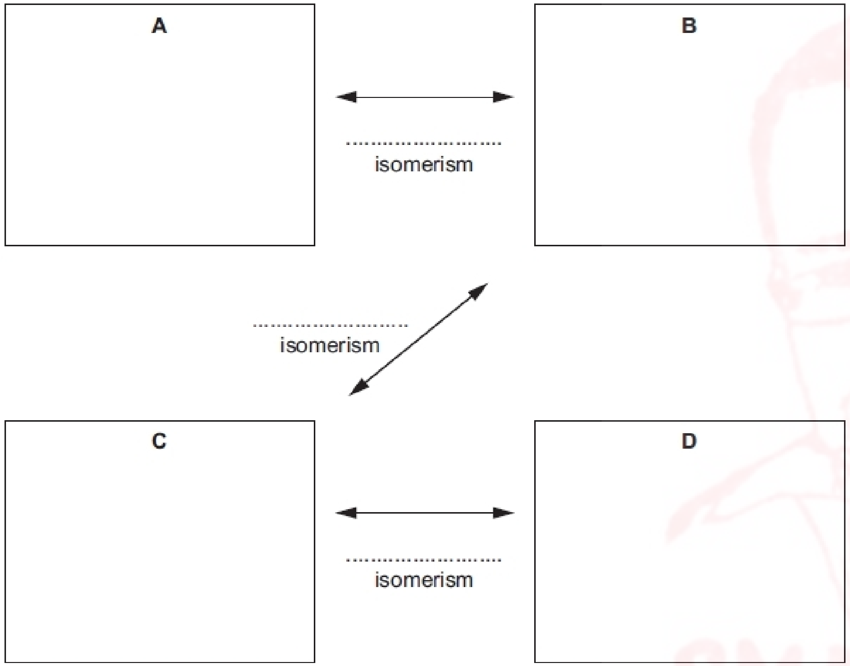
Topic **Chem 16 Q# 370/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 There are four alcohols, **A**, **B**, **C** and **D**, which are structural isomers with the molecular formula $C_4H_{10}O$.

Alcohol **A** does not react with acidified potassium dichromate(VI) solution but **B**, **C** and **D** do.

All four alcohols react with hot, concentrated sulfuric acid to form products with the molecular formula C_4H_8. **A**, **C** and **D** each give a single product in this reaction. **B** gives a mixture of two structural isomers, one of which shows stereoisomerism.

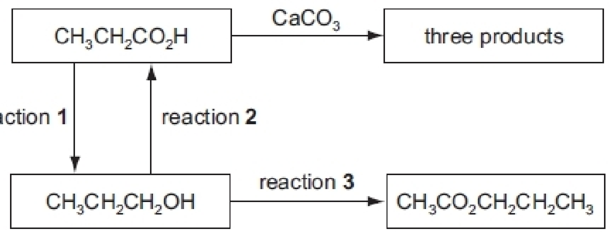
(a) Give the **skeletal** formula for each of the four alcohols and complete the diagram with the names of the types of structural isomerism shown by each linked pair of compounds.



[7]

Topic **Chem 16 Q# 371/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 A series of reactions based on propanoic acid is shown.



(b) **(i)** What type of reaction is reaction **2**?

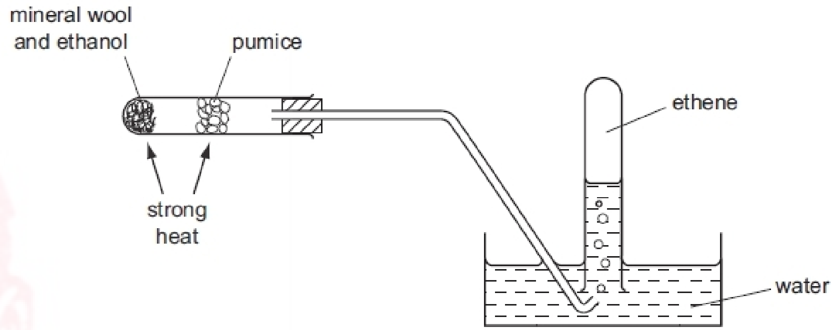
.... [1]

(ii) Suggest a suitable reagent and conditions for reaction **2**.

.... [2]

Topic **Chem 16 Q# 372/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 One method of preparing ethene in a school or college laboratory is from ethanol by using the apparatus shown below.



(a) **(i)** Write a balanced equation for this reaction.

....

(ii) What *type of reaction* is this?

....

(iii) Give the chemical name of a reagent other than pumice that could be used to carry out this reaction. It is not necessary to use the same apparatus.

....

[3]

Topic Chem 17 Q# 373/ ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) **W**, **X** and **Y** have the same molecular formula, $C_5H_{10}O$.

W, **X** and **Y** are added separately to different reagents. Observations for these reactions are described in Table 4.1.

Table 4.1

	+ 2,4-dinitrophenylhydrazine	+ alkaline I_2(aq)	+ Fehling's reagent and warm
W	orange precipitate seen	no change	orange-red precipitate seen
X	orange precipitate seen	yellow precipitate seen	no change
Y	orange precipitate seen		

(i) **W**, **X** and **Y** each contain a common functional group.

Name the functional group that is present in all three compounds.

.... [1]

(ii) State the formula of the yellow precipitate produced when **X** is added to alkaline I_2(aq).

.... [1]

(iii) **W** could be one of four structural isomers.

- Draw the skeletal formulae for two possible structural isomers of **W**.
- Describe the type of structural isomerism shown.

isomer 1

isomer 2

type of structural isomerism

.... [3]

Topic Chem 17 Q# 374/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 Compounds **J** and **K** are found in plant oils.

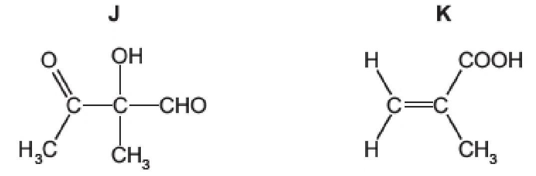


Fig. 4.1

(a) (i) Complete Table 4.1 to state what you would **observe** when **J** reacts with the reagents listed.

Table 4.1

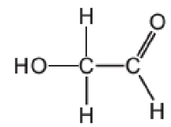
reagent	observation with **J**
2,4-dinitrophenylhydrazine (2,4-DNPH)	
Tollens' reagent	
sodium metal	

[3]

Topic Chem 17 Q# 375/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 Hydroxyethanal, $HOCH_2CHO$, has been observed in dust clouds near the centre of our galaxy.

hydroxyethanal



(b) Hydroxyethanal reacts separately with 2,4-dinitrophenylhydrazine (2,4-DNPH) and with Tollens' reagent.

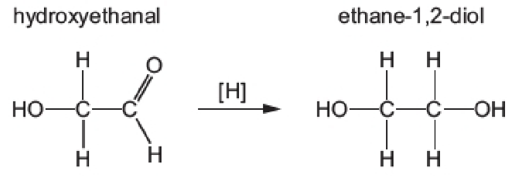
State what you would observe in each reaction.

reaction with 2,4-DNPH ....

reaction with Tollens' reagent ....

[2]

(d) Hydroxyethanal can be reduced to ethane-1,2-diol, $(CH_2OH)_2$, as shown.



(i) Write an equation for the reduction of hydroxyethanal to $(CH_2OH)_2$.

Use [H] to represent an atom of hydrogen from the reducing agent.

.... [1]

(ii) Identify a reagent for this reduction reaction.

.... [1]

Topic **Chem 17 Q# 376/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Iodine is used in many inorganic and organic reactions.

Iodoalkanes contain carbon-iodine bonds.

The simplest iodoalkane is CH_3I.

(i) CH_3I can be made from methanol, CH_3OH.

(vi) Propanone reacts with excess alkaline aqueous iodine.

Complete and balance the equation for this reaction.

CH_3COCH_3 + ...I_2 + ...OH^- ⟶ .....CH_3COO^- + ...H_2O + ...I^- + ... [2]

(vii) State **one** observation that can be made in the reaction in **(c)(vi)**.

.... [1]

[Total: 16]

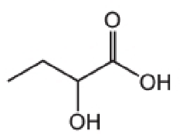
Topic **Chem 17 Q# 377/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

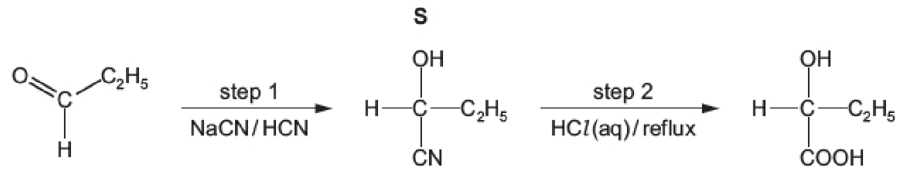
(a) **(i)** At 200 °C, aluminium chloride exists as Al_2Cl_6(g).

(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.

2-hydroxybutanoic acid



A third student prepares 2-hydroxybutanoic acid using propanal as the starting material. In step 1 the student reacts propanal with a mixture of NaCN and HCN.



(iii) Draw the mechanism for the reaction of propanal with the mixture of NaCN and HCN to form **S**.

- Identify the ion that reacts with propanal.
- Draw the structure of the intermediate of the reaction.
- Include all charges, partial charges, lone pairs and curly arrows.

[4]

Topic **Chem 17 Q# 378/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 **(a)** Below is a list of species which can react with organic compounds.

CN^- HCl Cl H_2O CO_3^{2-}

(c) **(i)** Name an organic functional group which reacts with a nucleophile in an addition reaction.

.... [1]

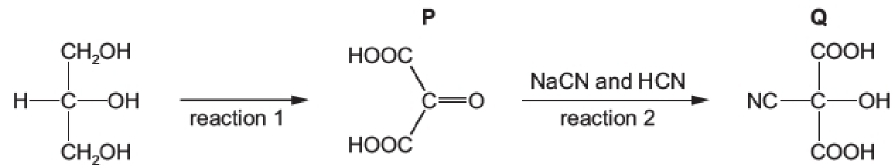
(ii) Name an organic functional group which tends to react with a nucleophile in an S_N1 substitution mechanism.

.... [1]

Topic **Chem 17 Q# 379/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Glycerol, $CH_2(OH)CH(OH)CH_2OH$, is widely used in the food industry and in pharmaceuticals.

(a) A series of reactions starting from glycerol is shown.



(ii) Name the reaction mechanism for reaction 2.

.... [1]

(iii) Give the observation you would make when 2,4-dinitrophenylhydrazine is added to **P**.

.... [1]

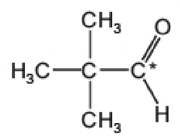
Topic **Chem 17 Q# 380/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 $(CH_3)_3CCHO$ is used in the synthesis of some antibiotics.

(a) (i) Give the name of $(CH_3)_3CCHO$.

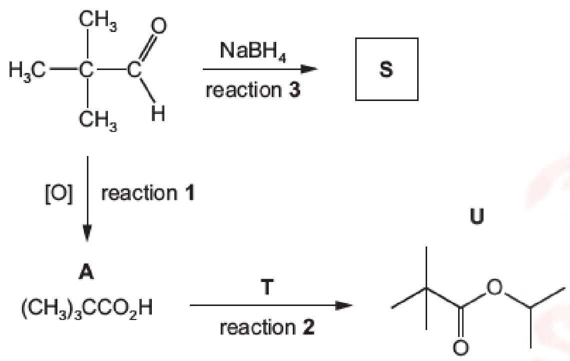
.... [1]

(ii) State the hybridisation of the carbon atom labelled with an asterisk, *.



.... [1]

(b) Two reaction sequences are shown.



(i) Reaction **1** is an oxidation reaction.

Identify the reagent(s) and conditions for reaction **1**.

.... [1]

(iii) Give the balanced equation for the reaction of $(CH_3)_3CCHO$ with $NaBH_4$ to form **S**.

Use [H] to represent an atom of hydrogen provided by $NaBH_4$.

.... [1]

(c) **X**, **Y** and **Z** are all isomers of $(CH_3)_3CCHO$.

A summary of some of the reactions and properties of **X**, **Y** and **Z** is shown in the table.

compound	observations with 2,4-DNPH	observations with Fehling's solution	principal absorptions in infra-red spectrum
X		no reaction	1715 cm^{-1}
Y		red precipitate	1730 cm^{-1}
Z	no reaction	no reaction	3200–3600 cm^{-1} 1630 cm^{-1} 1050 cm^{-1}

(i) **X** and **Y** each contains a carbonyl group.

Complete the table with the expected observations for the reactions of **X** and **Y** with 2,4-DNPH. [1]

(ii) Identify the functional group present in **Y** that causes the recorded observation with Fehling's solution.

.... [1]

(iii) **Y** has a chiral centre and exists as a pair of optical isomers.

State what is meant by the term *chiral centre*.

....

.... [1]

(iv) Draw the optical isomers of **Y** using the conventional three-dimensional representation.

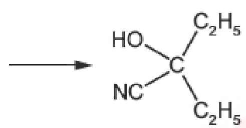
[2]

(vii) **X** contains a carbonyl group. **X** reacts with HCN, in the presence of a small amount of NaCN, to form $(C_2H_5)_2C(OH)CN$ as shown.

$$\mathbf{X} + HCN \rightarrow (C_2H_5)_2C(OH)CN$$

Draw the mechanism of the reaction of **X** with HCN.

- Draw the structure of **X** and the intermediate.
- Include all charges, partial charges, lone pairs and curly arrows.



[3]

(viii) State the role of NaCN in the reaction in **(c)(vii)**.

.... [1]

[Total: 22]

Topic **Chem 17 Q# 381/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Ethanal reacts with a mixture of HCN and NaCN to make 2-hydroxypropanenitrile, $CH_3CH(OH)CN$.

The reaction mechanism is nucleophilic addition.

(a) Explain the meaning of the term *nucleophile* and identify the species which acts as the nucleophile during this reaction.

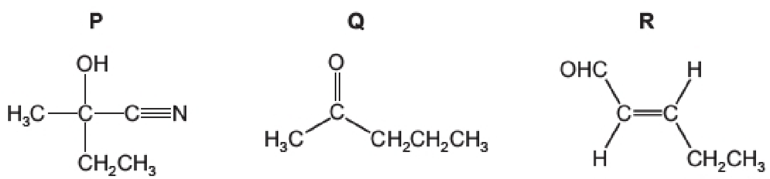
....

....

species acting as nucleophile .... [2]

Topic **Chem 17 Q# 382/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **P**, **Q** and **R** all contain five carbon atoms.



(b) **Q** is reduced by $NaBH_4$.

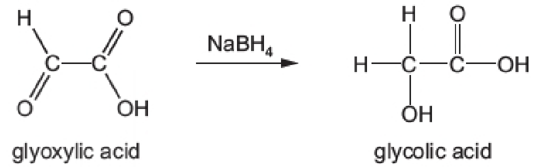
Write an equation for the reaction of **Q** with $NaBH_4$.

In your answer, use [H] to represent $NaBH_4$.

$C_5H_{10}O$ + ... [1]

Topic **Chem 17 Q# 383/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) Glycolic acid can also be made by reacting glyoxylic acid with $NaBH_4$.



(i) State the role of $NaBH_4$ in this reaction.

.... [1]

(ii) Write an equation for this reaction using molecular formulae.
Use [H] to represent $NaBH_4$.

.... [2]

Topic **Chem 17 Q# 384/** ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 **P**, **Q** and **R** all have the molecular formula C_3H_6O. They are all structural isomers of each other.

(c) **P** and **Q** (C_3H_6O) both form an orange precipitate when reacted with 2,4-DNPH. Only **Q** produces a yellow precipitate when reacted with alkaline aqueous iodine.

(i) Name **P** and **Q**.

P ....

Q ....

[2]

(ii) Identify the yellow precipitate formed by the reaction of **Q** with alkaline aqueous iodine.

.... [1]

(ii) Ethanal, CH_3CHO, also reacts with hydrogen cyanide. The product of this reaction is $CH_3CH(OH)CN$.

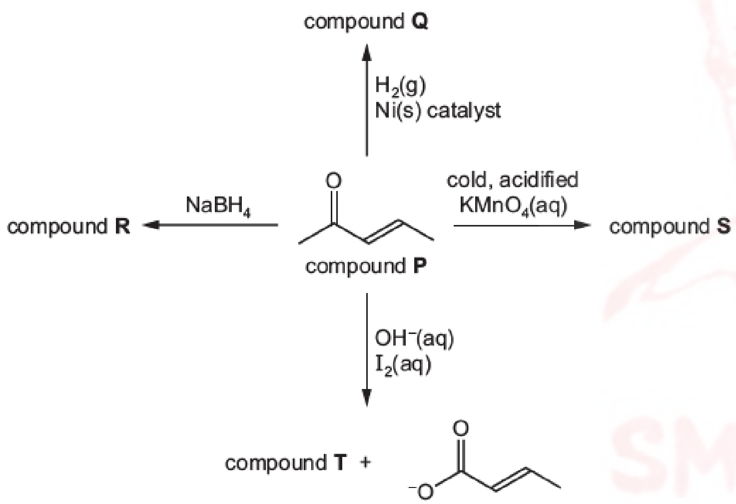
Draw the mechanism of this reaction.
Include all necessary charges, dipoles, lone pairs and curly arrows.

[3]

[Total: 19]

Topic **Chem 17 Q# 385/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5/www.SmashingScience.org

5 Some reactions of compound **P**, C_5H_8O, are shown.



(ii) Give the systematic name of compound **P**.

.... [1]

(iii) What would you observe when compound **P** is reacted with 2,4-dinitrophenylhydrazine (2,4-DNPH)?

.... [1]

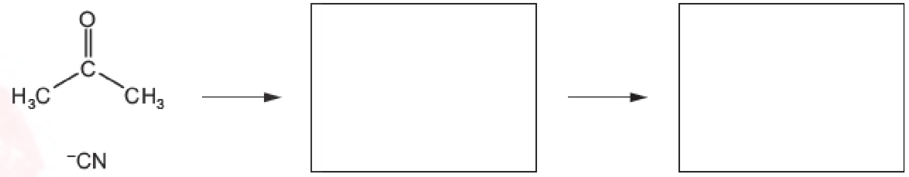
Topic **Chem 17 Q# 386/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(d) The reaction of hydrogen cyanide with propanone is an important first step in many organic syntheses.

(i) Give the full name of the mechanism of this reaction.

.... [1]

(ii) Complete the diagram to show the mechanism of the reaction of hydrogen cyanide with propanone.
Draw the structure of the intermediate and the product of the reaction.
Include all relevant charges, partial charges, curly arrows and lone pairs.



[5]

[Total: 17]

Topic **Chem 17 Q# 387/** ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Ethanal reacts with hydrogen cyanide, in the presence of a small amount of NaCN, as shown.

$$CH_3CHO + HCN \rightarrow CH_3CH(OH)CN$$

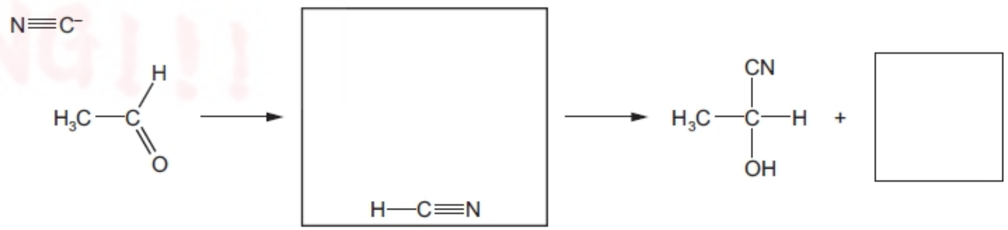
(b) The product of this reaction shows stereoisomerism as it contains a chiral centre. This reaction produces an equimolar mixture of two optical isomers.

(ii) Suggest why the two optical isomers are produced in equal amounts by this reaction.

....

.... [1]

(c) **(i)** Complete the diagram to show the mechanism of this reaction. Include all necessary charges, partial charges, lone pairs and curly arrows and show the structure of the intermediate.



[5]

(ii) With reference to your mechanism in **(i)**, explain the role of the NaCN in this reaction.

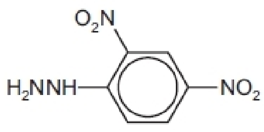
....

.... [1]

Topic **Chem 17 Q# 388/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Many organic compounds, including alcohols, carbonyl compounds, carboxylic acids and esters, contain oxygen.

(b) Some oxygen-containing compounds react with 2,4-dinitrophenylhydrazine.



2,4-dinitrophenylhydrazine

(i) Draw the structural formula of the organic compound formed when $HOCH_2CH_2CHO$ reacts with 2,4-dinitrophenylhydrazine reagent.

(ii) Suggest the colour of the organic product.

.... [2]

[Total: 12]

Topic **Chem 17 Q# 389/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Ketones are widely used as solvents and as intermediates in the chemical industry.

Ketones contain the reactive keto group, >C=O.

(a) Propanone, CH_3COCH_3, undergoes a reaction with hydrogen cyanide, HCN.

(i) What type of reaction is this?

....

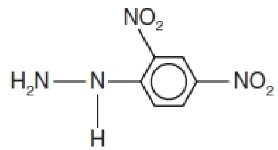
(ii) What reagents are used?

....

(iii) Draw a diagram to show the dipole present in the propanone molecule.

[3]

(b) Propanone reacts with 2,4-dinitrophenylhydrazine reagent.

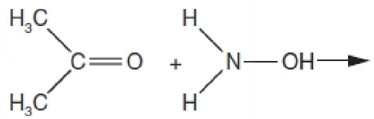


2,4-dinitrophenylhydrazine

(i) Construct a balanced equation for the reaction between propanone and 2,4-dinitrophenylhydrazine.

(ii) A similar type of reaction occurs between propanone and hydroxylamine, NH_2OH.

Draw the displayed formula of the organic product of this reaction.



[3]

Topic **Chem 17 Q# 390/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(e) HCN reacts with ethanal, CH_3CHO.

(i) Give the **displayed formula** of the organic product formed.

(ii) What type of reaction is this?

....

(iii) Draw the mechanism of this reaction. You should show all full and partial charges and represent the movement of electron pairs by curly arrows.

[5]

[Total: 13]

Topic Chem 18 Q# 391/ ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(b) **V** contains two types of functional group: a carboxylic acid and an alkene.

(i) Describe a chemical test and observation which confirms the presence of a carboxyl functional group.

....

.... [2]

Topic **Chem 18 Q# 392/** ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(b) **K** is used to make the addition polymer Perspex®. A synthesis of Perspex® is shown in Fig. 4.2.

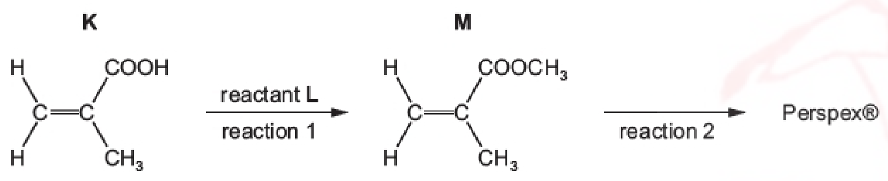


Fig. 4.2

(i) Identify **L**. State the conditions required for reaction 1.

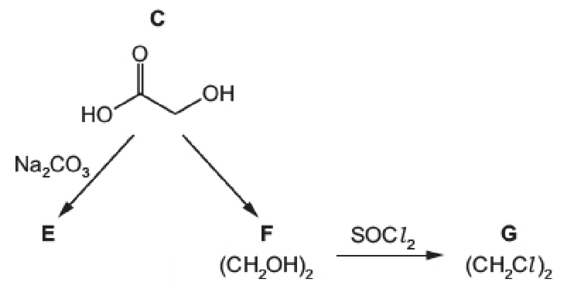
L = ...

conditions = ...

[2]

Topic **Chem 18 Q# 393/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) Some other reactions of **C** are shown.



(i) Draw the structure of **E**.

[1]

(ii) Suggest why $NaBH_4$ is not a suitable reagent to make **F**, $(CH_2OH)_2$, from **C**. Explain your answer.

....

.... [1]

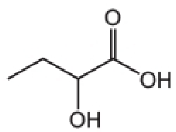
Topic **Chem 18 Q# 394/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

(a) **(i)** At 200 °C, aluminium chloride exists as Al_2Cl_6(g).

(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.

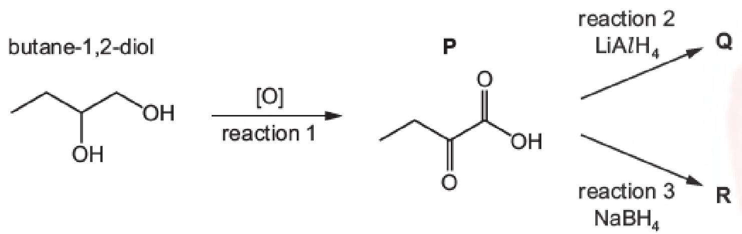
2-hydroxybutanoic acid



Both students oxidise butane-1,2-diol to form **P** in reaction 1.

One student then reduces **P** using $LiAlH_4$. **Q** is formed.

The other student reduces **P** using $NaBH_4$. **R** is formed.



(ii) Only one of the students successfully prepares 2-hydroxybutanoic acid.

Identify which of **Q** or **R** is 2-hydroxybutanoic acid and explain the difference between reactions 2 and 3.

....

....

.... [2]

Topic **Chem 18 Q# 395/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

(f) Propanoic acid, $CH_3CH_2CO_2H$, is reduced by $LiAlH_4$.

(i) Write an equation to show this reaction. Use [H] to represent an atom of hydrogen from the reducing agent.

.... [1]

(ii) Name the organic product formed in this reaction.

.... [1]

(g) Organic compound **W** is an ester which is a structural isomer of propanoic acid.

(i) State the molecular formula of **W**.

.... [1]

(ii) Draw a possible structure of **W**.

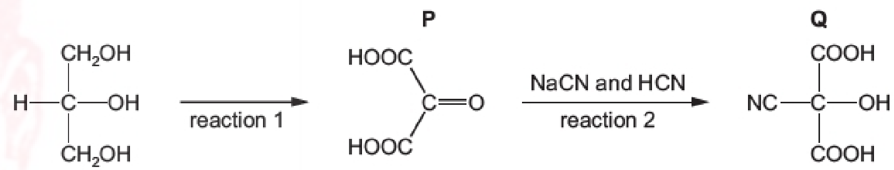
[1]

[Total: 12]

Topic **Chem 18 Q# 396/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

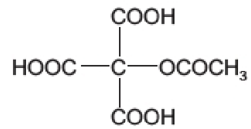
3 Glycerol, $CH_2(OH)CH(OH)CH_2OH$, is widely used in the food industry and in pharmaceuticals.

(a) A series of reactions starting from glycerol is shown.



(v) When **Q** is heated with excess aqueous ethanoic acid in the presence of a catalytic amount of sulfuric acid, two reactions take place to form compound **R**.

R



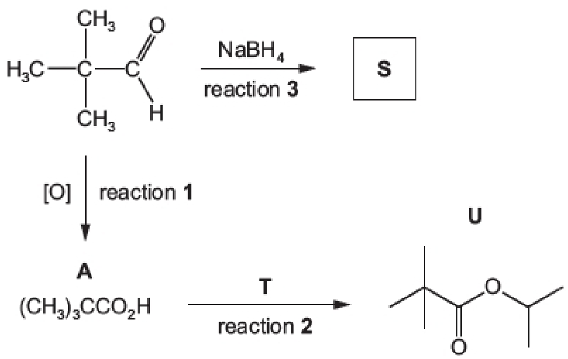
Identify the two types of reaction that occur.

1 ....

2 .... [2]

Topic **Chem 18 Q# 397/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

Two reaction sequences are shown.



(b)

(ii) **A**, $(CH_3)_3CCO_2H$, is a solid at room temperature.

B, $CH_3CO_2(CH_2)_2CH_3$, is an isomer of **A**. **B** is a liquid at room temperature.

Explain the difference in the physical states of **A** and **B**, with reference to any intermolecular forces that may exist.

....

....

....

.... [3]

(iv) Draw the structure of the organic molecule **T** that reacts with **A**, $(CH_3)_3CCO_2H$, in reaction **2**, to form **U**.

Suggest a catalyst for reaction **2**.

T

catalyst ....

[2]

Topic **Chem 18 Q# 398/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(d) Samples of organic compounds, **A**, **B**, **C** and **D**, are placed in unlabelled bottles.

A	**B**	**C**	**D**
$CH_3CH_2COCH_3$	$CH_3(CH_2)_2CHO$	CH_3CH_2OH	CH_3CO_2H

(i) Identify all of the compound(s), **A**–**D**, that contain a carbonyl group.

.... [1]

(ii) **A**–**D** are reacted separately with the reagents given in the table.

Complete the table to:

- identify which of the compounds, **A**–**D**, reacts with the reagents
- give an appropriate observation when a reaction occurs.

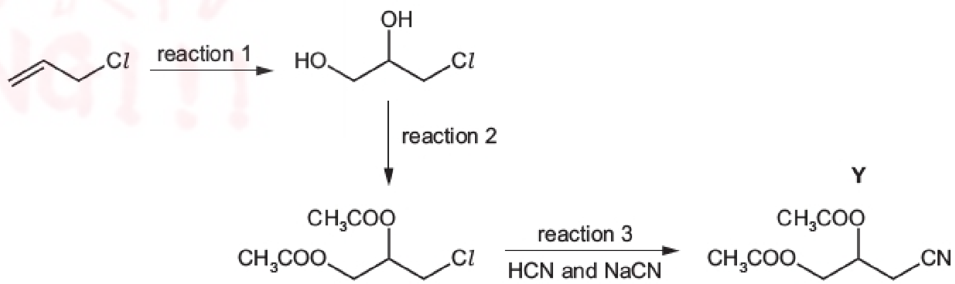
reagent	compounds identified	observation when a reaction occurs
Tollens' reagent		
alkaline solution of iodine		
sodium metal		

[8]

[Total: 15]

Topic **Chem 18 Q# 399/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(c) A series of reactions starting from allyl chloride is shown.



(ii) In reaction 2, the organic product of reaction 1 is mixed with concentrated H_2SO_4 and an organic acid, and then heated under reflux.

State the role of the concentrated H_2SO_4. Identify the organic acid used.

role of the concentrated H_2SO_4 ....

identity of the organic acid ....

[2]

(iv) The organic product of reaction 3 is **Y**.

Y can be hydrolysed using excess aqueous H_2SO_4 to form **Z**.

The molecular formula of **Z** is $C_4H_8O_4$.

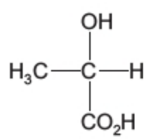
Draw the structure of **Z**.

[2]

Topic **Chem 18 Q# 400/** ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Calcium and its compounds have a large variety of applications.

(d) Calcium lactate is used in some medicines. It forms when lactic acid (2-hydroxypropanoic acid) reacts with calcium carbonate.



lactic acid

(i) Identify the **two** other products of the reaction of lactic acid with calcium carbonate.

.... [1]

Topic **Chem 18 Q# 401/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(d) $CH_3(CH_2)_3CO_2H$ is a colourless liquid with an unpleasant odour.

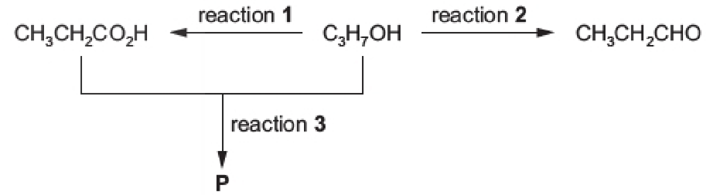
It reacts with methanol in the presence of an acid catalyst to produce an organic product **V**, which has a pleasant fruity smell.

(i) Name **V**.

.... [1]

Topic **Chem 18 Q# 402/** ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 A sequence of reactions is shown starting with an alcohol, C_3H_7OH.



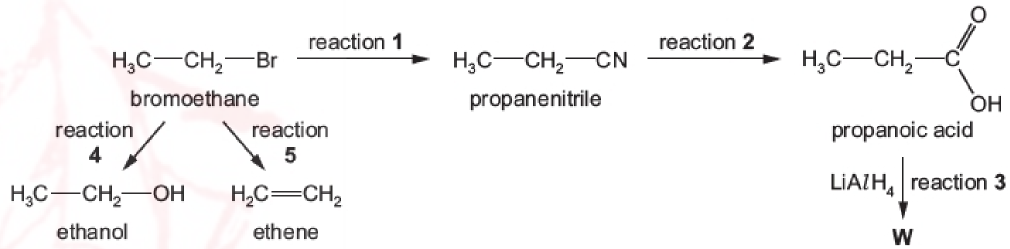
(d) Name **P**, the organic product of reaction **3**.

.... [1]

[Total: 6]

Topic **Chem 18 Q# 403/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 A reaction sequence is shown.



(d) Under appropriate conditions, ethanol and propanoic acid undergo a condensation reaction.

(i) State the condition necessary for the reaction.

.... [1]

(ii) Draw the skeletal formula of the organic product of this reaction.

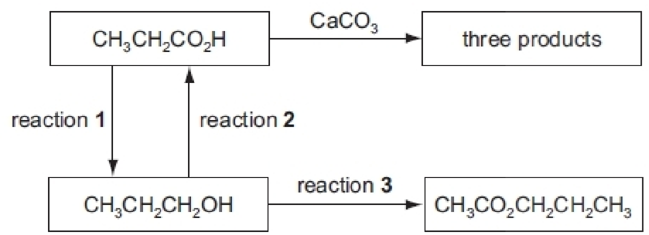
[1]

(iii) Name the organic product of this reaction.

.... [1]

Topic **Chem 18 Q# 404/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 A series of reactions based on propanoic acid is shown.



(a) Write an equation for reaction **1**, using [H] to represent the reducing agent.

.... [2]

(c) Write an equation for the reaction of propanoic acid with calcium carbonate, $CaCO_3$.

.... [2]

(d) **(i)** Suggest a suitable reagent and conditions for reaction **3**.

....

.... [2]

(ii) Identify the **other** product of reaction **3**.

.... [1]

[Total: 10]

Topic **Chem 18 Q# 405/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Compound **R** is a weak diprotic (dibasic) acid which is very soluble in water.

(b) Three possible structures for **R** are shown below.

S	T	U
$HO_2CCH=CHCO_2H$	$HO_2CCH(OH)CH_2CO_2H$	$HO_2CCH(OH)CH(OH)CO_2H$

(e) The acid **S** shows stereoisomerism. Draw structures to show this isomerism.
Label each isomer.

[2]

(f) When one of the isomers of **S** is heated at 110 °C in the absence of air, a cyclic compound **V**, with molecular formula $C_4H_2O_3$, is formed.
The other isomer of **S** does not react at this temperature.

Suggest the displayed formula of V.

[2]

[Total: 18]

Topic **Chem 18 Q# 406/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Organic compounds which contain oxygen may contain alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. The functional groups may be identified by their reactions with specific reagents.

Compound **X** has the empirical formula CH_2O and M_r of 90.

(a) There is no reaction when **X** is treated with $NaHCO_3$.

What functional group does this test show to be **not** present in **X**?

.... [1]

Topic **Chem 18 Q# 407/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Isomerism occurs in many organic compounds. The two main forms of isomerism are structural isomerism and stereoisomerism. Many organic compounds that occur naturally have molecules that can show stereoisomerism, that is *cis-trans* or optical isomerism.

Unripe fruit often contains polycarboxylic acids, that is acids with more than one carboxylic acid group in their molecule.

One of these acids is commonly known as tartaric acid, $HO_2CCH(OH)CH(OH)CO_2H$.

(b) Give the structural formula of the organic compound produced when tartaric acid is reacted with an excess of $NaHCO_3$.

[1]

A third polycarboxylic acid present in unripe fruit is a colourless crystalline solid, **W**, which has the following composition by mass: C, 35.8%; H, 4.5%; O, 59.7%.

(d) **(i)** Show by calculation that the empirical formula of **W** is $C_4H_6O_5$.

(ii) The M_r of **W** is 134. Use this value to determine the molecular formula of **W**.

[3]

A sample of **W** of mass 1.97 g was dissolved in water and the resulting solution titrated with 1.00 mol dm^{-3} NaOH. 29.4 cm^3 were required for complete neutralisation.

(e) **(i)** Use these data to deduce the number of carboxylic acid groups present in one molecule of **W**.

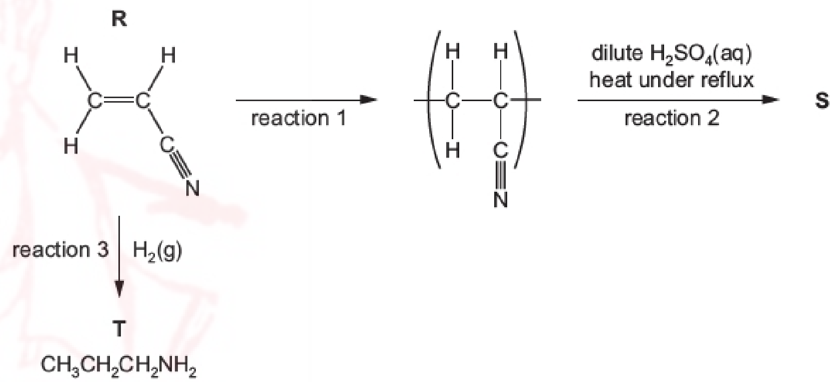
(ii) Suggest the displayed formula of **W**.

[5]

[Total: 13]

Topic Chem 19 Q# 408/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(d) The flow chart shows some reactions of **R**.



(ii) Draw the structure of **S**, the organic product of reaction 2.

[1]

(iii) Name **T**.

.... [1]

(iv) **T** can also be formed by the reaction of $CH_3CH_2CH_2Br$ with ammonia.

State the necessary conditions of this reaction.

.... [1]

[Total: 13]

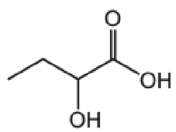
Topic **Chem 19 Q# 409/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 The reducing agent $LiAlH_4$ can be synthesised by reacting aluminium chloride with lithium hydride, LiH.

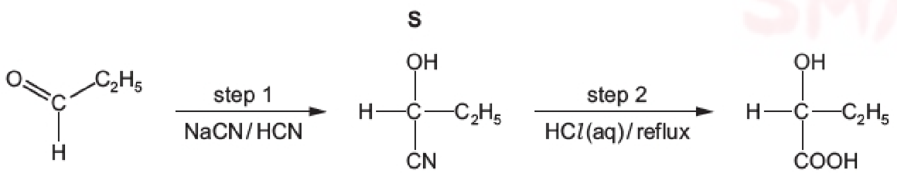
(a) (i) At 200 °C, aluminium chloride exists as Al_2Cl_6(g).

(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.

2-hydroxybutanoic acid



A third student prepares 2-hydroxybutanoic acid using propanal as the starting material. In step 1 the student reacts propanal with a mixture of NaCN and HCN.



(iv) Complete the equation for the reaction in step 2, when **S** is heated under reflux with HCl(aq).

$C_2H_5CH(OH)CN$ + ... → $C_2H_5CH(OH)COOH$ + ...

[1]

Topic **Chem 19 Q# 410/** ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Ethanal reacts with a mixture of HCN and NaCN to make 2-hydroxypropanenitrile, $CH_3CH(OH)CN$.

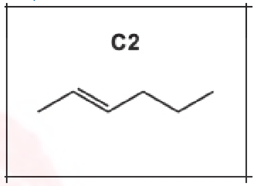
The reaction mechanism is nucleophilic addition.

(c) Give the structure of the organic product of the reaction of $CH_3CH(OH)CN$ with dilute sulfuric acid.

.... [1]

[Total: 7]

Topic Chem 20 Q# 411/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org



(d) **C2** forms a polymer when heated gently.

(i) Identify the type of polymer that forms from **C2**.

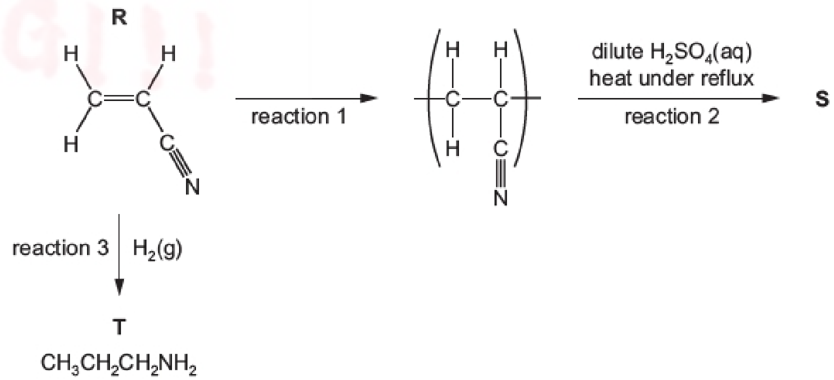
.... [1]

(ii) Draw one repeat unit of the polymer formed from **C2**.

[2]

Topic **Chem 20 Q# 412/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(d) The flow chart shows some reactions of **R**.



(i) Name the type of reaction shown in reaction 1.

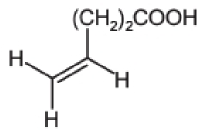
.... [1]

Topic **Chem 20 Q# 413/** ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(c) Fats are compounds made from glycerol and unsaturated carboxylic acids.

4-pentenoic acid is an example of an unsaturated carboxylic acid.

4-pentenoic acid



(ii) Draw the repeat unit of the addition polymer that can be formed from 4-pentenoic acid.

[1]

Topic **Chem 20 Q# 414/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Trihalomethanes are organic molecules in which three of the hydrogen atoms of methane are replaced by halogen atoms, for example $CHCl_3$.

(c) $CHClF_2$ is also used to produce the monomer tetrafluoroethene, C_2F_4.

This monomer can be used to produce poly(tetrafluoroethene), PTFE.

(i) State the type of polymerisation that occurs during the production of PTFE.

.... [1]

(ii) Draw the repeat unit of PTFE.

[1]

(iii) Suggest why PTFE is used as a coating for cooking pans.

....

....

....

.... [1]

(iv) Waste disposal can cause litter problems.

State two **other** difficulties associated with the disposal of PTFE.

1 ....

....

2 ....

....

[2]

[Total: 17]

Topic **Chem 20 Q# 415/** ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) Cracking one mole of dodecane, $C_{12}H_{26}$, produces two moles of ethene and one mole of another hydrocarbon molecule.

The ethene can be used in the production of poly(ethene).

(ii) Give the full name of the process used to produce poly(ethene) from ethene.

.... [1]

(iii) Give **two** reasons why poly(ethene) should be reused or recycled rather than just thrown away.

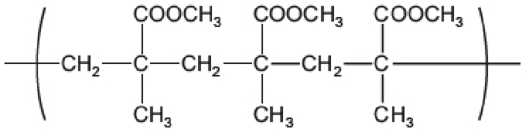
....

....

....

.... [2]

(iv) Part of a polymer chain, produced by the same type of process as poly(ethene), is shown.



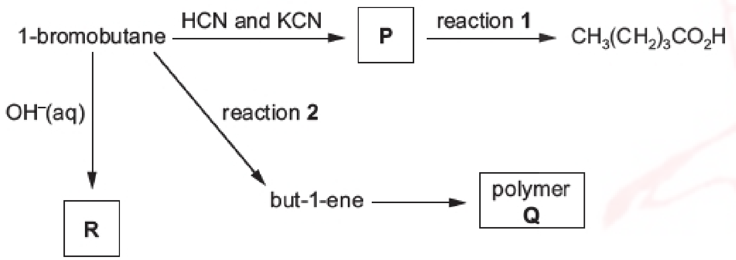
Give the **displayed** formula of the monomer used to produce this polymer.

[2]

[Total: 9]

Topic **Chem 20 Q# 416/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** A series of reactions starting from 1-bromobutane is shown.



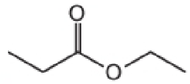
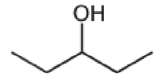
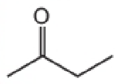
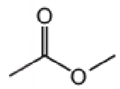
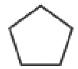
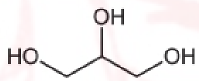
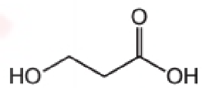
(iii) Draw the structure of the repeat unit of polymer **Q**.

[2]

Topic Chem 21 Q# 417/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Organic compounds can be distinguished using chemical tests.
Table 4.1 shows four pairs of compounds.

Table 4.1

organic compounds		reagent	positive result of chemical test on identified compound
A1 	**A2** 		
B1 	**B2** 		
C1 	**C2** 		
D1 	**D2** 		

(a) Complete Table 4.1 to:
- identify a reagent that could distinguish between the compounds in each pair
- give the **positive** result of the chemical test **and** identify which compound shows this result.

Use a different reagent for each test. [8]

4 Compounds **J** and **K** are found in plant oils.

Fig. 4.1

(b) **K** is used to make the addition polymer Perspex®. A synthesis of Perspex® is shown in Fig. 4.2.

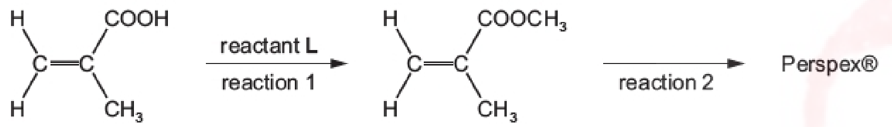


Fig. 4.2

(i) Identify **L**. State the conditions required for reaction 1.

L = ...

conditions = ...

[2]

(b)

(iv) **K** can be made from propanone in the three-step synthesis shown in Fig. 4.3.

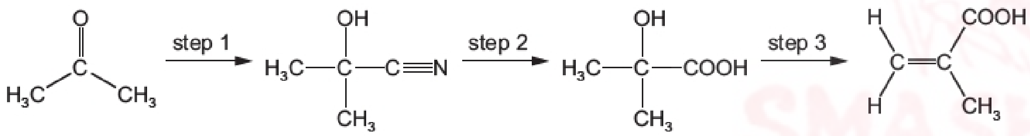


Fig. 4.3

Complete Table 4.3 to identify the reagent(s) used and the type of reaction in each step.

Complete Table 4.3 to identify the reagent(s) used and the type of reaction in each step.

Table 4.3

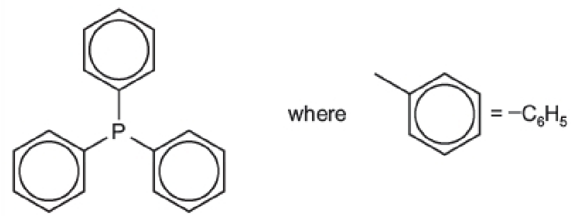
step	reagent(s)	type of reaction
1		
2		
3	Al_2O_3	

[5]

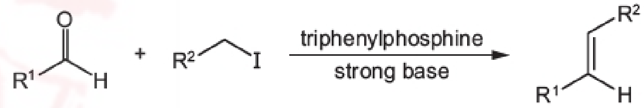
[Total: 15]

(c) Triphenylphosphine is used in a type of reaction known as a *Wittig reaction*.

triphenylphosphine



In a Wittig reaction, an aldehyde reacts with a halogenoalkane to form an alkene. The conversion is shown in the following unbalanced equation.



Compound **H** can be made from propanal, C_2H_5CHO. Stage 3 in the reaction scheme is a Wittig reaction.

stage 1 $C_2H_5CHO \xrightarrow{NaBH_4}$ **G**

stage 2 **G** $\xrightarrow{\text{red phosphorus and } I_2} C_2H_5CH_2I$

stage 3 (Wittig reaction) $C_2H_5CH_2I + C_2H_5CHO \xrightarrow[\text{strong base}]{\text{triphenylphosphine}}$ **H**

(ii) State the types of reaction that occur in stages 1 and 2.

stage 1 ....

stage 2 .... [2]

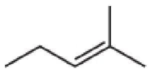
(iii) Draw the structures of **G** and **H** in the boxes provided.

G	**H**

[2]

(d) Identify the organic products formed when compound **J**, shown below, is heated with hot concentrated acidified manganate(VII) ions.

J



$\xrightarrow[H_2SO_4]{\text{hot concentrated } MnO_4^-}$

[2]

[Total: 14]

Topic **Chem 21 Q# 421/** ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(ii) Draw the structure of the organic products formed in the following reactions.

CH_3CH_2Br $\xrightarrow[\text{dissolved in ethanol}]{NaCN}$ [ ] $\xrightarrow[\text{heat under reflux}]{H_2SO_4(aq)}$ [ ]

$\xrightarrow[\text{and HCN}]{NaCN}$ [ ]

[3]

[Total: 13]

Topic **Chem 21 Q# 422/** ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 **(a)** Below is a list of species which can react with organic compounds.

CN^- HCl Cl H_2O CO_3^{2-}

(iii) From the list, identify a species which can be used to distinguish between solutions of propanoic acid and propan-1-ol. Describe any relevant observations.

....

....

.... [2]

(d) But-1-ene reacts with steam in the presence of concentrated phosphoric acid to form two isomers of molecular formula $C_4H_{10}O$.

Each reaction occurs via a different intermediate ion.

(i) Draw the structure of both intermediate ions.

[2]

(ii) Circle the more stable intermediate ion drawn in **(d)(i)**. Explain your answer.

....

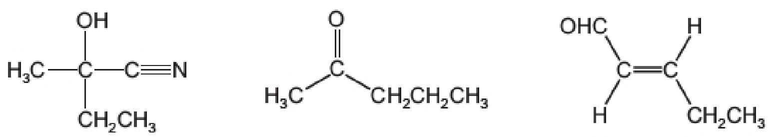
....

.... [2]

[Total: 12]

3 **P**, **Q** and **R** all contain five carbon atoms.

P **Q** **R**



A student carries out several tests to distinguish between **P**, **Q** and **R**.

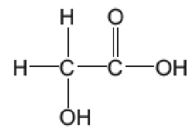
(a) Complete the table, identifying any observations for the reaction of each reagent with **P**, **Q** and **R**.

If no reaction occurs, write 'no reaction'.

reagent	observations with		
	P	**Q**	**R**
Na(s)			
2,4-DNPH	no reaction		
acidified $K_2Cr_2O_7$(aq)	no reaction		

[3]

4 The structure of glycolic acid is shown.



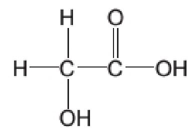
glycolic acid

(a) Complete the table to show what you would **observe** when an aqueous solution of glycolic acid is added separately to each of the reagents. If a reaction occurs, state the functional group of glycolic acid that is responsible for the reaction.

reagent	observation with glycolic acid	does a reaction occur? ✓/✗	functional group
Na_2CO_3(aq)			
2,4-DNPH			
acidified $Cr_2O_7^{2-}$			

[4]

4 The structure of glycolic acid is shown.



glycolic acid

(b) Two reaction sequences to make glycolic acid are shown.

sequence A $\quad HCHO \xrightarrow[\text{reaction 1}]{\text{HCN and NaCN}} \mathbf{X} \xrightarrow[\text{reaction 2}]{} CH_2(OH)CO_2H$

sequence B $\quad CH_3CO_2H \xrightarrow[\text{reaction 3}]{Br_2} CH_2BrCO_2H \xrightarrow[\text{reaction 4}]{} CH_2(OH)CO_2H$

(i) Draw the structure of **X**.

[1]

(ii) Name the reagent for reaction **2**.

.... [1]

(iii) Name the mechanism of reaction **3**.

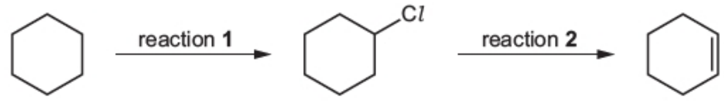
.... [1]

(iv) Suggest the essential condition for reaction **3**.

.... [1]

4 Cyclohexane is a colourless liquid used in industry to produce synthetic fibres.

A reaction scheme involving cyclohexane is shown.

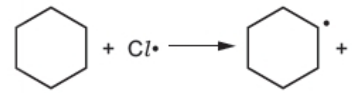
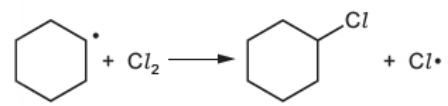
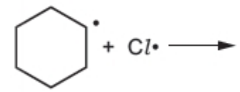


(a) Reaction **1** involves a free radical substitution mechanism.

(i) State the essential condition required for reaction **1** to occur.

.... [1]

(ii) Complete the table to give details of the mechanism in reaction **1**.

name of step	reaction
....	$Cl_2 \rightarrow 2Cl\bullet$
propagation	 ....
....	
termination	 ....

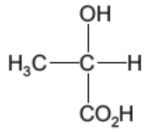
[4]

(b) Name the type of reaction that occurs in reaction **2**.

.... [1]

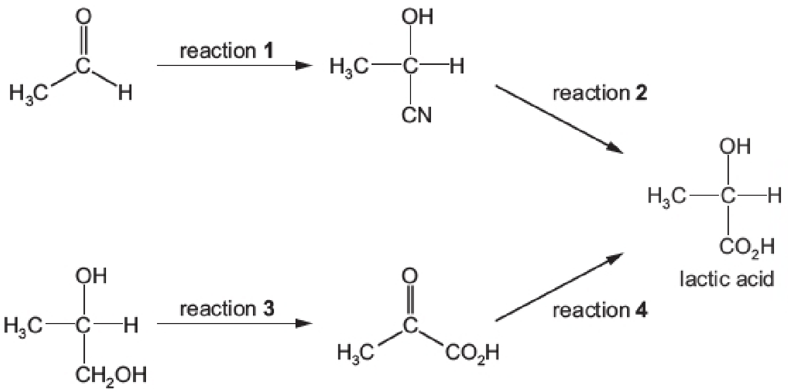
3 Calcium and its compounds have a large variety of applications.

(d) Calcium lactate is used in some medicines. It forms when lactic acid (2-hydroxypropanoic acid) reacts with calcium carbonate.



lactic acid

Two possible methods of making lactic acid are shown.



(ii) State suitable reagents and conditions for reactions **1** and **3**.

reaction	reagents and conditions
1	
3	

[4]

(iii) Name the type of reaction that occurs in reaction **2**.

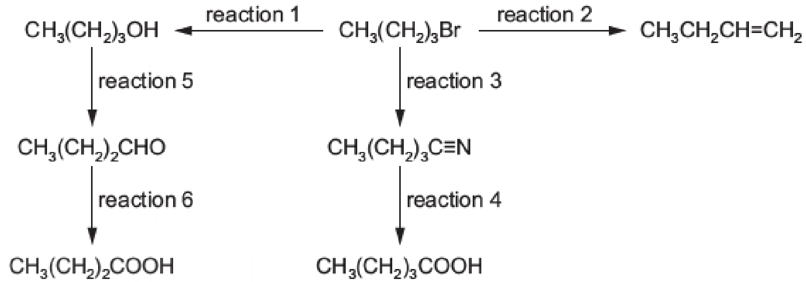
.... [1]

(iv) Reaction **4** uses $NaBH_4$.

Identify the role of $NaBH_4$ in this reaction.

.... [1]

3 Some reactions based on 1-bromobutane, $CH_3(CH_2)_3Br$, are shown.



(a) For each of the reactions state the reagent(s), the particular conditions required, if any, and the type of reaction.

For the type of reaction choose from the list.
Each type may be used once, more than once or not at all.
Each reaction may be described by more than one type.

elimination hydrolysis substitution

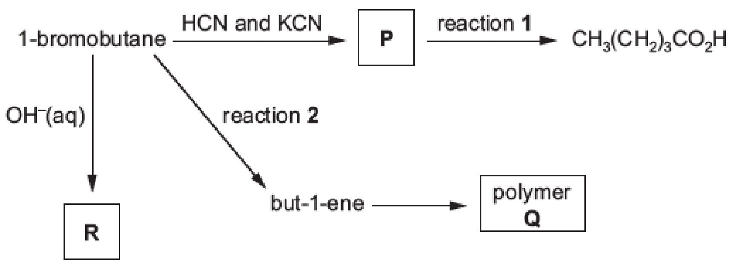
oxidation addition condensation

reaction	reagent(s) and conditions	type(s) of reaction
1		
2		
3		
4		
5		
6		

[6]

Topic **Chem 21 Q# 429/** ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** A series of reactions starting from 1-bromobutane is shown.



(i) Draw the **displayed** formula of compound **P**.

[1]

(ii) Identify the reagent(s) and conditions for reactions **1** and **2**.

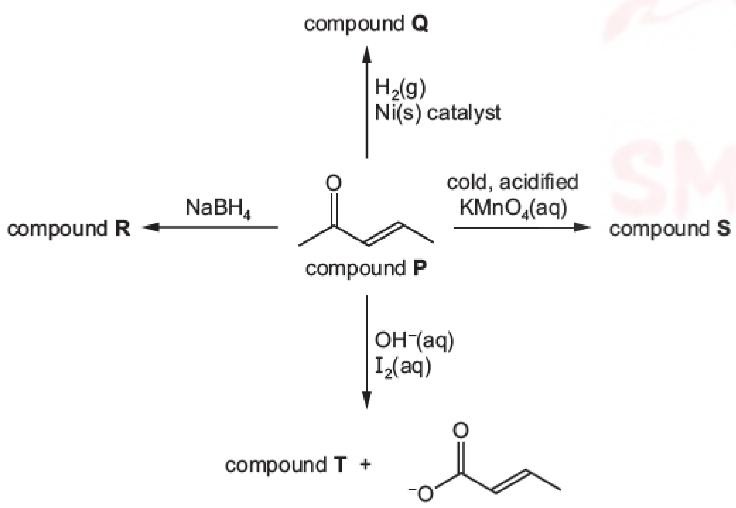
reaction **1** ....

reaction **2** ....

[2]

Topic **Chem 21 Q# 430/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5/www.SmashingScience.org

5 Some reactions of compound **P**, C_5H_8O, are shown.



(a) **(i)** Give the structures for organic compounds **Q**, **R**, **S** and **T**.

Q

R **S**

T

[4]

Topic **Chem 21 Q# 431/** ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 **P**, **Q** and **R** are structural isomers with the molecular formula C_4H_8.

All three compounds readily decolourise bromine in the dark.

P and **Q** do not exhibit stereoisomerism but **R** exists as a pair of geometrical (cis-trans) isomers.

All three compounds react with hot concentrated, acidified potassium manganate(VII) to produce a variety of products as shown in the table.

compound	products
P	CO_2 and **S** (C_3H_6O)
Q	CO_2 and $CH_3CH_2CO_2H$
R	CH_3CO_2H only

S reacts with 2,4-dinitrophenylhydrazine reagent, 2,4-DNPH, to form an orange crystalline product but does not react with Fehling's reagent.

(a) Give the structural formulae of **P**, **Q**, **R** and **S**.

P .... **Q** ....

R .... **S** ....

[4]

(ii) Draw the **displayed** formulae of the geometrical isomers of **R** and name them both.

name .... name .... [2]

(c) State a reagent that could be used for the reduction of **S** and **name** the organic product of this reduction.

reagent .... product .... [2]

[Total: 10]

Topic **Chem 21 Q# 432/** ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Compound **R** is a weak diprotic (dibasic) acid which is very soluble in water.

(b) Three possible structures for **R** are shown below.

S	T	U
$HO_2CCH{=}CHCO_2H$	$HO_2CCH(OH)CH_2CO_2H$	$HO_2CCH(OH)CH(OH)CO_2H$

It is possible to convert **S**, **T**, or **U** into one another.

(c) State the reagent(s) and essential conditions that would be used for the following conversions.

S into **T**

....

S into **U**

....

T into **S**

.... [5]

(d) Give the structural formula of the organic product formed in **each** of the following reactions.

T reacting with an excess of Na

U reacting with an excess of Na_2CO_3

[2]

Topic **Chem 21 Q# 433/** ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Crotonaldehyde, $CH_3CH{=}CHCHO$, occurs in soybean oils.

(a) In the boxes below, write the **structural formula** of the organic compound formed when crotonaldehyde is reacted separately with each reagent under suitable conditions. If you think no reaction occurs, write 'NO REACTION' in the box.

reaction	reagent	product
A	Br_2 in an inert organic solvent	
B	PCl_3	
C	H_2 and Ni catalyst	
D	$NaBH_4$	
E	$K_2Cr_2O_7/H^+$	

[5]

(d) The product of reaction E in the table opposite will react with a solution containing acidified manganate(VII) ions.
Draw the **structural formulae** of the organic products when the reagent is

(i) cold, dilute;

(ii) hot, concentrated.

[3]

[Total: 12]

Topic **Chem 21 Q# 434/** ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Organic chemistry is the chemistry of carbon compounds. The types of organic reactions that you have studied are listed below.

addition　　elimination　　hydrolysis

oxidation　　reduction　　substitution

Addition and substitution reactions are further described as follows.

electrophilic　　nucleophilic　　free radical

Complete the table below.
Fill in the central column by using **only** the types of reaction given in the lists above.
Use **both** lists when appropriate.
In the right hand column give the formula(e) of the reagent(s) you would use to carry out the reaction given.

organic reaction	type of reaction	reagent(s)
$CH_3CH_2CH_2CH_2Br \rightarrow CH_3CH_2CH_2CH_2NH_2$		
$CH_3CH_2CH_2CH_2OH \rightarrow BrCH_2CH_2CH_2CH_2OH$		
$CH_3COCH_3 \rightarrow CH_3C(OH)(CN)CH_3$		
$CH_3CH(OH)CH_2CH_3 \rightarrow CH_3CH{=}CHCH_3$		

[Total: 11]

Topic **Chem 21 Q# 435/** ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Compound **X** has the molecular formula $C_4H_8O_2$.

(a) **(i)** Treatment of **X** with sodium metal produces a colourless flammable gas.
What does this result tell you about the functional groups that could be present in **X**?

....

....

(ii) There is no reaction when **X** is treated with sodium hydrogencarbonate, $NaHCO_3$.
What does this result tell you about the functional groups that could be present in **X**?

....

....

(iii) When **X** is shaken with aqueous bromine the orange colour disappears.
What does this result tell you about the functional groups that could be present in **X**?

....

....

[3]

(b) The molecule of **X** has the following features.

- The carbon chain is unbranched and the molecule is not cyclic.
- No oxygen atom is attached to any carbon atom which is involved in π bonding.
- No carbon atom has more than one oxygen atom joined to it.

There are five possible isomers of **X** which fit these data. Four of these isomers exist as two pairs of stereoisomers.

(i) Draw displayed formulae of **each** of these two pairs.

pair 1		
pair 2		

(ii) These four isomers of **X** show two types of stereoisomerism.

State which type of isomerism each pair shows.

pair 1 ....

pair 2 ....

[6]

[Total: 9]

4 Many organic compounds, including alcohols, carbonyl compounds, carboxylic acids and esters, contain oxygen.

(a) The table below lists some oxygen-containing organic compounds and some common laboratory reagents.

(i) Complete the table as fully as you can.
If you think no reaction occurs, write 'no reaction' in the box for the structural formula(e).

reaction	organic compound	reagent	structural formula(e) of organic product(s)
A	$(CH_3)_3COH$	$Cr_2O_7^{2-}$ / H^+ heat under reflux	
B	CH_3CH_2CHO	Fehling's reagent warm	
C	$HCO_2CH(CH_3)_2$	NaOH(aq) warm	
D	$CH_2{=}CHCHO$	$NaBH_4$	
E	$(CH_3)_3COH$	$NaBH_4$	
F	$CH_3CH_2COCH_3$	MnO_4^- / H^+ heat under reflux	

(ii) During some of the reactions in **(i)** a colour change occurs.
Complete the table below for any such reactions, stating the letter of the reaction and what the colour change is.

reaction	colour at the beginning of the reaction	colour at the end of the reaction

[10]

Topic **Chem 21 Q# 437/** ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Organic compounds which contain oxygen may contain alcohol, aldehyde, carboxylic acid, ester or ketone functional groups. The functional groups may be identified by their reactions with specific reagents.

Compound **X** has the empirical formula CH_2O and M_r of 90.

(a) There is no reaction when **X** is treated with $NaHCO_3$.

(b) When 0.600 g of **X** is reacted with an excess of Na, 160 cm³ of H_2, measured at room temperature and pressure, is produced.

(i) What functional group does this reaction show to be present in **X**?

....

(ii) Use the data to calculate the amount, in moles, of hydrogen **atoms** produced from 0.600 g of **X**.

(iii) Hence, show that each molecule of **X** contains **two** of the functional groups you have given in **(i)**.

[4]

(c) When **X** is warmed with Fehling's reagent, a brick red precipitate is formed.
Treatment of **X** with 2,4-dinitrophenylhydrazine reagent produces an orange solid.

(i) What functional group do these reactions show to be present in **X**?
Draw the displayed formula of this functional group.

(ii) Use your answers to **(b)(i)**, **(b)(ii)** and **(c)(i)** to deduce the structural formula of **X**.

(iii) What is the structural formula of the organic product of the reaction of **X** with Fehling's reagent?

[3]

(d) Compound **X** can be both oxidised and reduced.

(i) Give the structural formula of the compound formed when **X** is reacted with $NaBH_4$ under suitable conditions.

(ii) Give the structural formula of the compound formed when **X** is heated under reflux with acidified $K_2Cr_2O_7$.

[2]

[Total: 10]

Topic **Chem 21 Q# 438/** ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Astronomers using modern telescopes of various types have found many molecules in the dust clouds in space. Many of these molecules are those of organic compounds and astronomers constantly look for evidence that amino acids such as aminoethanoic acid, $H_2NCH_2CO_2H$, are present.

One molecule that has been found in the dust clouds is hydroxyethanal, $HOCH_2CHO$.

(a) Hydroxyethanal contains two functional groups.

(i) Name, **as fully as you can**, each of the functional groups present in hydroxyethanal.

1 ....

2 ....

(ii) For **each** functional group, identify a reagent that will react with this group and **not** react with the other functional group present.
In each case, describe what would be observed when this reaction is carried out.

functional group 1 reagent ....

observation..

functional group 2 reagent ....

observation.. [7]

(b) Give the **skeletal** formulae of the organic compounds formed when hydroxyethanal is reacted separately with the following.

(i) $NaBH_4$

(ii) $Cr_2O_7^{2-}/H^+$ under reflux conditions

[2]

In a school or college laboratory, it is possible to convert a sample of hydroxyethanal into aminoethanoic acid in a three-step process.

$$HOCH_2CHO \xrightarrow{\text{step 1}} \mathbf{X} \xrightarrow{\text{step 2}} \mathbf{Y} \xrightarrow{\text{step 3}} H_2NCH_2CO_2H$$

By considering the possible reactions of the functional groups present in hydroxyethanal, you are to deduce a possible route for this conversion.

(c) **(i)** In the boxes below, draw the structural formulae of your suggested intermediates **X** and **Y**.

X	**Y**

(ii) State the reagents for **each** of the three steps you have chosen.

step 1..

step 2..

step 3.. [5]

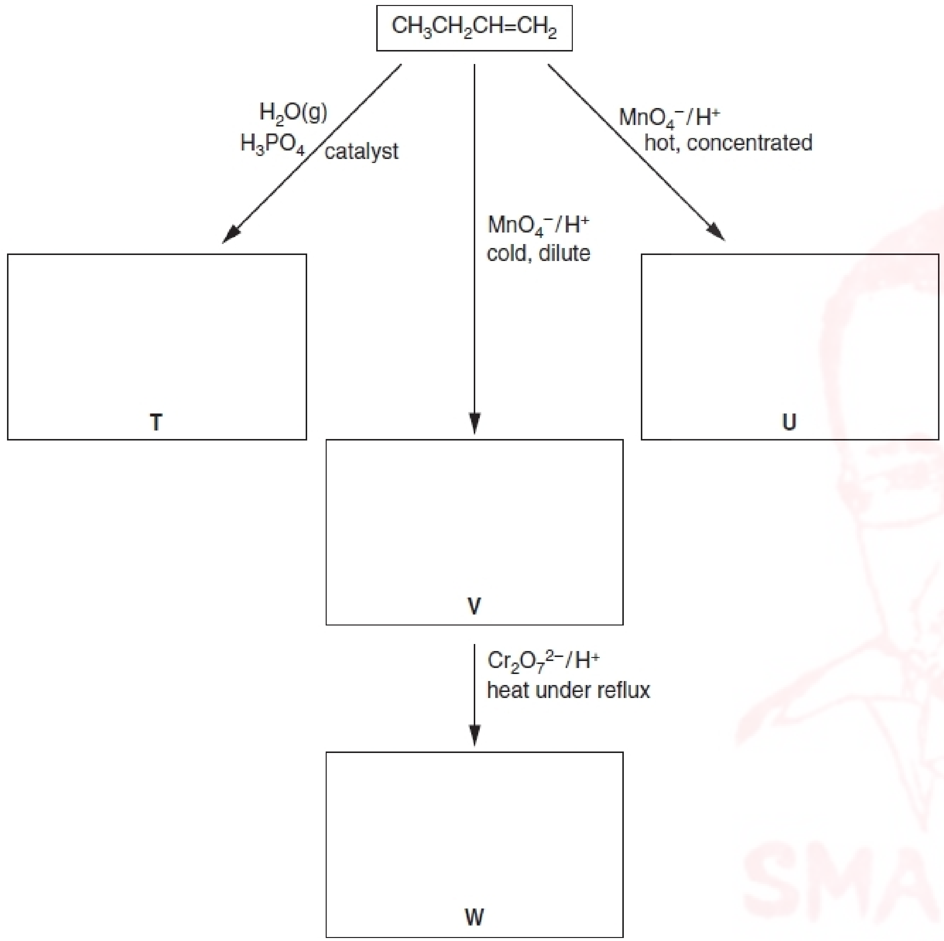
[Total: 14]

Topic **Chem 21 Q# 439/** ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 But-1-ene, $CH_3CH_2CH{=}CH_2$, is an important compound in the petrochemical industry.

(a) Some reactions of but-1-ene are given below.

In **each** empty box, draw the structural formula of the organic compound formed.



[5]

(b) Compound **T** reacts with compound **U**.

Draw the **displayed** formula of the organic product of this reaction.

[2]

[Total: 7]

Topic **Chem 21 Q# 440/** ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 Compound **A** is an organic compound which contains carbon, hydrogen and oxygen.

When 0.240 g of the vapour of **A** is slowly passed over a large quantity of heated copper(II) oxide, CuO, the organic compound **A** is completely oxidised to carbon dioxide and water. Copper is the only other product of the reaction.

The products are collected and it is found that 0.352 g of CO_2 and 0.144 g of H_2O are formed.

(a) **In this section, give your answers to <u>three</u> decimal places.**

(i) Calculate the mass of carbon present in 0.352 g of CO_2.

Use this value to calculate the amount, in moles, of carbon atoms present in 0.240 g of **A**.

(ii) Calculate the mass of hydrogen present in 0.144 g of H_2O.

Use this value to calculate the amount, in moles, of hydrogen atoms present in 0.240 g of **A**.

(iii) Use your answers to calculate the mass of oxygen present in 0.240 g of **A**.

Use this value to calculate the amount, in moles, of oxygen atoms present in 0.240 g of **A**.

[6]

(b) Use your answers to **(a)** to calculate the empirical formula of **A**.

[1]

(c) When a 0.148 g sample of **A** was vapourised at 60°C, the vapour occupied a volume of 67.7 cm³ at a pressure of 101 kPa.

(i) Use the general gas equation $pV = nRT$ to calculate M_r of **A**.

M_r = ...

(ii) Hence calculate the molecular formula of **A**.

[3]

(d) Compound **A** is a liquid which does **not** react with 2,4-dinitrophenylhydrazine reagent or with aqueous bromine.

Suggest **two** structural formulae for **A**.

[2]

(e) Compound **A** contains only carbon, hydrogen and oxygen.

Explain how the information on the opposite page about the reaction of **A** with CuO confirms this statement.

....

.... [1]

[Total: 13]

Topic **Chem 21 Q# 441/** ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 The gas ethyne, C_2H_2, more commonly known as acetylene, is manufactured for use in the synthesis of organic compounds. It is also used, in combination with oxygen, in 'oxy-acetylene' torches for the cutting and welding of metals.

Industrially, ethyne is made from calcium carbide, CaC_2, or by cracking liquid hydrocarbons. Ethyne can also be obtained from ethene by using the following sequence of reactions.

$$CH_2CH_2 \xrightarrow{\text{step 1}} ClCH_2CH_2Cl \xrightarrow{\text{step 2}} HC{\equiv}CH$$

(b) (i) What types of reaction are step 1 and step 2?

step 1 ....

step 2 ....

(ii) Suggest what reagent and conditions would be used in a laboratory in step 2.

reagent ....

conditions .... [5]

When ethyne is passed into water at 60 °C, in the presence of a little H_2SO_4 and Hg^{2+} ions, a pungent, colourless organic liquid, **Q**, with M_r of 44 is obtained. This is step 3.

When **Q** is warmed with Tollens' reagent in a test-tube, a silver mirror is formed.
On acidification, the solution remaining in the test-tube is found to contain the organic compound **R** which has M_r of 60. This is step 4.

(c) (i) Give the structural formulae of **Q** and **R**.

$$HC{\equiv}CH \xrightarrow{\text{step 3}} \boxed{\mathbf{Q}} \xrightarrow{\text{step 4}} \boxed{\mathbf{R}}$$

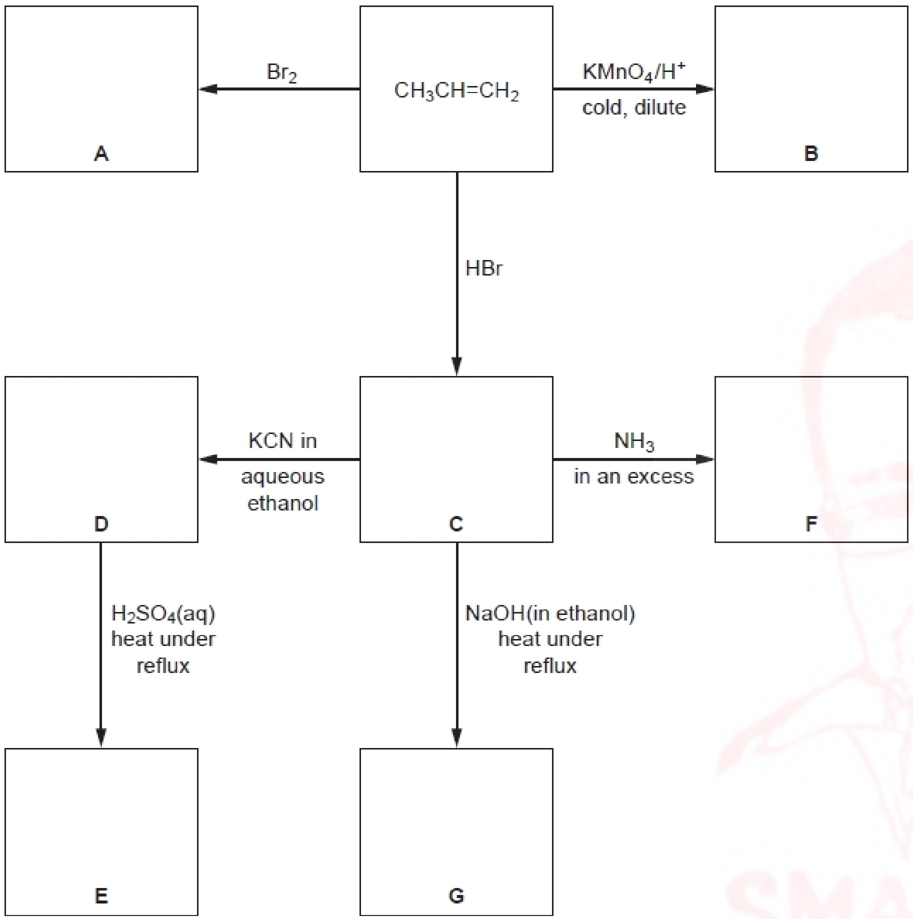
(ii) What type of reaction is step 3 and step 4?

step 3 ....

step 4 .... [4]

Topic **Chem 21 Q# 442/** ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 **(a)** Complete the following reaction scheme which starts with propene.
In **each empty** box, write the **structural formula** of the organic compound that would be formed.



[7]

(b) Under suitable conditions, compound **E** will react with compound **B**.

(i) What functional group is produced in this reaction?

....

(ii) How is this reaction carried out in a school or college laboratory?

....

.... [3]

[Total: 10]

Topic **Chem 21 Q# 443/** ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Three organic compounds, **G**, **H**, and **J**, each have the empirical formula CH_2O.
The numbers of carbon atoms in their molecules are shown in the table.

compound	number of C atoms
G	1
H	2
J	3

In **H** and in **J**, the carbon atoms are bonded directly to one another.

G gives a silver mirror when treated with Tollens' reagent.

H and **J** each give a brisk effervescence with Na_2CO_3(aq).

(a) Identify **G**.

.... [1]

(b) **(i)** What functional group is common to both **H** and **J**?

....

(ii) Identify **H**.

....

(iii) Identify **J**.

.... [3]

(c) When **J** is heated under reflux with acidified $K_2Cr_2O_7$, the product, **K**, gives a red-orange precipitate with 2,4-dinitrophenylhydrazine reagent.

Draw the structural formula of **K**, the compound formed from **J**.

[1]

(d) When **J** is warmed with concentrated sulfuric acid, a cyclic compound, **L**, is formed. **L** has the molecular formula $C_6H_8O_4$.

(i) Suggest a displayed formula for **L**.

(ii) What type of reaction occurs when **L** is formed from **J**?

.... [2]

[Total: 7]

4 The structural formulae of six different compounds, **A – F**, are given below. **Each** compound contains four carbon atoms in its molecule.

$CH_3CH{=}CHCH_3$	$CH_3CH_2COCH_3$	$CH_2{=}CHCH_2CH_3$
A	**B**	**C**
$CH_3CH_2CH(OH)CH_3$	$HOCH_2CH_2CH_2CH_2OH$	$CH_3CH_2OCH_2CH_3$
D	**E**	**F**

(a) **(i)** What is the empirical formula of compound **E**? ....

(ii) Draw the skeletal formula of compound **D**.

(iii) Structural formulae do not show all of the isomers that may exist for a given molecular formula. Which **two** compounds **each** show **different** types of isomerism and what type of isomerism does each compound show? Identify each compound by its letter.

compound	type of isomerism

[4]

Compound **D** may be converted into compound **C**.

(b) **(i)** What type of reaction is this?

....

(ii) What reagent would you use for this reaction?

....

(iii) What is formed when compound **E** undergoes the same reaction using an excess of the same reagent?

.... [3]

Compound **A** may be converted into compound **B** in a two-stage reaction.

$CH_3CH{=}CHCH_3 \xrightarrow{\text{stage I}} \text{intermediate} \xrightarrow{\text{stage II}} CH_3CH_2COCH_3$

(c) **(i)** What is the structural formula of the intermediate compound formed in this sequence?

(ii) Outline how stage I may be carried out to give this intermediate compound.

....

....

....

(iii) What reagent would be used for stage II?

.... [4]

(d) Compounds **D** and **F** are isomers.

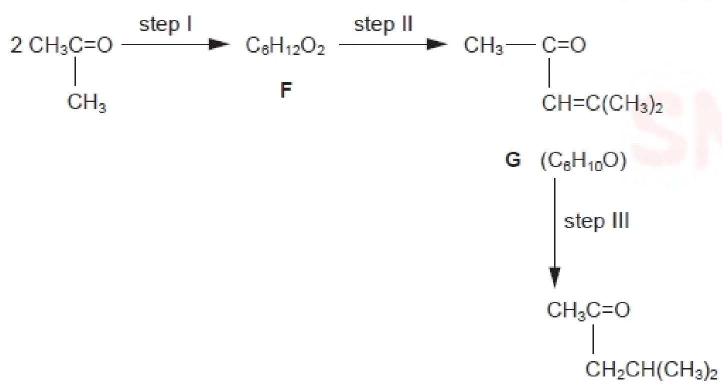
What type of isomerism do they show?

.... [1]

[Total: 12]

Topic **Chem 21 Q# 445/** ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Propanone, CH_3COCH_3, an important industrial solvent, can be converted into another industrially important solvent, MIBK, by the following sequence.



MIBK

(a) When **F** is formed in step I no other compound is produced.
Suggest a structural formula for **F**, which contains one –OH group.

[1]

(b) Compound **G** has two functional groups.

Name **one** functional group present in **G** and show how you would identify it. Put your answers in the table.

functional group in G	reagent used in test	what would be seen

[3]

(c) **G** is formed from **F** in step II.
Use your answers to **(a)** and **(b)** to suggest

(i) what type of reaction occurs in step II,

....

(ii) a reagent for step II.

.... [2]

(d) The production of MIBK from **G** in step III involves the hydrogenation of the >C=C< group and is carried out catalytically. A mixture of compounds is formed because the >C=O group is also reduced.

What reagent(s) and solvent are normally used in a laboratory to reduce a >C=O group without reducing a >C=C< group present in the same molecule?

reagent(s) ....

solvent .... [2]

G has a number of structural isomers.

(e) Draw the displayed formulae of a pair of structural isomers of **G** which contain the CH_3CO– group and which exhibit *cis-trans* isomerism.

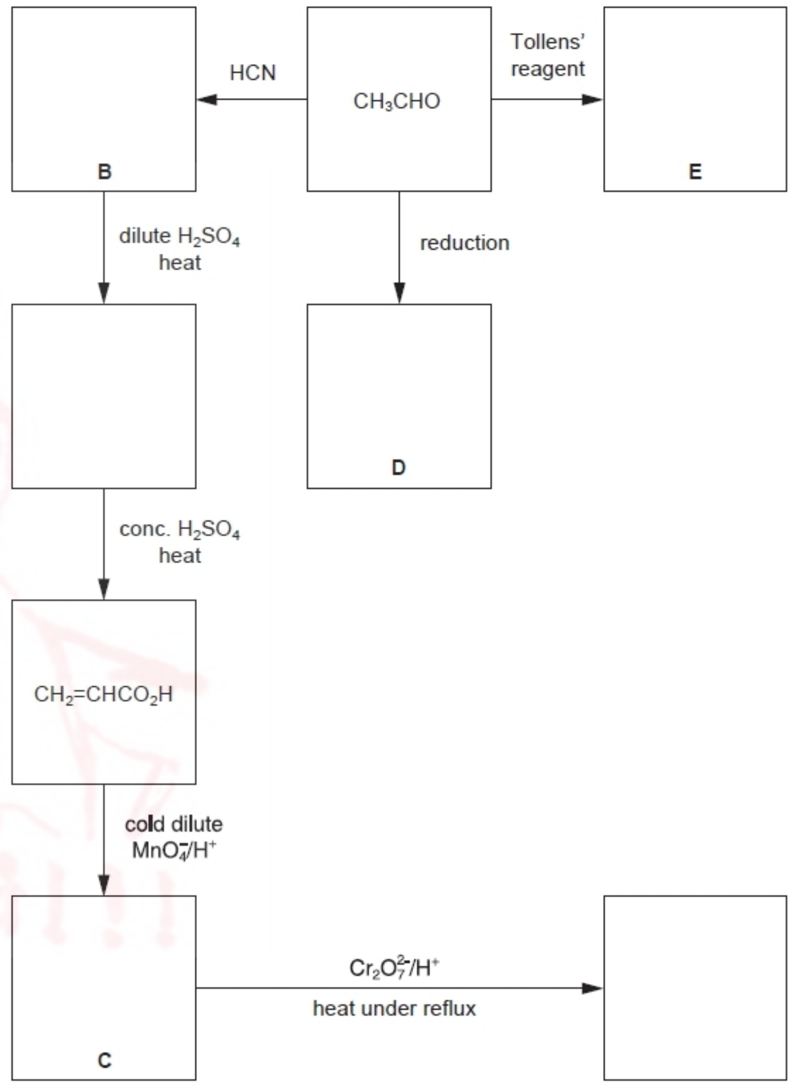
Label each structure *cis* or *trans* and give your reasoning.

[3]

[Total: 11]

4 **(a)** Complete the following reaction scheme which starts with ethanal.

In **each empty** box, write the **structural formula** of the organic compound that would be formed.



[6]

(b) Write the structural formula for the organic compound formed when, under suitable conditions,

(i) compound **C** reacts with compound **D**,

(ii) compound **C** reacts with compound **E**.

[2]

(c) Compound **B** is chiral. Draw displayed formulae of the two optical isomers of compound **B**, indicating with an asterisk (*) the chiral carbon atom.

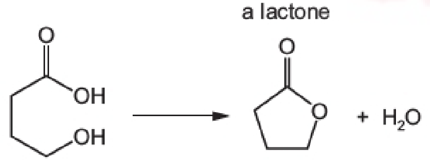
[3]

[Total: 11]

Topic Chem 22 Q# 447/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Lactones are cyclic esters. Under suitable conditions, lactones form from molecules that have both an alcohol and a carboxylic acid functional group.
Equation **1** shows an example of the formation of a lactone.

equation **1**



(c) Unknown lactone **Q** is analysed using mass spectrometry.
Table 5.2 shows information from the mass spectrum.

Table 5.2

peak	*m/e*	abundance
M+	72	95.5
M+1	73	3.15

Use these data to deduce the structure of **Q**.
Show your working.

Q

....

....

[2]

[Total: 9]

Topic **Chem 22 Q# 448/** ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 Lactones are cyclic esters. Under suitable conditions, lactones form from molecules that have both an alcohol and a carboxylic acid functional group.
Equation **1** shows an example of the formation of a lactone.

equation **1**

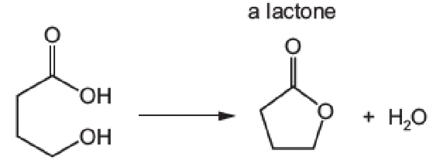


Fig. 5.1 shows the synthesis of lactone **P** from compound **M**.

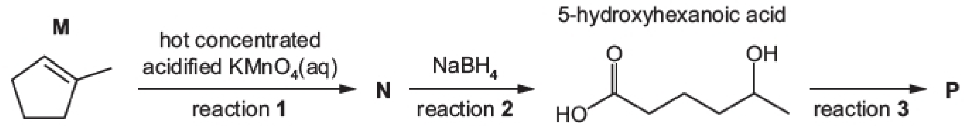


Fig. 5.1

(a) (i) **M** reacts with hot concentrated acidified $KMnO_4(aq)$ to form **N**, $C_6H_{10}O_3$, in reaction **1**.

Draw the structure of **N**.

[1]

(ii) **N** is reduced by $NaBH_4$ to form 5-hydroxyhexanoic acid in reaction **2**.

Construct an equation for reaction **2** using molecular formulae.
In the equation, use [H] to represent one atom of hydrogen from the reducing agent.

.... [1]

(iii) Reaction **2** is a nucleophilic addition.

Suggest why reaction **2** creates a mixture of two organic compounds.

....

.... [2]

(iv) Draw lactone **P**, the product of reaction **3**.

[1]

(b) A student monitors the progress of reaction **2** using infrared spectroscopy.

Use Table 5.1 to suggest why it is difficult to distinguish between **N** and 5-hydroxyhexanoic acid using infrared spectroscopy.

....

.... [2]

Table 5.1

bond	functional group containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

Topic **Chem 22 Q# 449/** ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(d) Fig. 5.1 shows the mass spectrum of ketone **Z**, $C_6H_{10}O$.

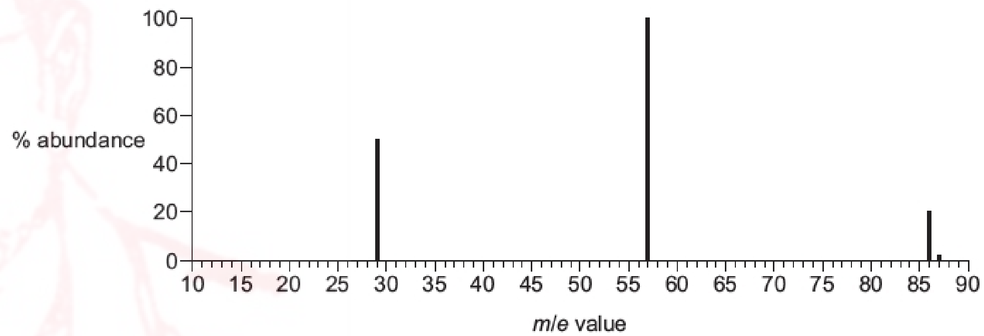


Fig. 5.1

Use the information in Fig. 5.1 to suggest the formulae of the fragments with *m/e* peaks at 29 and 57. Deduce the identity of **Z**.

m/e = 29 ....

m/e = 57 ....

identity of **Z** .... [3]

[Total: 14]

(b) **K** is used to make the addition polymer Perspex®. A synthesis of Perspex® is shown in Fig. 4.2.

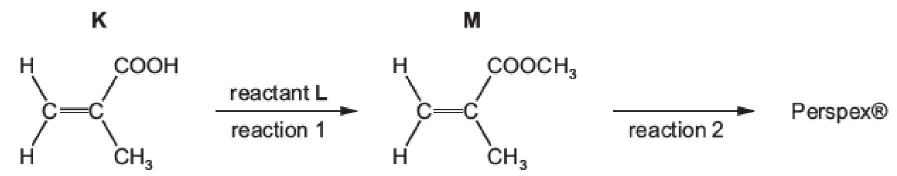


Fig. 4.2

(ii) Draw **one** repeat unit of the addition polymer Perspex®.

[2]

(iii) Use information from Table 4.2 to suggest how the infrared spectra of **M** and Perspex® would differ. Explain your answer.

....

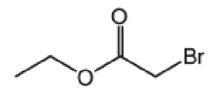
.... [1]

Table 4.2

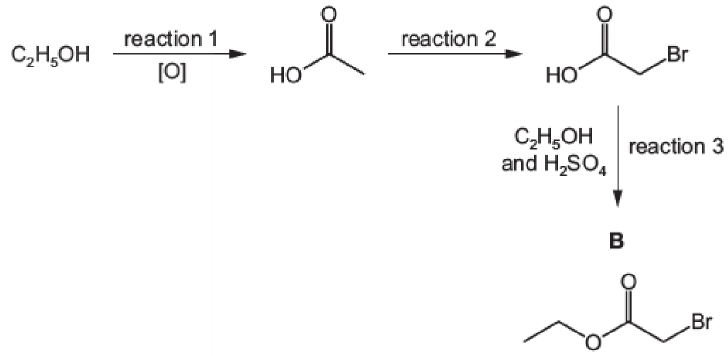
bond	functional group containing the bond	characteristic infrared absorption range (in wavenumbers) / cm^{-1}
C–O	hydroxy, ester	1040–1300
C=C	aromatic compound, alkene	1500–1680
C=O	amide carbonyl, carboxyl ester	1640–1690 1670–1740 1710–1750
C≡N	nitrile	2200–2250
C–H	alkane	2850–3100
N–H	amine, amide	3300–3500
O–H	carboxyl hydroxy	2500–3000 3200–3650

4 Compound **B** is a liquid with a fruity smell.

B



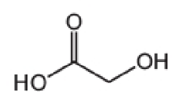
The reaction scheme shows how **B** can be made from ethanol, C_2H_5OH.



(a) **(i)** Reaction 1 is an oxidation reaction.

(b) Reaction 2 needs to take place in the absence of water to prevent formation of compound **C**.

C



If **C** is present in the reaction mixture of reaction 3, a different compound, compound **D**, will also form. Compound **D** has two identical functional groups.

The infrared spectrum of **D** shows strong absorptions at 1100 cm^{-1} and 1720 cm^{-1}, but no absorption due to O–H bonds.

Use the *Data Booklet* to identify the functional group present in **D**.

Explain your answer as fully as you can.

....

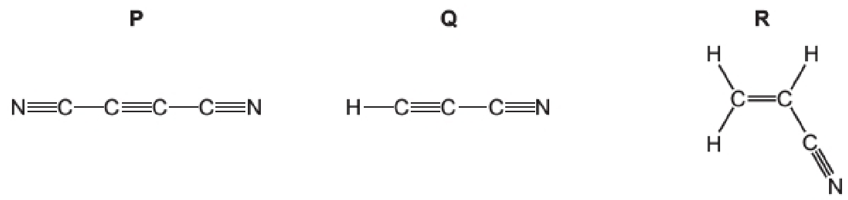
....

....

.... [3]

Topic **Chem 22 Q# 452/** ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.



(c) **P** and **Q** can be detected in the atmosphere by infrared spectroscopy.

Identify **two** absorptions, and the bonds that correspond to these absorptions, that will appear in the infrared spectra of both **P** and **Q**.

1 ....

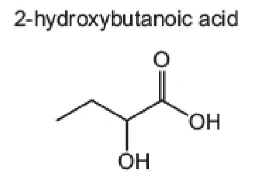
....

2 ....

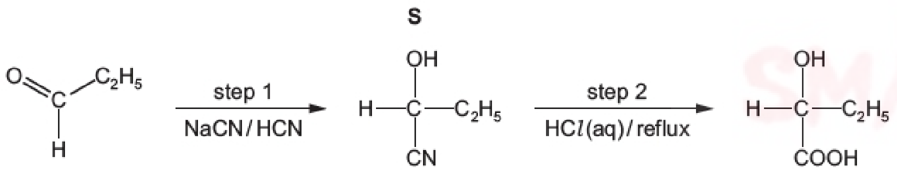
.... [2]

Topic **Chem 22 Q# 453/** ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

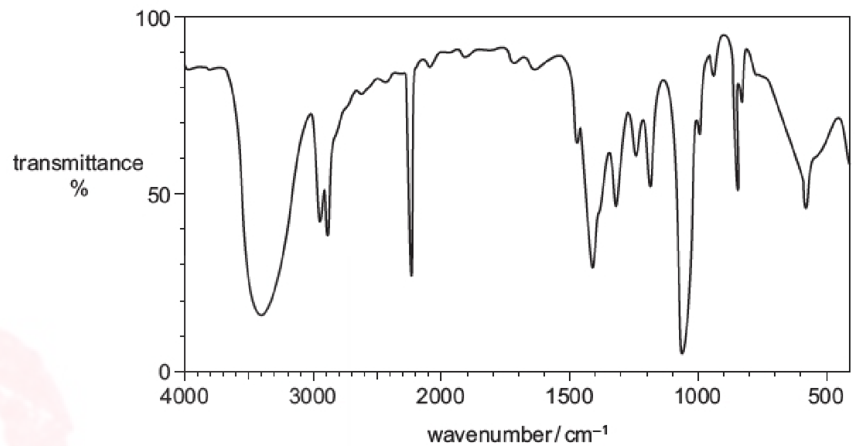
(c) Two students try to prepare 2-hydroxybutanoic acid in the laboratory.



A third student prepares 2-hydroxybutanoic acid using propanal as the starting material. In step 1 the student reacts propanal with a mixture of NaCN and HCN.



(v) The infrared spectrum of an organic compound is shown. The organic compound is either **S** or 2-hydroxybutanoic acid.



Deduce the identity of the compound. Give **two** reasons for your answer.

In your answer, identify any relevant absorptions **above 1500 cm^{-1}** in the spectrum and the bonds that correspond to these absorptions.

....

....

....

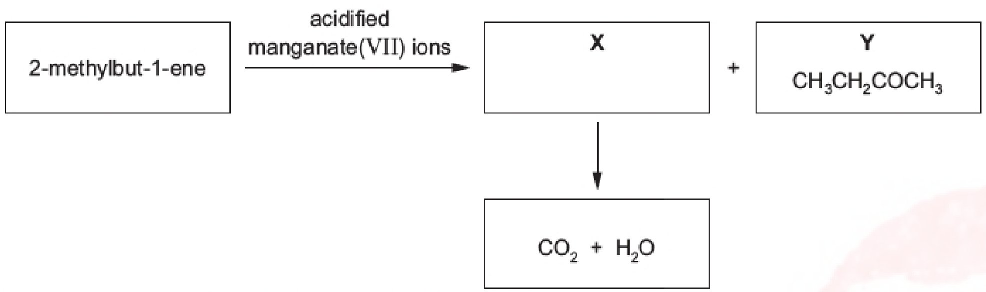
....

.... [2]

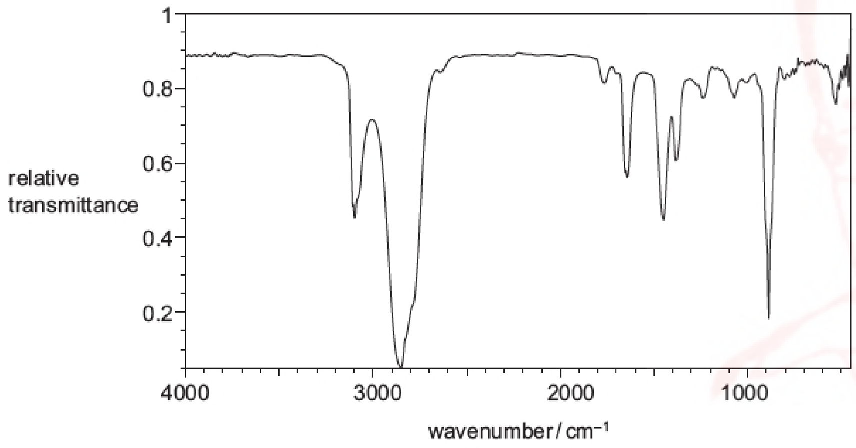
[Total: 17]

6 2-methylbut-1-ene reacts with acidified manganate(VII) ions, under specific conditions, to produce two organic compounds **X** and **Y**.

X immediately reacts with the acidified manganate(VII) ions to form carbon dioxide and water. **Y** has the structural formula $CH_3CH_2COCH_3$.



(e) The infra-red spectrum of 2-methylbut-1-ene is shown.



Predict two main differences that would be seen between the spectra of **Y**, $CH_3CH_2COCH_3$, and of 2-methylbut-1-ene. Give reasons for your predictions.

Your answer should refer only to the region of each spectrum **above 1500 cm^{-1}**.

....

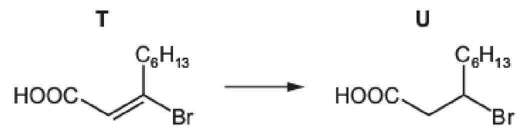
....

....

....

.... [2]

(d) A reaction of another unsaturated carboxylic acid, **T**, is shown.



(iii) The C–Br bond has an absorption between 500 cm^{-1} and 600 cm^{-1} in an infrared spectrum.

The infrared spectra for both **T** and **U** have absorptions between 2850 cm^{-1} and 2950 cm^{-1}. These correspond to C–H bonds.

Identify:
- two other absorptions that would be seen in the infrared spectra of both **T** and **U**
- one other absorption that would **only** be seen in the infrared spectrum of **T**.

For each absorption, give the range of the absorption and the bonds that correspond to these absorptions.

absorption 1 present in both spectra ....

....

....

absorption 2 present in both spectra ....

....

....

absorption **only** present in spectrum of **T** ....

....

....

[3]

[Total: 24]

Topic **Chem 22 Q# 456/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

Z, $C_5H_{10}O$, has a branched carbon chain. It shows geometrical isomerism.

(v) Complete the table with the bond responsible for each of the principal absorptions seen in the infra-red spectrum of **Z**.

principal absorptions in infra-red spectrum	bond responsible
3200–3600 cm^{-1}	
1630 cm^{-1}	
1050 cm^{-1}	

[1]

(vi) Draw the skeletal formula of **Z**.

[3]

Topic **Chem 22 Q# 457/** ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Crude oil is a natural source of hydrocarbons that are used as fuels.

(iv) Identify an analytical technique that can be used to monitor the levels of CO in the atmosphere.

Outline how this analytical technique may be used to monitor the levels of CO.

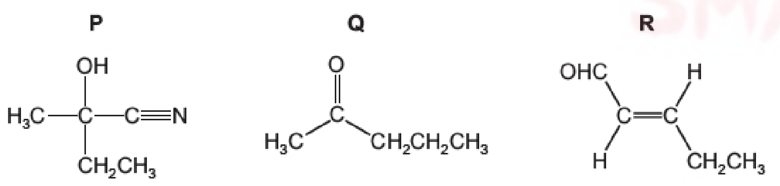
....

....

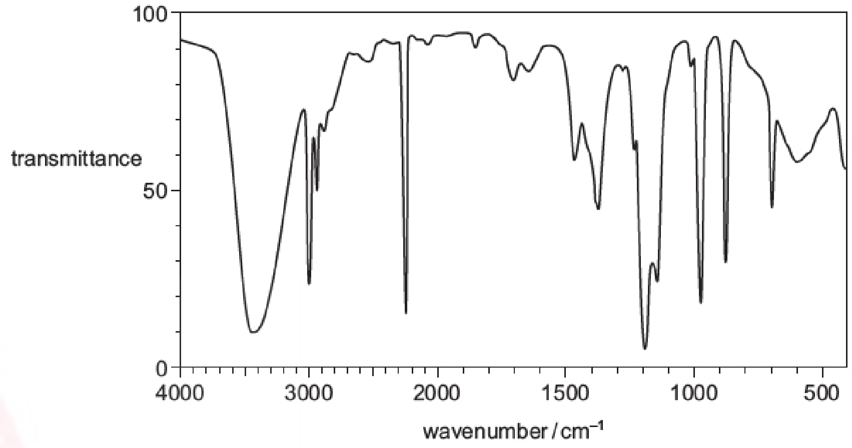
.... [2]

Topic **Chem 22 Q# 458/** ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 **P**, **Q** and **R** all contain five carbon atoms.



(d) The infra-red spectrum shown corresponds to one of **P**, **Q** or **R**.



Deduce which of the compounds, **P**, **Q** or **R**, produces this spectrum. Explain your reasoning.

In your answer, identify any relevant absorptions in the infra-red spectrum and the bonds that correspond to these absorptions in the region **above** 1500 cm^{-1}.

compound ....

explanation ....

....

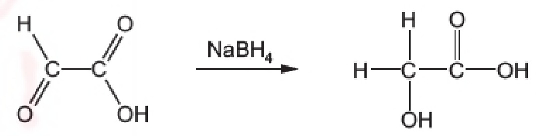
....

[3]

[Total: 9]

Topic **Chem 22 Q# 459/** ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) Glycolic acid can also be made by reacting glyoxylic acid with $NaBH_4$.



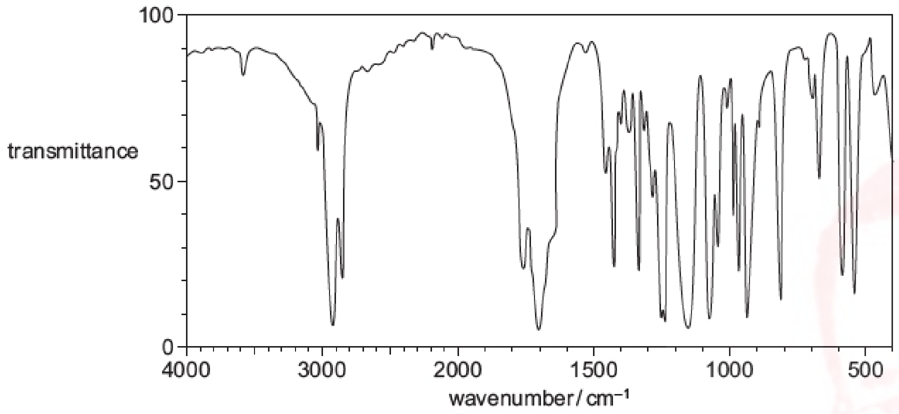
glyoxylic acid   glycolic acid

(d) When glycolic acid is heated in the presence of a sulfuric acid catalyst, a new compound, **Y**, $C_4H_4O_4$, is formed.
The equation for the reaction is given.

$$2CH_2(OH)CO_2H \rightarrow C_4H_4O_4 + 2H_2O$$

glycolic acid — **Y**

(i) The infra-red spectrum of **Y** is shown.



State how this spectrum differs from an infra-red spectrum of glycolic acid. Explain your answer with particular reference to the peaks within the range 1500 – 4000 cm^{-1}.

....

....

.... [2]

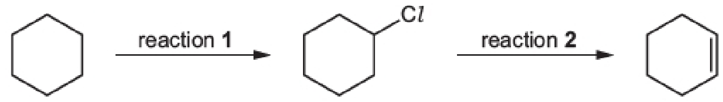
(ii) Suggest a structure for **Y**.

[2]

[Total: 17]

4 Cyclohexane is a colourless liquid used in industry to produce synthetic fibres.

A reaction scheme involving cyclohexane is shown.



(c) The product of reaction **2** is cyclohexene.

Cyclohexene can be converted into adipic acid (hexanedioic acid), $HO_2C(CH_2)_4CO_2H$.

(ii) Suggest **three** main differences between the infra-red spectra of cyclohexene and adipic acid.

In each case, identify the bond responsible and its characteristic absorption range (in wavenumbers).

1 ....

....

....

2 ....

....

....

3 ....

....

....

[3]

[Total: 11]

(d) $CH_3(CH_2)_3CO_2H$ is a colourless liquid with an unpleasant odour.

It reacts with methanol in the presence of an acid catalyst to produce an organic product **V**, which has a pleasant fruity smell.

(ii) A student analysed $CH_3(CH_2)_3CO_2H$, methanol and **V** using infra-red spectroscopy. The spectra were returned to the student without labels.

Identify which of the infra-red spectra, X, Y or Z, corresponds to **V**.

compound	$CH_3(CH_2)_3CO_2H$	methanol	**V**
spectrum			

Explain your answer with reference to relevant features of the **three** spectra in the region above 1500 cm^{-1}.

....

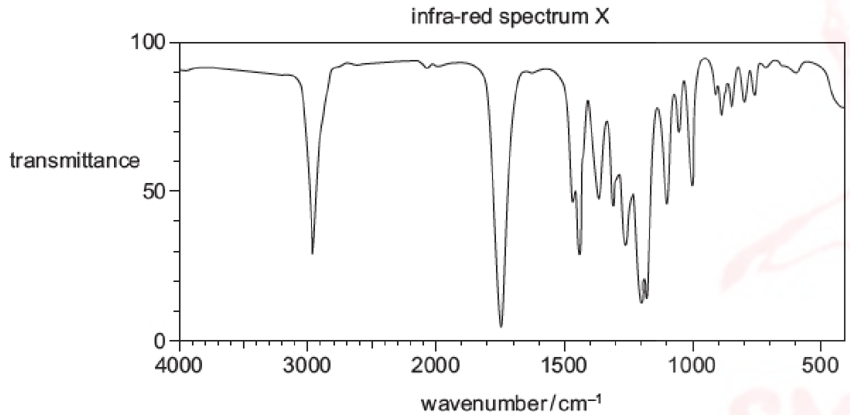
....

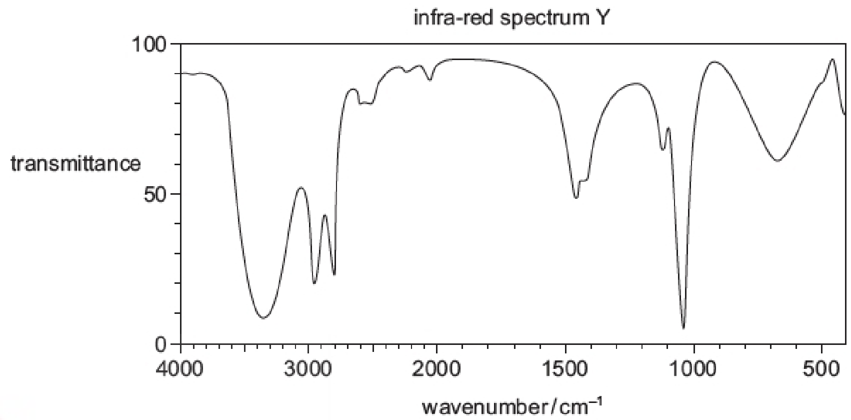
....

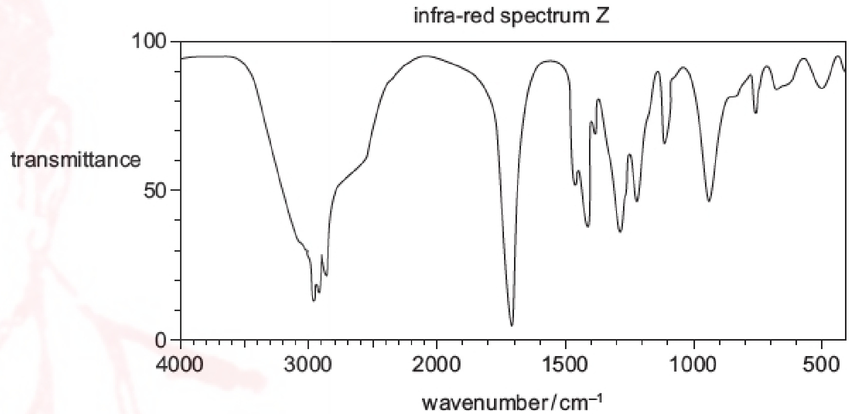
....

....

.... [4]



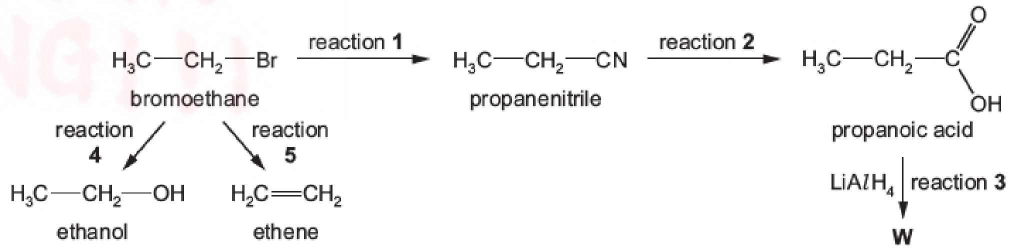




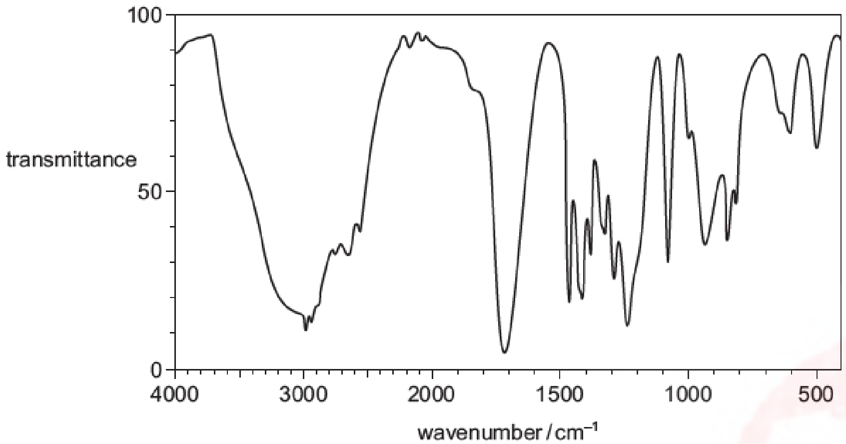
[Total: 21]

Topic **Chem 22 Q# 462/** ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 A reaction sequence is shown.



The infra-red spectrum of the propanoic acid produced by reaction **2** is shown.



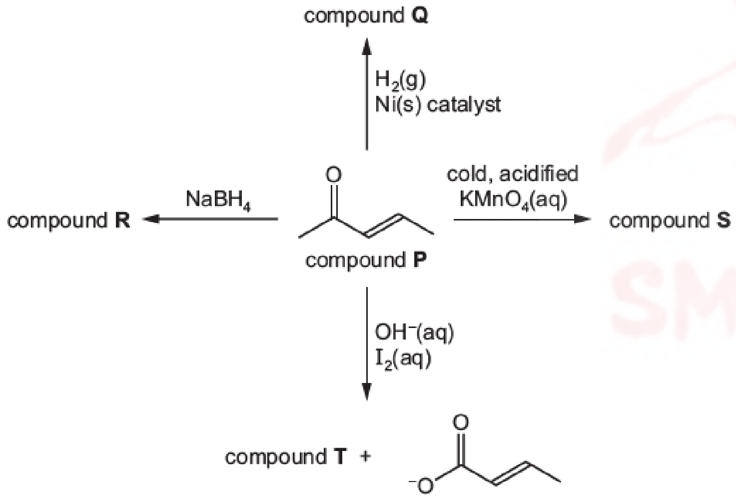
(ii) Describe and explain the main difference between the infra-red spectrum of **W** and that of propanoic acid.

....

.... [2]

Topic **Chem 22 Q# 463/** ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5/www.SmashingScience.org

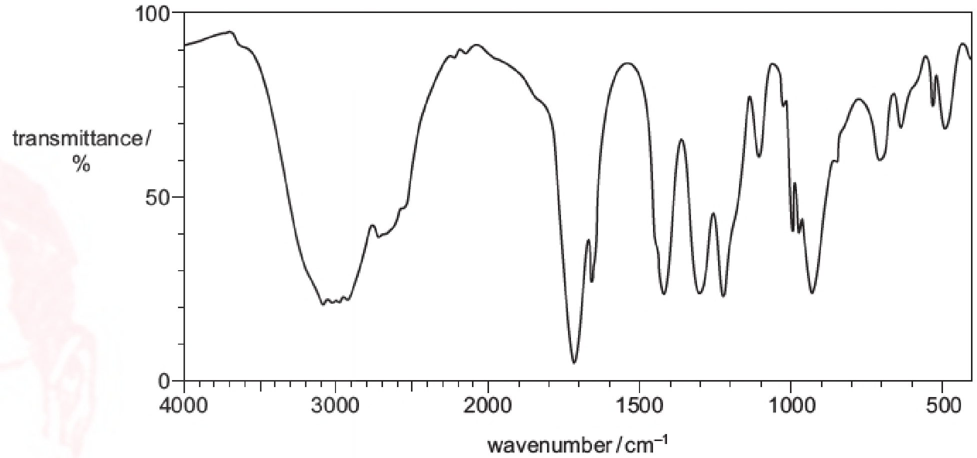
5 Some reactions of compound **P**, C_5H_8O, are shown.



(b) Compound **U** contains a chiral centre and has the same molecular formula as compound **P**, C_5H_8O.

- Compound **U** readily decolourises a sample of bromine water.
- Compound **U** does not show cis-trans isomerism.
- When compound **U** is heated under reflux in the presence of excess acidified potassium dichromate(VI), the organic product gives the infra-red spectrum shown.

infra-red spectrum of **product**



Use the information given to suggest a structure for compound **U**.
Explain your answer.

[4]

[Total: 10]

Paper 2 Mark Scheme

Q# 1/ Chem 1 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	they have the same electron arrangement / electronic configuration	1
1(b)(ii)	$1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$	1
1(b)(iii)	**M1** big increase in IE between first and second **M2** second (and third) electron(s) is removed from inner shell OR second (and third) electron(s) is removed from a shell closer to the nucleus OR second (and third) electron(s) has a stronger nuclear attraction ora	2

Q# 2/ Chem 1 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)	*Identify and draw the shape of highest energy orbital of Ca* 4s AND 	1
1(d)(i)	number of protons: 12 number of neutrons: 13	1
1(e)(iii)	**M1** (magnesium isotopes have) identical chemical properties **AND** same electron(ic) arrangement / configuration **M2** different physical properties **AND** different number of neutrons	2

Q# 3/ Chem 1 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)	$O(g) \rightarrow O^+(g) + e^-$	1
1(b)(i)	increase across period **AND** increased nuclear attraction for (valence / outer) electrons [1] increase in (positive) nuclear charge / number of protons (in the nucleus) [1] similar shielding (of outer electrons) [1]	3
1(b)(ii)	spin-pair repulsion (of electrons) in (2)p orbital [1] outweighs increased nuclear charge [1]	2
1(c)	$1s^2 2s^2 2p^6 3s^2 3p^1$ [1] greatest jump between 3rd and 4th ionisations [1] indicates three electrons in outer shell [1]	3

2(a)(i)	species that donates electrons	1
2(a)(ii)	$Na_2O + H_2O \rightarrow 2NaOH$	1
2(b)(i)	reacts with both acids and bases / shows both acidic and basic behaviour	1
2(b)(ii)	$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$	1
2(b)(iii)	two lines shown on diagram, *e.g.* E_A and $E_{A,cat}$ [1] greater proportion of molecules with $E \geq E_A$ [1] frequency of effective collisions increases [1]	3

Q# 4/ Chem 1 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	$Cl(g) - e^- \rightarrow Cl^+(g)$	1
2(b)(ii)	**M1:** increasing proton number but similar shielding **M2:** greater attraction of nucleus (for outer / valence electrons)	2
2(c)(i)	**M1:** (thermal stability) decreases (down group) **M2:** (H—X) bond energy / strength decreases	2

Q# 5/ Chem 1 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(iii)	Li^+ is $1s^2$ H^- is $1s^2$	1

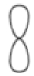
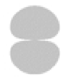
Q# 6/ Chem 1 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)	$Mg(g) \rightarrow Mg^+(g) + e^{(-)}$	1
1(b)	**M1:** distance between nucleus and outer e^- increases OR **outer electron** removed from higher energy shell	3
	M2: increased **shielding**	
	M3: decreased **nuclear** attraction	
1(c)	**M1: greater nuclear attraction**	2
	M2: (2nd / 2s) electron being removed from smaller (ion)	

Q# 7/ Chem 1 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	(different) number of neutrons.	1

Q# 8/ Chem 1 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)	$Ar^+(g) \rightarrow Ar^{2+}(g) + e^{(-)}$ OR $Ar^+(g) - e^{(-)} \rightarrow Ar^{2+}(g)$	1
3(b)	at $x = 8$, within range 13000–20000	1
	at $x = 9$, within range 35000–45000	1
3(c)	 OR 	1
3(d)(ii)	**Method 1** **M1** = $3.263 \times 10^{-3} \times 2$ **Method 2** **M1** = $\frac{0.23}{71.0} \times 2$ OR 6.53×10^{-3}	1
	M2 = $6.02 \times 10^{23} \times$ **M1** = 3.93×10^{21} atoms of *Cl* **M2** = $6.02 \times 10^{23} \times$ **M1** = 3.90×10^{21} atoms of *Cl*	1
3(d)(iii)	**M1** size / volume of **molecule** / **particle** becomes significant / non-negligible OR **IMFs** become significant / non-negligible	1
	M2 IMFs becomes significant / non-negligible / collisions are not elastic	1

Question	Answer	Marks
4(a)	3-chloroprop-1-ene	1
4(b)	a = 109(.5)°	1
	b = 120°	1
4(c)(i)	$C_3H_7ClO_2$	1
4(c)(ii)	oxidation	1

Q# 9/ Chem 1 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	$1s^2 2s^2 2p^6 3s^2 3p^6$	1

Q# 10/ Chem 1 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	**M1** ① mass of a molecule OR ② (weighted) average / mean mass of the molecules OR ③ mass of one mole of molecules **M2** ① / ② compared to $\frac{1}{12}$ (the mass) of an atom of carbon-12 OR on a scale in which a carbon-12 atom / isotope has a mass of (exactly) 12 (units) ③ relative / compared to $\frac{1}{12}$ (the mass) of 1 mole of carbon-12 OR on a scale in which 1 mole of carbon-12 (atoms / isotope) has a mass of (exactly) 12 g	2

2(a)(iv)	$CaCO_3(s) + 2HF(aq) \rightarrow CaF_2(aq) + CO_2(g) + H_2O(l)$ **M1** species and balancing **M2** state symbols	2

Q# 11/ Chem 1 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	$1s^2 2s^2 2p^6 3s^2 3p^6 3d^6 (4s^0)$	1

Q# 12/ Chem 1 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	increasing attraction between nucleus and (outer) electrons	1
	increasing nuclear charge with similar shielding / (electrons in) same (outer) shell	1
3(a)(ii)	(ions of Na to Si have) lost outer shell / outer electrons OR atoms have one more shell than (corresponding) ions OR effective nuclear charge is greater for the ion	1

3(a)(iii)	(P to C*l* form ions by) gaining electrons (to the same outer shell / p sub-shell)	1
	Increased repulsion between electrons in same / outer shell / p sub-shell	1
3(b)(i)	(outer) electron removed from 3p subshell / orbital	1
	(3p) higher in energy / more shielded / further from the nucleus	1
3(b)(ii)	(outer) electron for S is paired in a p orbital / S has a full p orbital	1
	causing (spin / electron) pair repulsion (which reduces attraction)	1

Q# 13/ Chem 1 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(ii)	$1s^2 2s^2 2p^6 3s^2 3p^6$	1

Q# 14/ Chem 1 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	□ energy required / energy change □ when one electron is removed □ from each atom in one mole of □ gaseous atoms	max 3
1(a)(ii)	*for element B* (outer electron is removed) from a higher energy level more shielding less attraction to nucleus	3
1(b)	line on graph decreases P—T increasing nuclear charge AND electrons in same shell greater attraction between nucleus (and electrons)	3

Q# 15/ Chem 1 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	due to increasing nuclear attraction (for electrons)	1
	due to increasing nuclear charge / atomic / proton number AND similar shielding / same (outer/number of) shell / energy level	1
2(a)(ii)	Cross shown on first vertical line from the y-axis (Group 0 / Ne) is clearly higher than all shown	1
	Cross shown on second vertical line from the y-axis (Group 1 / Na) lower than all shown	1
2(a)(iii)	A*l* (the outer / valence) electron (which is lost) is in (3)p sub-shell (Mg is in (3)s subshell) OR A*l* (the outer / valence) electron (which is lost) is in higher energy sub-shell ora	1
	(electron to be removed) is more shielded / experiences greater screening effect ora	1
	S has a pair of electrons in (a) (3)p orbital / (a 3)p orbital is full ora	1
	electron pair repulsion	1

Q# 16/ Chem 1 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	(from Na to C*l*) nuclear charge increases	1
	electrons are in the same shell / have same shielding	1
	greater / stronger attraction (of electrons to nucleus)	1
1(a)(iii)	Mg^{2+} **AND** S^{2-}	1
	ion of Mg / Mg^{2+} has one fewer shell (than ion of S / S^{2-})	1

Q# 17/ Chem 1 ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	(Atoms/ ions become larger as) the number of (electron) shells increases (down the group) Increased distance of (outer) electrons (from the nucleus) OR Increased shielding results in weaker (nuclear) attraction / pull	1 1	2
3(a)(ii)	top line / dotted line is atomic radii / bottom line / line with crosses is ionic radii (as atoms bigger than ions) Atom has one more shell (than corresponding ion) (ora) OR Atom loses two electrons / outer (shell) electrons / valency electrons (ora) OR Atom loses electrons and so (nuclear) attraction is stronger OR Nuclear charge in ion is greater than the electron(ic) charge (ora) OR Effective nuclear charge in ion is greater (ora)	1 1	2

Q# 18/ Chem 1 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a)

name of element	nucleon no.	atomic no.	no. of protons	no. of neutrons	no. of electrons	overall charge
lithium	6	3	3	3	2	+1
oxygen	17	8	8	9	10	–2
iron	54	26	26	28	24	+2
chlorine	35	17	17	18	17	0

[1] [1] [1] [1] — [4]

(b)	line straight on labelled 'neutrons' line (curving) up labelled 'protons' proton line clearly shows less (overall) deflection than electron curve	[1] [1] [1]	[3]
(c) (i)	Group 16 / 6 / VI AND Big (owtte) increase / big difference / big gap / big jump / jump in increase / jump in difference after 6th IE	[1]	[1]
(ii)	increases (across period) due to increasing attraction (of nucleus for electrons) due to increasing nuclear charge / atomic / proton number AND constant/similar shielding / same (outer / number of) shell / energy level	[1] [1]	[2]
(iii)	electron (pair) repulsion (Y has a) pair of electrons in a (3)p orbital / a (3)p orbital is full ORA	[1] [1]	[2]
(iv)	$(1s^2)2s^2 2p^6 3s^2 3p^5$	[1]	[1]

Q# 19/ Chem 1 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1 (a) (i)	greater attractive force OR greater force between nucleus and (outer) electrons proton number / atomic number / nuclear charge increases across period AND electrons occupy same shell / shielding roughly constant	[1] [1]	[2]
(ii)	sulfur's electron removed from full (3p) orbital OR sulfur has two electrons in the same orbital electron–electron repulsion (reduces energy required)	[1] [1]	[2]

Q# 20/ Chem 1 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a)

sub-atomic particle	relative mass	relative charge		
neutron	1	0	[1]	
electron	1/1836	–1	[1]	
proton	1	+1	[1]	[3]

Q# 21/ Chem 1 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) (i)	increasing **distance** of (outer) electron(s) from nucleus OR increasing distance of outer/valence shell from nucleus	1	
	increased **shielding**/screening (from inner shells)	1	
	reduces **attraction**	1	[3]
(ii)	(3rd electron for each in) inner/lower energy level/ **shell**/ closer to nucleus (than first two)/less shielding	1	
	(large) increase in nuclear attraction	1	[2]
(b) (i)	$(1s^2 2s^2 2p^6) 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^2$	1	[1]

Q# 22/ Chem 1 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a)	The amount of energy required/energy change/enthalpy change when one electron is removed from each atom/(cat)ion in one mol of gaseous atoms/(cat)ions **OR** energy change when 1 mole of electrons is removed from one mole of gaseous atoms/ions $X(g) \rightarrow X^+(g) + e^-$ gains 2 marks	1 1 1	3
(b) (i)	Group V/5/15	1	
	Big difference between fifth and sixth ionisation energies	1	2
(ii)	$1s^2 2s^2 2p^3$ ecf from **(b)(i)** if period 2	1	1

Q# 23/ Chem 1 ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) $S(g) \rightarrow S^+(g) + e^-$
correct equation (1)
correct state symbols (1) [2]

(b) **from Na to Ar,**
electrons are added to the same shell/have same shielding (1)
electrons are subject to increasing nuclear charge/proton number (1)
electrons are closer to the nucleus **or** atom gets smaller (1) [3]

(c) (i) **Mg and A*l***
in Mg outermost electron is in 3s **and**
in A*l* outermost electron is in 3p (1)

3p electron is at higher energy **or**
is further away from the nucleus **or**
is more shielded from the nucleus (1)

(ii) **S and P**
for S one 3p orbital has paired electrons **and**
for P 3p sub-shell is singly filled (1)

paired electrons repel (1) [4]

Q# 24/ Chem 1 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) same proton number/atomic number (1)
different mass number/nucleon number (1) [2]

(c)

isotopes	number of		
	protons	neutrons	electrons
^{226}Ra	88	138	88
^{238}U	92	146	92

allow **one mark** for each correct column (3 × 1)
if there are no correct columns,
allow **maximum one mark** for a correct row [3]

Q# 25/ Chem 1 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) A*l* $1s^2 2s^2 2p^6 3s^2 3p^1$ (1)

Ti $1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$ **or**

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^2$ penalise any error (1) [2]

Q# 26/ Chem 2 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	columns 1 & 3 identical	1
	(see table below) • √ √	1
1(a)(ii)	**M1** (weighted) average/mean mass of the isotopes/average mass of the atom(s) (of an element)	1
	M2 compared to (the mass of) the unified atomic mass unit	1
1(a)(iii)	$69.723 = 68.926x + 70.925(1-x)$ ∴ $x = 0.6013$ / $69.723 = \frac{68.926x + 70.925(100-x)}{100}$	1
	60.13%	1

isotope	No of p's	No of n's	No of e's
^{69}Ga	31	38	31
^{71}Ga	31	40	31

Q# 27/ Chem 2 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)	**M1** % / A_r for C H O **M2** each % / A_r for C H O divided by the smallest value for % / Ar to give simplest whole number ratio / empirical formula **M3** compare M_r from **M2** ratio with 280 to deduce the actual molecular formula C: 77.2 / 12 = 6.433, 9(.03); H: 11.4 / 1 = 11.4, 16; O: 11.4 / 16 = 0.7125, 1 $M_r(C_9H_{16}O)$ = 140 so molecular formula of V = $C_{18}H_{32}O_2$	3

4(b)(i)	**M1** (add) group 1 carbonate / group 1 bicarbonate / Na_2CO_3 / $NaHCO_3$ etc. **M2** effervescence / fizzing / bubbling	2

Q# 28/ Chem 2 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(e)(i)	1 / 12 (one twelfth) the mass of a carbon-12 / ^{12}C atom	1
1(e)(ii)	**M1** correct expression relating A_r to the mass / % abundance of the three isotopes $24.31 = x \times 0.7899 + 24.99 \times 0.1000 + 25.98 \times 0.1101$ **M2** correct answer to 4 sig figs atomic mass of **X** = 23.99	2

Q# 29/ Chem 2 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	species that donates electrons	1
2(c)(ii)	(+)3 / III	1

Q# 30/ Chem 2 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(d)(i)	**M1** moles of $NH_3 = 1.50 \times 10^6 \times 10^6 \div 17 = 8.82 \times 10^{10}$ **M2** mass of $CaCN_2 = \frac{\frac{1}{2} \times M1 \times 80.1}{10^6} = 3.53 \times 10^6$	2

Q# 31/ Chem 2 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(d)(i)	**M1** moles of $As_2S_3 = 0.198 / 246.1 / 8.05 \times 10^{-4}$ **M2** moles SO_2 (using moles of As_2S_3 as limiting factor) = $2.41(36) \times 10^{-3}$ moles ($6 / 2 \times 8.05 \times 10^{-4}$) Volume $SO_2 = 2.41(36) \times 10^{-3} \times 24 = 0.0579\ dm^3$ **M3** Moles O_2 used in reaction = $8.05 \times 10^{-4} \times 9 / 2 = 3.62 \times 10^{-3}$ Volume O_2 used in reaction = $3.62 \times 10^{-3} \times 24 = 0.0869\ dm^3$ **M4** Final total volume gas = (0.1 – 0.0869) + 0.0579 = [0.0131 + 0.0579] = <u>0.071</u>(0) dm^3 **M4 ONLY award 4th mark if the final answer rounds to <u>0.071</u>** Answer to minimum of 2 sig figs **MAX 3** for using ecf from M1 to M2 to M3 and M4 **Award all 4 marks if final answer rounds to 0.071**	4

Q# 32/ Chem 2 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	**option 1** **M1** the mass of a molecule OR the (weighted) average / (weighted) mean mass of the molecule(s)	1
	option 1 and **M2** relative / compared to 1 / 12 (the mass) of an atom of carbon–12	1
	OR on a scale in which a carbon–12 atom / isotope has a mass of (exactly) 12 (units) **option 2** **M1** mass of one mol of molecules	
	option 2 **M2** relative / compared to 1 / 12 (the mass) of 1 mol of C-12 OR which one mol C-12 (atom / isotope) has a mass of (exactly) 12 g	
1(a)(ii)	CO_2H	1
1(a)(iii)	$0.18/90 \times 2 \times 6.02 \times 10^{23} = 2.408 \times 10^{21}$ (atoms) OR **2.4(1) × 10^{21}** (atoms) **M1** no mole ethanedioic acid 0.18 / 90 = 0.0020	1
	M2 no mole ethanedioic acid × 2 0.0020 × 2 = 0.0040	1
	M3 no mole ethanedioic acid × 6.02×10^{23} 2.4×10^{21}	1

Q# 33/ Chem 2 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)	Mass of 0.0982mol $CuSO_4$ in 17.43g $CuSO_4.yH_2O$	**M1** *calculate M_r $CuSO_4$ using Ar from data booklet* 63.5 + 32.1 + 64.0 = 159.6 **M2** *use Mr to calculate mass of $CuSO_4$* (0.0982 × M1) =15.67272g	4
	number of water in 17.43g of $CuSO_4$ yH_2O	**M3** *calculate the mass amount of water in sample AND use this value to calculate the amount of water present* (17.43-15.67)/18 = 0.097778 mol	
	value of y	**M4** *use the ratio of M2: 0.0982 to find y* (mol H_2O ÷ mol $CuSO_4$) = 1	

Q# 34/ Chem 2 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	the relative abundance / % abundance of (each) the isotopes.	1

Q# 35/ Chem 2 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	**M1** *correct conversions of data to SI/consistent units* $p = 404\,000$; $V = 20 \times 10^{-6}$; $T = 298$	1
	M2 *calculation of n (= pV/RT) from M1 values* $n = \frac{404000 \times 20 \times 10^{-6}}{8.31 \times 298} = 3.263 \times 10^{-3}$ mol of Cl_2	1
	M3 *finding the mass of Cl_2* $= 3.263 \times 10^{-3} \times 71.0 = 0.23$ (g)	1
3(d)(ii)	**Method 1** $M1 = 3.263 \times 10^{-3} \times 2$ **Method 2** $M1 = \frac{0.23}{71.0} \times 2$ OR 6.53×10^{-3}	1
	Method 1: $M2 = 6.02 \times 10^{23} \times M1$ $= 3.93 \times 10^{21}$ atoms of Cl **Method 2:** $M2 = 6.02 \times 10^{23} \times M1$ $= 3.90 \times 10^{21}$ atoms of Cl	1
3(d)(iii)	**M1** size / volume of molecule / particle becomes significant / non-negligible OR IMFs become significant / non-negligible	1
	M2 IMFs becomes significant / non-negligible / collisions are not elastic	1

Q# 36/ Chem 2 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)	$Mg_2Si(s) + 4H_2O(l) \rightarrow 2Mg(OH)_2(aq) + SiH_4(g)$ **M1** correct balancing and formulae	1
	M2 state symbols	1

Q# 37/ Chem 2 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	$3Mg + N_2 \rightarrow Mg_3N_2$	1
1(b)(ii)	solid disappears	1

Q# 38/ Chem 2 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	$Ca + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2$	1

Q# 39/ Chem 2 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iii)	$Mg_2Si(s) + 4HCl(aq) \rightarrow SiH_4(g) + 2MgCl_2(aq)$ species AND balancing state symbols	2
2(d)(v)	$SiH_4 + 2O_2 \rightarrow SiO_2 + 2H_2O$	1

Q# 40/ Chem 2 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)	The mass of a molecule OR the (weighted) average / (weighted) mean mass of the molecules	1
	Relative / compared to $\frac{1}{12}$ (the mass) of an atom of carbon–12 OR on a scale in which a carbon–12 atom / isotope has a mass of (exactly) 12 (units)	1

Q# 41/ Chem 2 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(c)(iii)	**M1** % abundance of fourth isotope = 100 – (0.185 + 0.251 + 88.450) = 11.114	1
	M2 $\frac{(0.185\times135.907)+(0.251\times137.906)+(88.450\times139.905)+(11.114\times RIM)}{100}$ = 140.116 ∴ (140.116 × 100) – 12434.35 = 1577.246 = 11.114 × RIM	1
	M3 RIM = $\frac{1577.246}{11.114}$ = 141.915	1

Q# 42/ Chem 2 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) (i)	0.56(%)	[1]	[1]
(ii)	$\frac{(A\times0.56)+(86\times9.86)+(87\times7.00)+(88\times82.58)}{100}=87.71$ $A = 84$	[1] [1]	[2]
			[16]

Q# 43/ Chem 2 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(ii)	Al Cl $\frac{20.3}{27}$ $\frac{79.7}{35.5}$ $\frac{0.752}{0.752}$ $\frac{2.25}{0.752}$ 1 3 $AlCl_3$	[1] [1]	[2]
(iii)	$pV=\frac{m}{M_r}RT$ $M_r=\frac{mRT}{pV}$ $=\frac{1.36\times8.31\times473}{100\times10^3\times200\times10^{-6}}$ = 267 OR $pV=nRT$ $n=\frac{pV}{RT}$ $=\frac{100\times10^3\times200\times10^{-6}}{8.31\times473}$ $=5.09\times10^{-3}$ $M_r=\frac{1.36}{5.09\times10^{-3}}=267$	[1] [1] [1] [1]	[2]
(iv)	Al_2Cl_6	[1]	[1]
			[13]

Q# 44/ Chem 2 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) (i)	RAM = mean / average mass of the isotopes / an atom(s) relative to 1/12 the mass of an atom of ^{12}C / on a scale where an atom of ^{12}C is (exactly) 12 (units) isotope = atoms with the same number of protons / atomic number / proton number with different mass numbers / numbers of neutrons / nucleon number	[1] [1] [1]	[3]
(ii)	$\frac{(0.89\times74)+(9.37\times76)+(7.63\times77)+(23.77\times78)+(49.61\times80)+(8.73\times82)}{100}$ = 79.04 (2 d.p.) **AND** Se	[1] [1]	[2]
(c) (i)	Te Cl $\frac{47.4}{128}$ $\frac{52.6}{35.5}$ $\frac{0.370}{0.370}$ $\frac{1.48}{0.370}$ 1 4 so EF = $TeCl_4$ Empirical Formula Mass = 270 so MF = $TeCl_4$	[1] [1] [1]	[3]

Q# 45/ Chem 2 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(ii)	four isotopes owtte	1	[1]
(iii)	$\frac{(84\times0.56)+(86\times9.86)+(87\times7)+(88\times82.58)}{100}$ = 87.7 (must be 3 sig figs)	1 1	[2]
(ii)	Ba Cl O $\frac{45.1}{137}$ $\frac{23.4}{35.5}$ $\frac{31.5}{16}$ $\frac{0.329}{0.329}$ $\frac{0.659}{0.329}$ $\frac{1.969}{0.329}$ 1.00 2.00 5.98/6 emp form = $BaCl_2O_6$	1 1 1	[3]

Q# 46/ Chem 2 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) (i)	(Weighted) mean / average mass of an atom(s) (of an element) Relative to 1 / 12th of (the mass of an atom of) carbon-12 **OR** relative to carbon-12 which is (exactly) 12 (units) allow as an expression	1 1	2
(ii)	Z Cl $\frac{31.13}{A_r}$ $\frac{68.87}{35.5}$ = 1 : 2 So $\frac{68.87/35.5}{31.13/A_r}=2$ $A_r=\frac{2\times31.13\times35.5}{68.87}=32.0923=32.1$ to 3s.f. Allow alternative correct methods	1 1	2

Q# 47/ Chem 2 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) (i) to ensure all of the water of crystallisation had been driven off **or** to be at constant mass (1)

(ii) mass of $ZnSO_4$ = 76.34 – 74.25 = 2.09 g (1)

M_r $ZnSO_4$ = 65.4 + 32.1 + (4 × 16.0) = 161.5

allow use of Zn = 65 and/or S = 32 to give values between 161 and 161.5 (1)

$n(ZnSO_4) = \frac{2.09}{161.5} = 0.01294 = 1.29 \times 10^{-2}$

$ZnSO_4$ = 161 gives 1.30×10^{-2} (1)

(iii) mass of H_2O driven off = 77.97 – 76.34 = 1.63 g (1)

$n(H_2O) = \frac{1.63}{18} = 0.0905 = 9.1 \times 10^{-2}$ (1)

(iv) 1.29×10^{-2} mol $ZnSO_4$ are combined with 9.1×10^{-2} mol H_2O

1 mol $ZnSO_4$ is combined with $\frac{9.1 \times 10^{-2}}{1.29 \times 10^{-2}}$

= 7.054 ≡ 7 mol H_2O

answer must be expressed as a whole number
allow ecf on candidate's answers to **(b)(ii)** and **(b)(iii)** (1) [7]

(c) (i) $n(Zn) = n\ (CH_3CO_2)_2Zn.2H_2O$ (1)

$n(Zn) = \frac{0.015}{65.4} = 2.290 \times 10^{-4}$

$= 2.29 \times 10^{-4}$ (1)

mass of crystals = $2.29 \times 10^{-4} \times 219.4 = 0.0502655$ g
= 0.05 g = 50 mg (1)

(ii) concentration of $(CH_3CO_2)_2Zn.2H_2O = \frac{2.29 \times 10^{-4}}{0.005} = 0.0458$

$= 4.58 \times 10^{-2}$ mol dm^{-3} (1)

allow correct answers if Zn = 65 is used [4]

[Total: 13]

Q# 48/ Chem 2 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$ (1) [1]

Q# 49/ Chem 2 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) the actual number of atoms of each element present (1)

in one molecule of a compound (1) [2]

Q# 50/ Chem 2 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) $A_r = \frac{(24 \times 78.60) + (25 \times 10.11) + (26 \times 11.29)}{100}$ (1)

$= \frac{1886.4 + 252.75 + 293.54}{100} = \frac{2432.69}{100}$

which gives A_r = 24.33 (1)
penalise (–1) for misuse of significant figures [2]

(d) (i) Ra^{2+} (1)

(ii) less than (502 + 966)
allow answers in the range 1000–1400 kJ mol^{-1} (1)

ionisation energies decrease down the Group
or must be less than IE for $Ba \rightarrow Ba^{2+}$
or size of atom increases down Group/ electrons are further away from nucleus
or there is increased shielding down Group (1)

allow ecf on answer to (i) [3]

[Total: 10]

Q# 51/ Chem 2 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) (i) $n(Ti) = \frac{0.72}{47.9} = 0.015$ (1)

(ii) $n(Cl) = \frac{(2.85 - 0.72)}{35.5} = 0.06$ (1)

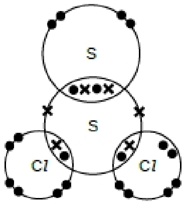
(iii) 0.015 : 0.06 = 1:4
empirical formula of **A** is $TiCl_4$
Allow ecf on answers to (i) and/or (ii). (1)

(iv) $Ti + 2Cl_2 \rightarrow TiCl_4$ (1)
Allow ecf on answers to (iii). [4]

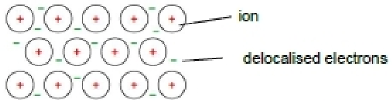
Q# 52/ Chem 3 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	NaCl AND $MgCl_2$	1

Q# 53/ Chem 3 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(v)	**M1** 90° < Cl—S—S ≤ 108°	1
	M2 sulfur has two lone pairs (of e⁻) (and two bonding pairs) AND repulsion from lone pairs (greater)	1
3(d)(vi)	 bonding electrons	1
	all other electrons correct	1

Q# 54/ Chem 3 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)	 **M1** diagram showing minimum of 4 particles (in total in two rows) (circles) • circles containing Mg^{n+} do not have to be labelled • (+) must be labelled as 'ion' OR empty circles / circles with Mg must be labelled + ion / positive ion / cation / Mg^{n+} AND • circles surrounded by electrons shown as e⁻ / – OR in an area around the circles labelled as 'electrons' OR little circles labelled electrons OR electrons drawn only on perimeter of structure	1
	M2 label / legend showing <u>delocalised</u> electrons	1

Q# 55/ Chem 3 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)	**M1** one sigma / σ bond and two pi / π bonds **M2** sp hybridisation (in each N atom) **M3** sigma / σ forms from direct / head-on / end-on overlap of orbitals AND pi / π forms sideways / lateral overlap of (p) orbitals	3

Q# 56/ Chem 3 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(c)(i)	(structure =) simple/molecular, because it has a low melting/boiling point [1] (bonding =) covalent, because it is hydrolysed [1]	2

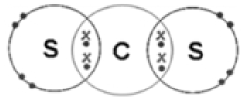
Q# 57/ Chem 3 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	**M1** simple molecular **M2** giant molecular **M3** weak IMFs (overcome) in P_4 AND strong (covalent) bonds (broken) in P	3

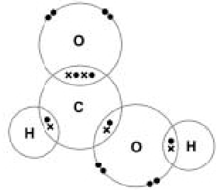
Q# 58/ Chem 3 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)(i)	Mixing / overlap / combination of one / an s and one / a p orbital	1
2(c)(ii)	*Sketch a diagram to show HOW two sp hybrid orbitals can form a SIGMA bond* **M1**  **M2** 	2

Q# 59/ Chem 3 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	 **M1** bonding pairs **M2** Correct number of remaining outer electrons	2
1(a)(iii)	180°	1
1(a)(iv)	**M1** CS_2 has more electrons **M2** So stronger induced dipole (forces) (between molecules)	2

Q# 60/ Chem 3 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(d)	 **M1** correct bonding electrons	1
	M2 correct number of non-bonding electrons around each oxygen	1

Q# 61/ Chem 3 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

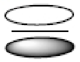
2(a)(i)	**M1** both make triple (covalent) bond / 3 shared pairs of electrons	1
	M2 one bond in CO is coordinate / dative covalent / formed by donating a pair of electrons from O (to C)	1
2(a)(ii)	(see table below)	2

	N_2	CO
number of electrons per molecule	14	14
type of van der Waals'	temporary / instantaneous dipole–induced dipole	permanent dipoles–(permanent) dipoles (and temporary / induced / instantaneous dipoles)

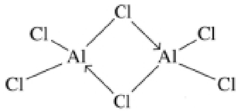
Q# 62/ Chem 3 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(a)	**M1:** x = 108–110° **M2:** y = 118–122°	2

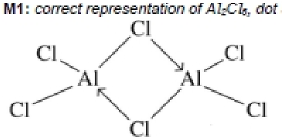
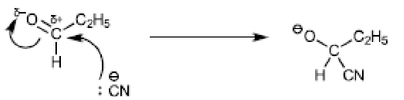
Q# 63/ Chem 3 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)(ii)	**M1:** overlap of two p orbitals side-on / above and below the plane **M2:**  pi (π) orbital	2

Q# 64/ Chem 3 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

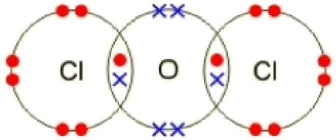
2(e)(i)	 **M1:** 2 × coordinate bonds in the right place **M2:** all other bonds	2

Q# 65/ Chem 3 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	**M1:** *correct representation of Al_2Cl_6, dot and cross or line diagram*  **M2:** TWO correct co-ordinate bonds identified	2
3(a)(ii)	120	1
3(a)(iii)	Li^+ is $1s^2$ H^- is $1s^2$	1
3(a)(iv)	(Lattice of) cations / positive ions surrounded by **delocalised** electrons'	1
3(b)	$Al(OH)_3$ / aluminium hydroxide	1
3(c)(i)	**M1:** potassium dichromate[(VI)] **M2:** acid(ified) AND (heat under) **reflux**	2
3(c)(ii)	(**M1:** *correct identity of R and statement re: reaction 3 ONLY ketone reduced*) R (is 2-hydroxybutanoic acid) AND as (only) C=O / ketone reduced (**M2:** *correct explanation re: strength of reducing agents*) $NaBH_4$ cannot reduce the COOH / **carboxylic acid** OR $LiAlH_4$ can reduce the COOH / **carboxylic acid**	2
3(c)(iii)	 **M1:** Presence of :CN (if bonding shown, must be unambiguous triple bond) **M2:** curly arrow from :CN lone pair to carbonyl carbon **M3:** correct dipole AND curly arrow from double bond to oxygen **M4:** correct intermediate drawn	4
3(c)(iv)	$C_2H_5CH(OH)CN + \mathbf{HCl} + \mathbf{2H_2O} \rightarrow C_2H_5CH(OH)COOH + \mathbf{NH_4Cl}$	1
3(c)(v)	Any two of three absorption references: • absorption 2200–2250 (cm^{-1}) shows presence of C≡N • lack of absorption at 1680–1730 (cm^{-1}) shows lack of C=O • lack of absorption at 2500–3000 (cm^{-1}) shows lack of RCO_2–H / O–H in RCO_2H	2

Q# 66/ Chem 3 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(iii)	Simple and covalent OR molecular and covalent	1

2(d)(i)		1

Q# 67/ Chem 3 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c) — 3 marks

	name of shape	bond angle / °
CO_2	Linear	180
NH_3	Pyramid(al)	107
H_2O	non-linear / V / bent	104.5

All 6 correct – 3 marks
4 or 5 correct – 2 marks
2 or 3 correct – 1 mark

Q# 68/ Chem 3 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	**M1** *attractions between atoms within a gallium trichloride molecule* covalent (bonds) **M2** *attractions between gallium trichloride molecules* temporary induced dipoles	2
1(b)(ii)	coordinate / dative (covalent)	1

Q# 69/ Chem 3 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	$CaO + H_2O \rightarrow Ca(OH)_2$	1

Q# 70/ Chem 3 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

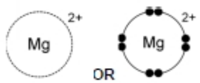
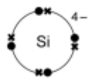
2(a) — 2 marks

Na_2O	MgO	Al_2O_3	SiO_2	SO_3
ionic	ionic	ionic	covalent	covalent
giant	giant	giant	giant / macro-molecular	simple / molecular

Award one mark for each correct row.

2(b)(i)	**M1** SiO_2 has a **network** of strong bonds / SiO_2 has **many** strong bonds **M2** SO_3 has weak intermolecular forces OR weak VdW forces (between molecules) **M3** high(er) / more energy required to break **bonds** than overcome **forces** (between molecules)	3
2(c)(i)	octahedral	1

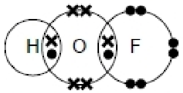
Q# 71/ Chem 3 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)	**M1** *magnesium* +2 charge on two Mg AND both with 0 or 8 electrons 	1
	M2 *silicide* -4 charge on one Si and 8 electrons 	1

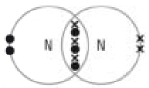
2(c)	**M1** simple (covalent) / molecular / molecules	1
	M2 weak IMF / (temporary) induced dipole (forces)	1
2(d)(i)	$C^{\delta-}$–$H^{\delta+}$	1
	$Si^{\delta+}$–$H^{\delta-}$	1
2(d)(ii)	**M1** tetrahedral (molecule)	1
	M2 (so individual bond) dipoles / partial charges cancel	1
2(e)	**M1** Si—H bond is (much) weaker than C—H bond	1
	M2 low activation energy *ORA*	1

2(f)(i)	**M1** sodium silicate / Na_2SiO_3	1
	M2 water / H_2O	1
2(f)(ii)	acid(ic)	1

Q# 72/ Chem 3 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(ii)	**M1** identification of the IMF between F_2 molecules and between HCl molecules HCl has (permanent) dipoles and / or induced dipoles F_2 has induced dipoles **M2** comparison of strength of IMF's in F_2 and HCl Intermolecular forces in HCl are stronger than F_2	2
2(a)(iii)	strong (electrostatic) forces of attraction between (oppositely charged) ions	1
2(c)(i)	 **M1** bonding pairs correct **M2** rest of molecule, incl. lone pairs.	2
2(c)(iv)	$\overset{\delta+}{H}$—$\overset{\delta-}{F}$ ıııııııı $\overset{\delta+}{H}$—$\overset{\delta-}{F}$ **M1** H-bond labelled / shown as distinct from H—F bond **M2** correct sequence of three correct dipoles M3 lone pair on F in line with H-bond	3

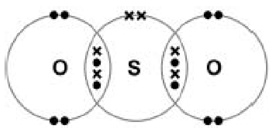
Q# 73/ Chem 3 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(ii)	 6 e^- between atoms AND two electrons on each N atom	1

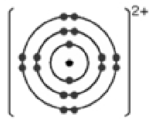
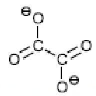
Q# 74/ Chem 3 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)	**M1** attraction/hold **M2** positive ions / cations **AND** delocalised electrons (may be seen in a labelled diagram)	2

Q# 75/ Chem 3 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(f)(i)		1

Q# 76/ Chem 3 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	 dot-and-cross diagram AND 2+	1
3(b)(ii)	 displayed structure of ethanedioate two – charges on carboxylates OR 2– charge overall	2

Q# 77/ Chem 3 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iv)	tetrahedral	1

Q# 78/ Chem 3 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	energy needed / required to break a mole of (covalent) bonds	1
	(All) in the gaseous state	1

Q# 79/ Chem 3 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

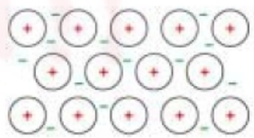
2(b)(i)	hydrogen bonding	1

2(b)(ii)	H-bond between O and H of different molecules	1
	minimum **three** partial charges (in a row) over **two** H_2O molecules, i.e.: either $^{\delta-}O$—$H^{\delta+}$ - - - - $^{\delta-}O$ or $H^{\delta+}$ - - - - $^{\delta-}O$—$H^{\delta+}$	1
	lone pair of electrons on O of H-bond, in line with H-bond	1

Q# 80/ Chem 3 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	bond in which the centres of positive and negative charges do not coincide **OR** electron distribution is asymmetric / unequal **OR** two (bonded) atoms are partially charged	**1**
2(a)(ii)	HF has the strongest (permanent) dipole–dipole / van der Waals' (forces) / HF has hydrogen bonding	**1**
	requires more energy to overcome (than weaker (permanent) dipole–dipole/ van der Waals' forces between other hydrogen halides)	**1**

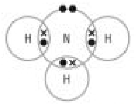
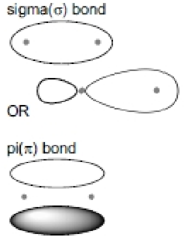
Q# 81/ Chem 3 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(c)(i)	 diagram showing regular arrangement of (positive) ions 1 surrounded by / sea of (delocalised) electrons 1	**2**

Q# 82/ Chem 3 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(d)	M1 = **H** has more / greater / stronger van der Waals' / intermolecular forces than **G** / ora M2 = (because) **H** has more electrons (than **G**) M3 = **J** has hydrogen bonding (between molecules) M4 = strong(er) / great(er) forces require AND high / more energy to overcome	[1] [1] [1] [1]	[4]

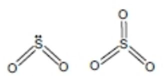
Q# 83/ Chem 3 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i)	 three bonding pairs lone pair AND octet shape = (trigonal) pyramidal	[1] [1] [1]	[3]
(ii)	sigma(σ) bond  OR pi(π) bond	[1] [1]	[2]

Q# 84/ Chem 3 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a)	regular arrangement/lattice of cations/positive ions surrounded by delocalised electrons	[1] [1]	[2]
(b) (i)	electrical conductor corrosion resistant low density ductile owtte	[1] [1]	[max2]
(c) (i)	Simple covalent/covalent molecule Weak intermolecular forces/VdW forces OR little energy needed to break down/overcome intermolecular/VdW forces	[1] [1]	[2]

Q# 85/ Chem 3 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) (i)	 M1 SO_2 correct M2 SO_3 correct	1+1	[2]
(ii)	115–120° bent / non-linear 120° trigonal planar	1 1	[2]

Q# 86/ Chem 3 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(e)	shape of SF_6 = Octahedral bond angle = 90°	1 1	2

Q# 87/ Chem 3 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a)

number of bond pairs	number of lone pairs	shape of molecule	formula of a molecule with this shape
3	0	trigonal planar	BH_3
4	0	tetrahedral	CH_4 allow other Group IV hydrides
3	1	pyramidal **or** trigonal pyramidal	NH_3 allow other Group V hydrides
2	2	non-linear **or** bent **or** V-shaped	H_2O allow other Group VI hydrides

1 mark for each correct row (3 × 1) [3]

(b) (i)

(1)

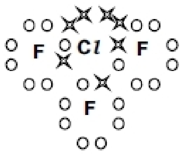
(ii) octahedral **or** square-based bipyramid (1)

(iii) 90° (1) [3]

[Total: 6]

Q# 88/ Chem 3 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) (i)



3 bonding pairs and
2 lone pairs around C*l* atom (1)
3 lone pairs on each of the F atoms (1)

(ii) either

referring to van der Waals' forces in BrF_3

van der Waals' or
intermolecular forces are greater/stronger (1)
because there are more electrons in BrF_3 than in ClF_3 (1)

OR referring to permanent dipoles

permanent dipole or intermolecular forces are stronger/greater in BrF_3 (1)
because BrF_3 has a larger permanent dipole than ClF_3

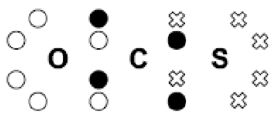
OR because difference in electronegativity is larger between Br and F than between C*l* and F (1)

part (ii) has a maximum of 2 marks (max 2) [4]

[Total: 15]

Q# 89/ Chem 3 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(f) (i)



(1)

(ii) 180° (1) [2]

[Total: 15]

Q# 90/ Chem 3 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) ethanol has hydrogen bonding, ethanethiol does not (1) [1]

Q# 91/ Chem 3 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) (i) NaF, MgF_2, AlF_3 – any two (1)

(ii) octahedral (1)

(iii) I atom is larger than C*l* atom (1)

(iv) cannot pack 7 F atoms around C*l* atom
or can pack 7 F atoms around I atom (1) [4]

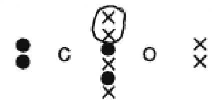
[Total: 12]

Q# 92/ Chem 3 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

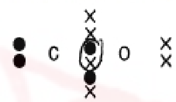
1 (a) fewer electrons in Cl_2 than in Br_2 (1)
smaller van der Waals' forces in Cl_2 or stronger van der Waals' forces in Br_2 (1) [2]

(b) CO has a permanent dipole or N_2 does not (1)
permanent dipole-permanent dipole interactions are stronger than those from induced dipoles (1) [2]

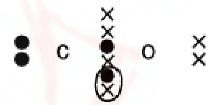
(c) (i) a co-ordinate bond (1)



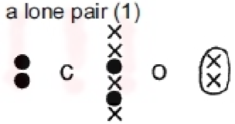
(ii) a covalent bond (1)



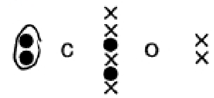
or



(iii) a lone pair (1)



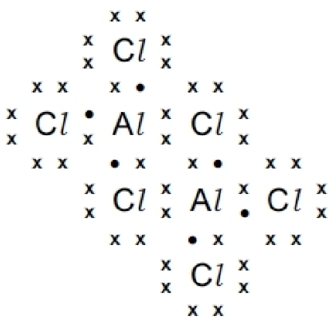
or



penalise any groups of 3 or 4 electrons that are circled [3]

Q# 93/ Chem 3 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(iii)



correct numbers of electrons, i.e.

3 • per *Al* atom and 7x per *Cl* atom

i.e. 6 • and 42 x in total (1)

dative bond *Cl* to *Al* clearly shown by $^{\times}{}_{\times}$ (1)

Q# 94/ Chem 4 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)(i)	high temperature AND low pressure	1
2(c)(ii)	**M1** CO is polar / has a permanent dipole OR N_2 is non-polar	1
	M2 IMF in CO are (more) significant / larger OR IMF in N_2 are smaller / less significant	1
	Alternative answer **M1** (Size of) N_2 smaller than CO OR volume of N_2 molecules / particles smaller	
	Alternative answer **M2** volume of N_2 molecules / particles is more negligible ORA	

2(d)	M1 correct conversion to consistent units P = 101 000 V = 100 / 1 000 000 = (1 × 10^{-4}) T = 293	1
	M2 use of all values from M1 in correct relationship, n = PV / RT	1
	M3 calculation = 4.15 × 10^{-3} mol	1

Q# 95/ Chem 4 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(b)(ii)	**M1:** moles of krypton = 2.00 ÷ 83.8 (= 0.0239 mol) **M2:** conversion of value into consistent units for $pV = nRT$ **M3:** $p = \frac{M1 \times 8.31 \times 393}{5.00 \times 10^{-3}}$ = 15600 Pa	3

1(b)(iii)	**M1:** low pressure AND high temperature **M2:** Either of: • volume of particles is negligible (compared to volume of container) • VdW forces are insignificant (owing to high kinetic energy of particles)	2

Q# 96/ Chem 4 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	**M1** no. of mol $O_2 = \frac{1.00 \times 10^5 \times 1.06 \times 10^{-3}}{(8.31 \times 850)}$ **M2** no. of mol of nitroglycerine = 4 × 0.0150 = 0.0600 (mol) **M3** mass of nitroglycerine = 0.0600 × 227 = 13.6(2) (g)	3
3(b)(ii)	1.06 × 29 = 30.7(4) dm^3	1

Q# 97/ Chem 4 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(iii)	**M1** size / volume of **molecule** / **particle** becomes significant / non-negligible OR IMFs become significant / non-negligible	1
	M2 IMFs becomes significant / non-negligible / collisions are not elastic	1

Q# 98/ Chem 4 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(i)	$pV = nRT \therefore n = \frac{pV}{RT} = \frac{101\,325 \times 0.001}{8.31 \times 273} = 0.0447$ mol $\therefore M_r = \frac{m}{n} = \frac{4.13}{0.0447} = 92.4$ or 92.5 M1 Use of T = 273 K, V = 0.001 m^3 and p = 101325 Pa M2 correct use of $pV = nRT$ using values from M1 M3 correct calculation of M_r using 4.13 ÷ moles from M2	3
2(d)(ii)	ClF_3	1

Q# 99/ Chem 4 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	simple molecular regular arrangement (of C_{60} molecules)	2
2(a)(ii)	C_{60} has (weak) intermolecular / VdW / London / dispersion / id–id forces (and covalent bonds) diamond has covalent bonds (diamond's) bonds are stronger more energy required / lots of energy to break (covalent bonds in diamond)	4
2(b)(i)	(a molecule / compound that is made up of) carbon and hydrogen (atoms) only	1
2(b)(ii)	add bromine (water) / $Br_2(aq)$ (brown to) colourless / decolourised	2
2(c)(i)	addition	1

2(c)(ii)	(n_{C60} = 0.144 / 720 =) 2 □ 10^{-4}	1
2(c)(iii)	$pV = nRT$ ∴ $\Delta n = (p_1 - p_2)V / RT$ Δn = (1.00 □ 10^5 – 2.21 □ 10^4).100 □ 10^{-6} / 8.31 □ 293 = 0.00320	2
2(c)(iv)	(C_{60}:H_2 =) 2.00 □ 10^{-4} : 0.00320 or 1:16 $C_{60}H_{32}$	2
2(d)(i)	giant (molecular) (each Si has four) covalent (bonds)	2

Q# 100/ Chem 4 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)	substance	type of bonding	type of lattice structure	
	copper	metallic	giant/metallic	1
	ice	covalent OR hydrogen(-bonding) / H(–bonding)	hydrogen-bonded / simple / molecular	1
	silicon(IV) oxide	covalent	giant (molecular) / macromolecular	1
	iodine	covalent	simple / molecular	1
	sodium chloride	ionic	giant / ionic	1
2(c)(i)	X = liquid AND Z = solid			1
	Y = liquid and solid OR 'liquid / solid' OR 'liquid OR solid'			1
2(c)(ii)	(kinetic) energy reducing			1
	motion slowing		owtte	1
2(c)(iii)	energy given out / released forming bonds / forming bonds exothermic			1
	compensates for / counteracts heat loss / cooling		owtte	1
			Total:	15

Q# 101/ Chem 4 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(iii)	sodium has mobile / free electrons / electrons free (to move throughout the structure)	[1]	[2]
	phosphorus is simple / covalent / molecular	[1]	
(iv)	magnesium has <u>two</u> free / delocalised / outer / valence electrons per atom OR <u>more</u> free / delocalised / <u>outer</u> electrons than sodium	[1]	[1]

Q# 102/ Chem 4 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i)	Straight line drawn horizontally from same intercept	[1]	[1]
(ii)	T_1 because it shows greatest deviation/furthest from ideal	[1]	[1]
(iii)	reducing T (reduces KE of particles) so intermolecular forces of attraction become more significant	[1]	[1]
(iv)	greatest deviation is at high pressure increasing pressure decreases volume so volume of particles becomes more significant ora	[1] [1]	[2]
(b)	Mass of air = 100 × 0.00118 = 0.118 g Mass of flask = 47.930 – 0.118 = **47.812** g Mass of **Y** = 47.989 – 47.812 = **0.177** g $pV = nRT = \frac{m}{M_r}RT$ $M_r = \frac{mRT}{pV} = \frac{0.177 \times 8.31 \times 299}{1 \times 10^5 \times 100 \times 10^{-6}}$ = **44.0** (43.979 to 2 or more sf)	[1] [1] [1] [1]	[4]

Q# 103/ Chem 4 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) $n = \frac{PV}{RT} = \frac{6 \times 10^5 \times 710 \times 10^{-6}}{8.31 \times 293}$ (1)

$= 0.175$ (1) [2]

(e) $P = \frac{nRT}{V} = \frac{0.175 \times 8.31 \times 278}{710 \times 10^{-6}}$ (1)

$= 569410.5634$ Pa $= 5.7 \times 10^5$ (1)

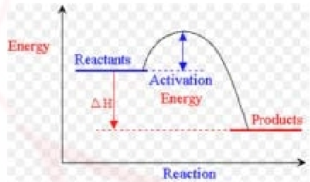
allow ecf on **(d)** [2]

[Total: 10]

Q# 104/ Chem 5 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(ii)	Correct use of enthalpy values / correct direction / use of arrows (with or without an energy cycle) **M1** ((–58.2) + (–40.6)) OR (–98.8) **M2** [(–58.2 + 4(–40.6) = 8ΔH_f)] Correct calculation and correct stoichiometry ΔH_f = –27.6 (kJ mol⁻¹)	2

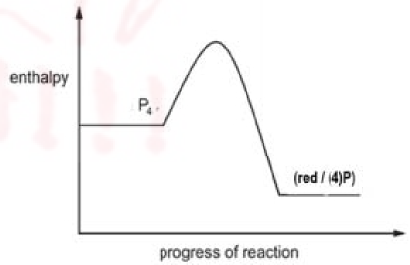
Q# 105/ Chem 5 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(f)(ii)	**M1** sketch shows exothermic reaction with a 'hump' AND labelled reactants (Mg + O_2) and products (MgO) **M2** arrow from reactants / Mg + O_2 to products / MgO shown as ΔH **M3** arrow showing activation energy / E_a / (+)148 	3

Q# 106/ Chem 5 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(c)(iii)	–1640 (kJ mol⁻¹)	1

Q# 107/ Chem 5 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(ii)		1

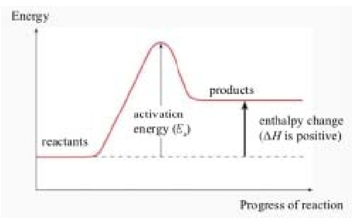
Q# 108/ Chem 5 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

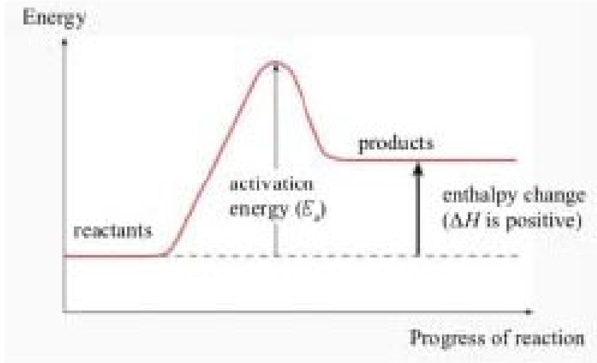
1(b)(i)	**M1** (enthalpy/energy change when) 1 mole of a compound **M2** *burns/combusts/reacts in excess oxygen/O_2* OR ***completely** burns/ **completely** combusts/**completely** reacts in oxygen/O_2*	**2**
1(b)(ii)	**M1** (–394 +2 (–297) – (+89.7) **M2** = –1080 (kJ mol^{-1})	**2**
1(c)(iii)	**M1** S (increases) oxidation number –2 → 0 so oxidation / or is oxidised **M2** O (decreases) O.N. 0 → –2 so reduction / is reduced	**2**
1(d)(i)	**M1** moles of As_2S_3 = 0.198 / 246.1 / 8.05 × 10^{-4} **M2** moles SO_2 (using moles of As_2S_3 as limiting factor) = 2.41(36) × 10^{-3} moles (6 / 2 × 8.05 × 10^{-4}) Volume SO_2 = 2.41(36) × 10^{-3} × 24 = 0.0579 dm^3 **M3** Moles O_2 used in reaction = 8.05 × 10^{-4} × 9 / 2 = 3.62 × 10^{-3} Volume O_2 used in reaction = 3.62 × 10^{-3} × 24 = 0.0869 dm^3 **M4** Final total volume gas = (0.1 – 0.0869) + 0.0579 = [0.0131 + 0.0579] = 0.071(0) dm^3 **M4 ONLY award 4th mark if the final answer rounds to 0.071** Answer to minimum of 2 sig figs **MAX 3 for using ecf from M1 to M2 to M3 and M4** **Award all 4 marks if final answer rounds to 0.071**	**4**
1(d)(ii)	acid rain	
1(d)(iii)	**M1** $SO_2(g)$ + 2NaOH(aq) → $Na_2SO_3(aq)$ + $H_2O(l)$ **AND** correct species and balancing **M2** State symbols	**2**

Q# 109/ Chem 5 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	**M1:** ΔH_f + (–2036) = 4 × –384 **M2:** ΔH_f = (+)500	**2**

Q# 110/ Chem 5 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(c)(i)	 **M1:** end higher than start **AND** 'hill' for E_a **M2:** E_a **AND** ΔH labelled	**2**



Q# 111/ Chem 5 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)(i)	thermal decomposition	**1**
2(c)(ii)	**M1:** ΔH_r = –1434 – (–635 + –297) **M2:** = –502 (kJ mol^{-1})	**2**

Q# 112/ Chem 5 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)	**M1** (enthalpy / energy change) when one mole of a compound/substance is formed **M2** from its elements in their standard states	**2**
3(b)	**M1** *use of correct stoichiometry in calculation* 3xΔH_f NO_2 1x-ΔH_f H_2O 2xΔH_f HNO_3 1xΔH_fNO **M2** *correct signs associated with the appropriate ΔH_f values/terms used for the calculation of* $\Delta H_{reaction}$ **M3** $\Delta H_{reaction}$ = –(102 – 286) + (–346 + 91.1) = –70.9 kJ mol^{-1}	**3**

Q# 113/ Chem 5 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(g)(i)	–1	**1**
1(g)(ii)	**M1** (enthalpy / energy change) when one mole of a compound / substance is formed **M2** from its elements in their standard states	**2**
1(g)(iii)	–(–602 + –188) + (ΔH_f[MgO_2] + –286) = –96 ΔH_f[MgO_2] = –600 (kJ mol^{-1})	**2**
1(g)(iv)	– (–600) – (+602) = –2 (kJ mol^{-1})	**1**

Q# 114/ Chem 5 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)(ii)	**M1** (enthalpy change when) 1 mol of a substance **M2** EITHER burns / combusts / reacts in excess air / oxygen OR completely burns / combusts / reacts in air / oxygen	**2**
3(b)(iii)	**M1** m = 200 and ΔT = 37.5–18.5 **M2** Q = *mc* ΔT = 200 × 4.18 × (37.5 – 18.5) = 15 884 (J)	**2**
3(b)(iv)	**M1** mol of thiophene used = 0.63 / 84.1 OR 7.49(1 082 045) × 10^{-3} **M2** calculation ÷ 1000 AND negative sign $\Delta H_c = \frac{-(iii)}{1000} \div n = \frac{-(iii)}{21000} \div (0.63 / 84.1)$ = –2120 (–2120.39) (kJ mol^{-1})	**2**

Q# 115/ Chem 5 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)(ii)	**M1:** use of the correct expression in terms of specific bond energies. (514 – xE_{Se-O} = –346) **M2:** use of correct stoichiometry AND correct processing of expression given in M1. Provided the values 514 and 346 are used. (514 – $2E_{Se-O}$ = –346) = (+)430 (kJ mol^{-1})	2

Q# 116/ Chem 5 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(e)	**M1** Si—H bond is (much) weaker than C—H bond	1
	M2 low activation energy *ORA*	1

Q# 117/ Chem 5 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(c)(iii)	**M1** labelled reactants **AND** products lower on right **M2** labelled enthalpy change with correct arrow	2

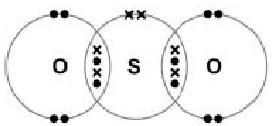
Q# 118/ Chem 5 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(d)(iii)	**M1** +82 (= $E_{O=O}$ – $2E_{N-O}$) = (+)496 – 2 × E_{N-O} **M2** E_{N-O} = ½ × (496–82) = ½ × 414 = 207 (kJ mol^{-1})	2

Q# 119/ Chem 5 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(ii)	–17.(0) (kJ mol^{-1}) ✓✓✓ **M1** ΔH_r = x(–482.2) + y(–92.3) – v(–103.2) – w(–273.3) where x y v and w are integers ⩾1 (ignore stoichiometry) **M2** use of correct stoichiometry where x = 1 y = 2 v = 1 and w = 2	3

Q# 120/ Chem 5 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)	–196 + 6S=O = (4 × 534) + 496	1
	S=O = 2828 / 6 = 471(.3)	1
1(c)	1 = B	1
	2 = A	1
	3 = D	1
1(f)(i)		1
1(f)(ii)	fully ionises/dissociates	1
	(Brønsted-Lowry acid is a) proton / H^+ donor	1
1(f)(iii)	$H_2SO_4(l)/(aq)$ + $H_2O(l)$ → $HSO_4^-(aq)$ + $H_3O^+(aq)$	
	species and balancing	1
	correct state symbols on left hand side; all products aqueous	1

Question	Answer	Marks
2(a)	Different (hydrocarbon) molecules have different numbers of electrons	1
	so different strengths / numbers / amount of VdW / IMFs / id-id	1
2(b)	Produces more useful / more valuable / higher demand substances / alkanes / alkenes	1
2(c)(i)	$C_{12}H_{26}$ → $2C_2H_4$ + C_8H_{18}	1
2(c)(ii)	addition polymerisation	1

Q# 121/ Chem 5 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	–92 = {944 + 3(436)} – 6E(N–H)	1
	E(N–H) = (+)390.7 / 390.67 / 391	1

Q# 122/ Chem 5 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(c)(i)	$\Delta_r H$ = $\Delta_f H$\{products\} – $\Delta_f H$\{reactants\} = 2 × (–242) – 4 × (–92)	**1**
	= –116 (sign **AND** answer)	**1**

Q# 123/ Chem 5 ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	Enthalpy / energy / heat change when one mole of a substance Burns / combusts / reacts in excess oxygen OR Completely burns / combusts / reacts in oxygen under standard conditions	1 1 1	3
2(a)(ii)	$C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$	1	1
2(b)(i)	6813.4 / 6813 / 6810 / 6800 (J)	1	1
2(b)(ii)	–1362.68 / –1362.7 / –1363 / –1360 / –1400 (kJ)	1	1
2(b)(iii)	Any 2 from: heat / energy losses (to air and/or to the container/surroundings) incomplete combustion (volatile) ethanol evaporated ethanol is impure not all energy is lost as heat	 1 1	2
2(c)(i)	$3C(s) + 4H_2(g) + ½O_2(g) \rightarrow C_3H_7OH(l)$ 3(–393.5) 4 × (–285.8) –2021.0 $3CO_2 + 4H_2O$	 1+1 1	3
2(c)(ii)	ΔH_f + (–2021.0) = 3(–393.5) + 4(–285.8) ΔH_f = –302.7 (kJ mol^{-1})	1 1	2
		Total:	13

Q# 124/ Chem 5 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i)	The enthalpy change when one mole of a compound is formed from its element(s)	[1] [1]	[2]
(ii)	$S(s) + 1½O_2(g) \rightarrow SO_3(l)$	[1]	[1]
(b) (i)	944 + (3 × 436) = 2252 6 × 390 = 2340 2252 – 2340 = –88 (kJ mol^{-1})	[1] [1] [1]	[3]

Q# 125/ Chem 5 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a)	Bond breaking = C=O = 740, C–H = 410 = 1150kJ	[1]	
	Bond forming = C–C = 350, C–O = 360, O–H = 460 = 1170kJ	[1]	
	Enthalpy change = 1150 – 1170 = **–20** kJ mol^{-1}	[1]	[3]

Q# 126/ Chem 5 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) (i) alkanes **or** paraffins **not** hydrocarbons (1)

(ii) $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ (1) [2]

(b) (i) **carbon** allow graphite (1)

(ii) $2C_4H_{10} + 5O_2 \rightarrow 8C + 10H_2O$
allow balanced equations which include CO and/or CO_2 (1) [2]

(c) enthalpy change when 1 mol of a substance (1)
is burnt in an excess of oxygen/air under standard conditions
or is completely combusted under standard conditions (1) [2]

(d) (i) $m = \frac{pVM_r}{RT} = \frac{1.01\times10^5 \times 125\times10^{-6} \times 44}{8.31\times293}$ g (1)

= 0.228147345 g
= 0.23 g (1)

(ii) heat released = m c δ T = 200 × 4.18 × 13.8 J (1)
= 11536.8 J = 11.5 kJ (1)

(iii) 0.23 g of propane produce 11.5 kJ
44 g of propane produce $\frac{11.5\times44}{0.23}$ kJ
= 2200 kJ mol^{-1} (1) [5]

Q# 127/ Chem 5 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) let ΔH_f° for NO be *y* kJ mol^{-1}

$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g)$

ΔH_f° 4 × (–46.0) 4*y* 6 × (–242) (1)

$\Delta H^\circ_{reaction}$ = 4*y* + [6 × (–242)] – [4 × (–46.0)] (1)
= 4*y* – 1452 + 184

$\Delta H^\circ_{reaction}$ is –906 kJmol^{-1} so
4*y* = –906 + 1452 – 184 = 362 (1)
whence y = ΔH_f° for NO = +90.5 kJ mol^{-1}
+ sign is required (1) [4]

[Total: 10]

Q# 128/ Chem 5 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) $C(s) + O_2(g) \rightarrow CO_2(g)$ (1)
the enthalpy change/energy change/heat change when
one mole of a compound/CO_2 (1)
is formed from its elements in their standard states (1) [3]

(b) (i)

	$CO_2(g)$	+	$3H_2(g)$	⇌	$CH_3OH(g)$	+	$H_2O(g)$
ΔH_f°/kJ mol^{-1}	–394		0		–201		–242

$\Delta H^\circ_{reaction}$ = –201 + (–242) – (–394) (1)
–49 kJ mol^{-1} (1)
correct sign (1)

Q# 129/ Chem 5 ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) the overall enthalpy change/energy change/Δ*H* for a reaction (1)

is independent of the route taken **or**
is independent of the number of steps involved
provided the initial and final conditions are the same (1) [2]

(b) (i) $K_2CO_3 + 2HCl \rightarrow 2KCl + H_2O + CO_2$ (1)

(ii) heat produced = m × c × δT = 30.0 × 4.18 × 5.2
= 652.08 J per 0.0200 mol of K_2CO_3 (1)

(iii) 0.020 mol K_2CO_3 ≡ 652.08 J

1 mol K_2CO_3 ≡ $\frac{652.08 \times 1}{0.0200}$ = 32604 J

enthalpy change = –32.60 kJmol^{-1} (1)

(iv) to prevent the formation of $KHCO_3$ **or**
to ensure complete neutralisation (1) [4]

(c) (i) $KHCO_3 + HCl \rightarrow KCl + H_2O + CO_2$ (1)

(ii) heat absorbed = m × c × δT = 30.0 × 4.18 × 3.7
= 463.98 J per 0.0200 mol of $KHCO_3$ (1)

(iii) 0.020 mol $KHCO_3$ ≡ 463.98 J

1 mol $KHCO_3$ ≡ $\frac{463.98 \times 1}{0.0200}$ = 23199 J

enthalpy change = +23.20 kJmol^{-1} (1) [3]

(d) Δ*H* = 2 × (+23.20) – (–32.60) = +79.00 kJ mol^{-1} (2) [2]

[Total: 11]

Q# 130/ Chem 5 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$ (1) [1]

(b) (i) step 1 electrophilic (1)
addition (1)
step 2 elimination **or** dehydrohalogenation (1)

(ii) reagent $NaOH/KOH/OH^-$ (1)
conditions in alcohol/ethanol (1)
only allow conditions mark if reagent is correct [5]

(c) (i) **Q** is CH_3CHO (as minimum) (1)
R is CH_3CO_2H (as minimum) (1)

(ii) step 3 is addition (1)
step 4 is oxidation/redox (1) [4]

(d) (i) **combustion**
$C_2H_2(g) + {}^5/_2O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$ **or**
equation must be for the combustion of one mole of C_2H_2
H_2O must be shown as liquid (1)
correct state symbols in this equation (1)

formation
$2C(s) + H_2(g) \rightarrow C_2H_2(g)$
no mark for state symbols here (1)

(ii) let **Z** be ΔH°_f of C_2H_2

	C_2H_2 +	${}^5/_2O_2$ →	$2CO_2$ +	H_2O
ΔH°_f	**Z**	0	2(-394)	-286

$\Delta H^\circ_c = -1300 = 2(-394) + (-286) - \mathbf{Z}$ (1)

whence $\mathbf{Z} = 2(-394) + (-286) - (-1300)$

$= +226\ kJ\ mol^{-1}$
value (1)
sign (1)
allow ecf on wrong equation [6]

[Total: 16]

Q# 131/ Chem 5 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(d) enthalpy change when 1 mol of a substance (1)

is burnt in an excess of oxygen/air under standard conditions
or is completely combusted under standard conditions (1) [2]

Q# 132/ Chem 5 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i)

	CH_4 +	Cl_2 →	CH_3Cl +	HCl
ΔH°_f	–75	0	–82	–92

(1)

$\Delta H^\circ_{reaction} = -82 + (-92) - (-75)$
$= -99\ kJ\ mol^{-1}$ (1)

(ii)

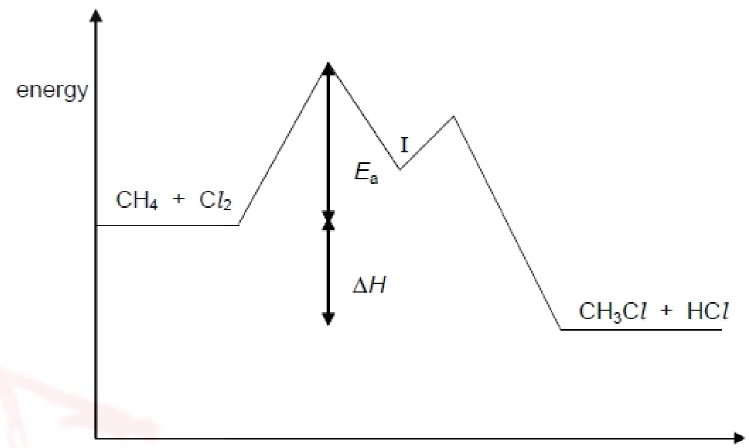
	CH_4 +	I_2 →		CH_3I +	HI
broken	C–H	I–I	made	C–I	H–I
	410	151		240	299

(1)

$\Delta H^\circ_{reaction} = -240 + (-299) + 410 + 151$
$= +22\ kJ\ mol^{-1}$ (1)

(iii) activation energy is too great (1) [5]

(c)



correct placement of 16 kJ (1)
correct placement of –99 kJ (allow ecf on wrong calculation in **(a) (i)**) (1)
intermediate clearly shown at I (1)
correct 'double peak' shape (1)
second peak lower than first (1) [5]

[Total: max 16]

Q# 133/ Chem 5 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i) $Mg^+(g) \rightarrow Mg^{2+}(g) + e^-$ eqn. (1)
state symbols (1)

(ii) $736 + 1450 = +2186\ kJ\ mol^{-1}$ (1) [3]

Q# 134/ Chem 6 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	(+)5/V	1

Q# 135/ Chem 6 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(c)(iii)	**M1** S (increases) oxidation number –2 → 0 so oxidation / or is oxidised **M2** O (decreases) O.N. 0 → –2 so reduction / is reduced	2

Q# 136/ Chem 6 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	$2CuSO_4(aq) + 4KI(aq) \rightarrow 2CuI(s) + (1)I_2(aq) + 2K_2SO_4(aq)$ M1 correct balancing M2 correct state symbols	2
2(a)(ii)	Oxidation state of copper in $CuSO_4$ (+)2 AND Oxidation state of copper in CuI (+)1	1
2(a)(iii)	M1 redox	1
	M2 iodide ions – lost electron(s) AND copper ions – gained electron(s)	1

Q# 137/ Chem 6 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	It oxidises chlorine from –1 to 0	1

Q# 138/ Chem 6 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	–1	1

Q# 139/ Chem 6 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	max O.N.	+1	(+)2	(+)3	(+)5	(+)6	+7	1

Q# 140/ Chem 6 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i)	$\frac{27.30}{1000} \times 0.020$ = **5.46 × 10⁻⁴** (mol)	[1]	[1]
(ii)	**(i)** × 6 = **3.28 × 10⁻³** (mol)	[1]	[1]
(iii)	**(ii)** × $\frac{250}{25.00}$ = **3.28 × 10⁻²** (mol)	[1]	[1]
(iv)	M_r of $FeCO_3$ = 55.8 + 12.0 + 3(16.0) = **115.8** **(iii)** × $M_r(FeCO_3)$ = **3.79** g	[1] [1]	[2]
(v)	$\frac{\text{(iv)}}{5.00} \times 100\%$ = **75.9%**	[1]	[1]
(b) (i)	$2Fe^{3+} + Sn^{2+} \rightarrow 2Fe^{2+} + Sn^{4+}$ species balancing	[1] [1]	[2]
(ii)	$SnCl_2(aq) + 2HgCl_2(aq) \rightarrow SnCl_4(aq) + Hg_2Cl_2(s)$ $SnCl_2$ AND 2 state symbols	[1] [1]	[2]
			[10]

Q# 141/ Chem 6 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) (i)	(a species that) gains/takes electron(s)	1	[1]

Q# 142/ Chem 6 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i)	(The MnO_4^- ions cause the Fe^{2+} ions to) lose electrons owtte/ora	1	1
(ii)	$MnO_4^-(aq) + 5Fe^{2+}(aq) + 8H^+(aq) \rightarrow Mn^{2+}(aq) + 5Fe^{3+}(aq) + 4H_2O(l)$	1+1+1	3
(b) (i)	$\frac{20.0 \times 0.020}{1000} = 4(.00) \times 10^{-4}$ (mol)	1	1
(ii)	$MnO_4^- : Fe^{2+}$ = 1 : 5 so amount of $Fe^{2+} = 5 \times 4.00 \times 10^{-4} = 2(.00) \times 10^{-3}$ (mol) ecf from **(b)(i)**	1	1
(iii)	$2.00 \times 10^{-3} \times 250/25 = 0.02(00)$ (mol) ecf from **(b)(ii)**	1	1

(iv)	3.40/0.02 = 170 ecf from **(b)(iii)**	1	1
(v)	170 – 151.8 = 18.2 18.2/18 = 1.01 x = 1 ecf from **(b)(iv)** if appropriate	1	1
			9

Q# 143/ Chem 6 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) (i) $Mg_3N_2 + 6H_2O \rightarrow 3Mg(OH)_2 + 2NH_3$ (1)

(ii) Mg_3N_2 N is –3 (1)
NH_3 N is –3 (1)

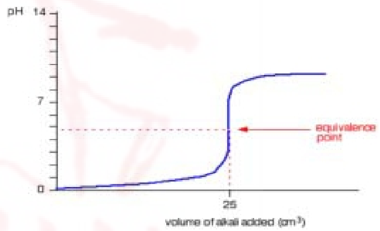
No because
there is no change in the oxidation no. of N (1) [4]
e.c.f on **(c)(i)** and values of oxidation numbers

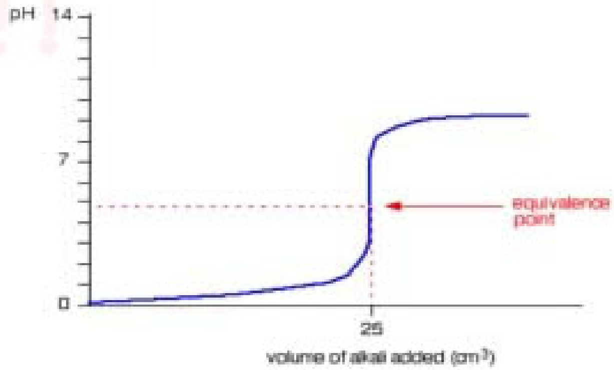
[Total: 11]

Q# 144/ Chem 7 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

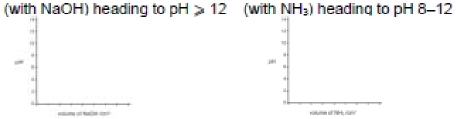
3(d)(iii)	equilibrium moves to left AND more moles / molecules of gas on LHS	1

Q# 145/ Chem 7 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)	any Group 1 hydroxide or $Ca(OH)_2$ / $Sr(OH)_2$ / $Ba(OH)_2$	1
2(d)(i)	M1 proton / H⁺ donor M2 fully dissociates (in aqueous solution / water / solvent)	2
2(d)(ii)	$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$	1
2(d)(iii)	M1 correct basic shape extending to ~50 cm³ with vertical portion of curve at 25 cm³ M2 initial pH at 0–2 (based on idea that HCl is a strong acid) AND final pH at between 8–12 (based on idea that NH_3 is a weak alkali) 	2



Q# 146/ Chem 7 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	proton / H^+ donor [1] fully dissociates (in aqueous solution / water / solvent) [1]	2
3(d)(ii)	M1: correct sigmoid shape with vertical section at 25 cm^3 for both M2: both curves show initial pH ⩽ 2 M3: (with NaOH) heading to pH ⩾ 12 (with NH_3) heading to pH 8–12 	3

Q# 147/ Chem 7 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iii)	position of equilibrium moves / farther to right (at 20 km) [1] (forward) reaction is exothermic AND temperature colder at 20 km (*cf.* 50 km) [1]	2

Q# 148/ Chem 7 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(c)(i)	*weak [acid]* partially dissociates/partially ionises (into H^+ ions/protons)	1
1(c)(ii)	HS^-	1

Q# 149/ Chem 7 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	**M1:** proton / H^+ donor **M2:** partially dissociates / does not fully dissociate (in solution)	2

Q# 150/ Chem 7 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	**M1:** proton / H^+ donor	2
	M2: partially dissociates (in solution)	

Q# 151/ Chem 7 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iii)	*(at 1000 K and 100 kPa)* **M1:** (yield) **decreases**	4
	M2: reaction is exothermic **AND** equilibrium moves **left**	
	(at 500 K and 500 kPa) **M3:** (yield) **increases**	
	M4: fewer moles (of gas) on right-hand side **AND** equilibrium moves right	

Q# 152/ Chem 7 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)	Accepts a proton / H^+ (ion)	1

Q# 153/ Chem 7 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(f)(i)	**M1** equal rates of forward and backward reactions **M2** closed system OR macroscopic properties unchanging	2
1(f)(ii)	**M1** Cl_2 / O_2 initial: x / 0 / mol equilibrium: $0.3x$ / $0.35x$ / mol mol fraction: $\frac{6}{13}$ / $\frac{7}{13}$ **M2** $K_p = \frac{100000 \times \frac{7}{13}}{(100000 \times \frac{6}{13})^2} = 2.53 \times 10^{-5}$ **M3** Pa^{-1}	3

Q# 154/ Chem 7 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(d)(i)	Increases rate AND explanation re collisions	1
	By increasing number / proportion of / more molecules / particles / species with $E \geqslant E_a$	1
	(So) increases frequency of successful collisions / more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
1(d)(ii)	(Increasing T) decreases yield (of SO_3)	1
	(Forward) reaction is exothermic (or reverse argument)	1
	So increasing T shifts (equilibrium) reaction to left / towards reactants / in endothermic direction (to oppose the change in T)	1
1(e)	$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$	1
1(f)(ii)	fully ionises/dissociates	1
	(Brønsted-Lowry acid is a) proton / H^+ donor	1
1(f)(iii)	$H_2SO_4(l)/(aq) + H_2O(l) \rightarrow HSO_4^-(aq) + H_3O^+(aq)$	
	species and balancing	1
	correct state symbols on left hand side; all products aqueous	1

Q# 155/ Chem 7 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(iii)	reduces yield (of ammonia).	1
	(increasing *T*) shifts equilibrium (reaction) to the left / in the reverse direction / towards N_2 and H_2 / towards reactants / in endothermic direction	1
	to oppose the change OR oppose the increase in temperature OR to absorb the (additional) heat / energy OR decrease the temperature	1
1(c)(i)	N_2 = 0.850 (mol)	1
	H_2 = 2.55 (mol)	1
1(c)(ii)	n_{TOTAL} = 3.7 mol	1
	mol fraction of NH_3 = 0.3 / 3.7	1
	$pNH_3 = 2 \times 10^7 \times (0.3 / 3.7) = 1.62 \times 10^6$	1
1(d)(i)	$K_p = \frac{pNH_3^{\ 2}}{pN_2 \times pH_2^{\ 3}}$	1
1(d)(ii)	$K_p = 1.(00) \times 10^{-15}$	1
	Pa^{-2}	1
1(d)(iii)	(yield of ammonia) increases	1
	(value of K_p) stays the same	1

Q# 156/ Chem 7 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	**M1** base is Cl^- **AND** conjugate acid is HCl **OR** base is HSO_4^- **AND** conjugate acid is H_2SO_4	1
	M2 Cl^- / HSO_4^- / base is a proton acceptor **OR** HCl / H_2SO_4 / (conjugate) acid has one more H^+	1

2(c)(iii)	reaction is exothermic	1
	(increased temperature) shifts equilibrium to the left **AND** decreases yield of products (Cl_2 and / or H_2O) / less product formed	1
2(c)(iv)	(see table below)	3

	HC*l*	O_2	Cl_2	H_2O
initial number of moles	1.60	0.500	0	0
M1 eqm number of moles	1.60 – 2 × 0.600 = 0.400	0.500 – ½ × 0.600 = 0.200	0.600	0.600
M2 mole fraction			$\frac{0.600}{1.80}$	
M3 partial pressure			$\frac{0.600}{1.80} \times p_{tot}$ = 5.00 × 10^4	

2(c)(v)	$K_p = \frac{(3.6\times10^4)^2 \times (3.6\times10^4)^2}{(4.8\times10^4)^4 \times 3.0\times10^4} = 1.05 \times 10^{-5}$	1
	units = Pa^{-1}	1
2(c)(vi)	K_p would not change	1

Q# 157/ Chem 7 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(b) (i)	forward and backward reactions occurring at same rate OR the rate of forward and backward reactions are equal	[1]	[1]
(ii)	M1 = decreased yield of products / less products formed / ora M2 = left-hand side has fewer moles of gas OR equilibrium shifts to the left	[1] [1]	[2]

Q# 158/ Chem 7 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(ii)	Fe catalyst 200 atm 400–500 (°)C	[1] [1] [1]	[3]
(iii)	High T increases rate AND Low T improves yield owtte Chosen temp is a compromise High P favours / increases (both rate and) yield owtte pressure chosen limited by cost (of compression and 'thick walls')	[1] [1] [1] [1]	[4]
(c) (i)	$2NH_3 + H_3PO_4 \rightarrow (NH_4)_2HPO_4$	[1]	[1]
(ii)	NH_3 identified as base AND H_3PO_4 identified as acid base accepts protons AND acid donates protons	[1] [1]	[2]

Q# 159/ Chem 7 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i) $H_2X + 2NaOH \rightarrow Na_2X + 2H_2O$ (1)

(ii) $n(OH^-) = \frac{21.6 \times 0.100}{1000} = 2.16 \times 10^{-3}$ mol (1)

(iii) $n(\mathbf{R}) = n(H_2X) = \frac{2.16\times10^{-3}}{2}$
$= 1.08 \times 10^{-3}$ mol in 25.0 cm^3 (1)

(iv) $n(\mathbf{R}) = 1.08 \times 10^{-3} \times \frac{250}{25.0} = 0.0108$ mol in 250 cm^3 (1)

(v) 0.0108 mol of **R** = 1.25 g of **R**
1 mol of **R** = $\frac{1.25\times1}{0.0108}$ = 115.7 = 116 g (1) [5]

(b) (i) M_r of **S** = 116
M_r of **T** = 134
M_r of **U** = 150 **all three needed** (1)

(ii) **S** (1) [2]

Q# 160/ Chem 7 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) $K_p = \frac{p(NO)^4\, p(H_2O)^6}{p(NH_3)^4\, p(O_2)^5}$ (1)

atmospheres **or** Pa **or** kPa (1)
allow ecf on incorrect powers [2]

(b) (i) **increasing temperature**
yield of NO is decreased **or** reaction moves to LHS (1)
forward reaction is exothermic (1)

(ii) **decreasing the pressure**
yield of NO is increased **or** reaction moves to RHS (1)
more moles/molecules of gas on RHS **or**
fewer moles/molecules of gas on LHS (1) [4]

Q# 161/ Chem 7 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) (i) $NaOH + HCl \rightarrow NaCl + H_2O$ (1)

$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2H_2O$ (1)

allow ionic equations in each case

(ii) $n(NaOH) = n(HCl) = \frac{39.2 \times 2.00}{1000} = 0.0784$ (1)

(iii) $n(NaOH) = n(HCl) = \frac{29.5 \times 2.00}{1000} = 0.059$ (1)

(iv) $n(NaOH) = 0.0784 - 0.059 = 0.0194$ (1)

(v) $n[(NH_4)_2SO_4] = \frac{0.0194}{2} = 9.7 \times 10^{-3}$ (1)

(vi) mass of $(NH_4)_2SO_4 = 9.7 \times 10^{-3} \times 132.1 = 1.2814$ g (1)

(vii) % of $(NH_4)_2SO_4 = \frac{1.2814 \times 100}{2.96} = 43.30405405 = 43.3$

give one mark for the correct expression (1)
give one mark for answer given as 43.3 – i.e. to 3 sig. fig. (1)
allow ecf where appropriate [9]

Q# 162/ Chem 7 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ **or**
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

state symbols required (1)

(ii) **pressure** between 60 and 250 atm **or** between 60×10^5 Pa and 250×10^5 Pa (1)

temperature between 300 and 550 °C (1)

catalyst iron / iron oxide (1)

(iii) manufacture of HNO_3 / as a cleaning agent / refrigerant / fertiliser / manufacture of fertilisers / explosives / to remove SO_2 from combustion products of hydrocarbon fuels (1) [5]

(b) (i) NH_4Cl and $Ca(OH)_2$
both formulae required (1)

(ii) $2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2NH_3 + 2H_2O$ **or**
$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$

correct products (1)
correctly balanced equation (1)

(iii) CaO (1)
it is not an acid / it is basic / it does not react with NH_3 **or**
both P_2O_5 / P_4O_{10} **and** H_2SO_4 are acidic / react with NH_3 (1) [5]

Q# 163/ Chem 7 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) $K_c = \frac{[HI]^2}{[H_2] \times [I_2]}$ (1)

no units – must be clearly stated (1) [2]

(c) (i) no change (1)
K_c has no units **or**
same no. of molecules / moles each side of equilibrium (1)

(ii) equilibrium moves to RHS (1)
K_c increases with decreasing temperature **or**
forward reaction is exothermic **or**
reverse reaction is endothermic (1) [4]

(d)

	$H_2(g)$	+	$I_2(g)$	⇌	$2HI(g)$
initial moles	0.02		0.02		0
equil. moles	(0.02 – y)		(0.02 – y)		2y
equil. conc/mol dm^{-3}	$\frac{(0.02-y)}{1}$		$\frac{(0.02-y)}{1}$		$\frac{2y}{1}$

(1)

$K_c = \frac{HI^2}{[H_2] \times [I_2]} = \frac{(2y)^2}{(0.02 - y)^2} = 59$ (1)

$\frac{2y}{(0.02 - y)} = \sqrt{59} = 77$

$2y = (7.7 \times 0.02) - 7.7y$

$9.7y = 0.154$

gives $y = \frac{0.154}{9.7} = 0.0159 = 0.016$ (1)

at equilibrium

$n(HI) = 2 \times 0.016 = 0.032$ **and**
$n(H_2) = n(I_2) = (0.02 - 0.016) = 0.004$ (1)

allow ecf where possible [4]

[Total: 13]

Q# 164/ Chem 7 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) In this part, in each case, the 'effect' must be correctly stated in order to gain the explanation mark.

higher temperature
yield is reduced/equilibrium goes to LHS (1)
because forward reaction is exothermic/reverse reaction is endothermic (1)

higher pressure
yield is increased **or** equilibrium goes to RHS (1)
fewer moles/molecules on RHS **or** more moles/molecules on LHS (1)

use of catalyst
yield does not change (1)
forward and backward rates speeded up by same amount (1) [6]

[Total: 14]

Q# 165/ Chem 7 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(e) temperature of 450°C (1)
pressure of 1 – 2 atm (1)
V_2O_5/vanadium(V) oxide/vanadium pentoxide catalyst (1) [3]

[Total: 15]

Q# 166/ Chem 7 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (1) [1]

(b) temperature between 300 and 550°C (1)

correct explanation of effect of temperature on rate of formation of NH_3 **or** on position of equilibrium (1)

catalyst of iron **or** iron oxide (1)

to speed up reaction **or** to reduce E_a (1) [4]

(c) manufacture of HNO_3
or explosives
or nylon
or as a cleaning agent
or as a refrigerant (1) [1]

Q# 167/ Chem 7 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) (i) iron **or** iron oxide (1)
100 to 500 atm **and** 400–550°C
units necessary – allow other correct values and units (1)

Q# 168/ Chem 7 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) low temperature (1)
because forward reaction is exothermic (1)

high pressure (1)
because forward reaction goes to fewer molecules (1)
or shows a reduction in volume

increase [CO] **or** [H_2]
or remove CH_3OH (1)

correct explanation in terms of the effect of the change on the position of equilibrium or on the rate of reaction (1)
(any two pairs) [4]

(ii) $CO_2 + H_2 \rightleftharpoons CO + H_2O$

	CO_2	H_2	CO	H_2O	
initial moles	0.50	0.50	0.20	0.20	
equil. moles	(0.50-x)	(0.50-x)	(0.20+x)	(0.20+x)	(1)
equil. concn.	$\frac{(0.50-x)}{1}$	$\frac{(0.50-x)}{1}$	$\frac{(0.20+x)}{1}$	$\frac{(0.20+x)}{1}$	

$K_c = \frac{[CO][H_2O]}{[CO_2][H_2]}$ (1)

$K_c = \frac{(0.20+x)^2}{(0.50-x)^2} = 1.44$ (1)

gives x = 0.18 (1)

at equilibrium,
$n(CO_2) = n(H_2) = 0.32$ **and**
$n(CO) = n(H_2O) = 0.38$ (1)

Allow ecf on wrong values of x that are less than 0.5. [7]

[Total: 13 max]

Q# 169/ Chem 8 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(g)	**M1** (heat / energy released from burning Mg) provides more particles with energy ≥ E_a **M2** frequency of successful / effective collisions is greater	2

Q# 170/ Chem 8 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(b)(iii)	two lines shown on diagram, *e.g.* E_A and $E_{A,cat}$ [1] greater proportion of molecules with $E \geq E_A$ [1] frequency of effective collisions increases [1]	3

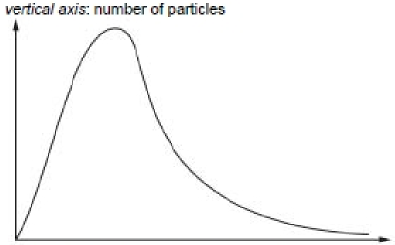
Q# 171/ Chem 8 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(iv)	in the same phase / in same state	1

Q# 172/ Chem 8 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(i)	rate = total change in concentration of Br_2 divided by time taken *calculation dependent on graph* *$(100 \times 10^{-6} - 12 \times 10^{-6}) / 600$* **M1** average rate of reaction 1.47×10^{-6}	1
	M2 units mol dm^{-3} s^{-1}	1
4(c)(ii)	graph shown on same axes has steeper initial gradient AND reaches the same final $[Br_2]$	1
4(c)(iii)	**M1** (at increased temp the average kinetic) energy of particles / species / molecules increases.	1
	M2 (many) more/greater proportion of particles with energy $\geqslant E_a$	1

Q# 173/ Chem 8 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	*vertical axis*: number of particles  *horizontal axis:* (kinetic / particle) energy **M1:** shape of curve correct **M2:** labelled axes	2
1(a)(ii)	Labelled line (T2) with lower peak to right of original	1
1(b)(i)	Any two from: • no VdW forces present / no forces of attraction between particles • (ideal gas) particles have no / negligible volume (compared to container) • collisions between (ideal gas) particles / walls of container are perfectly elastic • (ideal gas) particles behave as rigid spheres	2
1(c)(ii)	• rate increases • (increase in temperature means) more particles have energy $\geqslant$ activation energy • frequency of successful collisions increases	2

Q# 174/ Chem 8 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(e)(i)	in the same phase / state	1

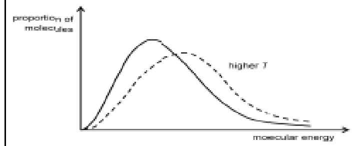
Q# 175/ Chem 8 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(iii)	**M1** in a different phase / state from reactants **M2** a substance that speeds up a (chemical) reaction **M3** catalyst is regenerated / not used up / undergoes temporary chemical change / recovered unchanged	3

Q# 176/ Chem 8 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	(It is a substance that) speeds up a reaction	1
	(by creating an alternative pathway / mechanism with) lower E_a	1
1(a)(ii)	(a heterogeneous catalyst is in a) different state / phase (to the reactants)	1

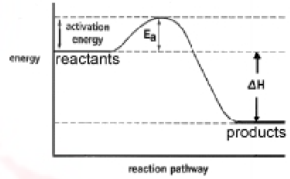
Q# 177/ Chem 8 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	general shape of the curve and peak are displaced to right of original line and starts at origin	1
	the peak is lower and curve crosses once only finishing above original line	1
		
1(b)(ii)	rate increases AND explanation in terms of collisions	1
	(at higher T) area above E_a is greater OR (at higher T) more molecules with $E \geqslant E_a$	1
	higher frequency of successful collisions OR more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1

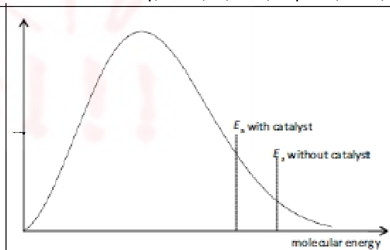
Q# 178/ Chem 8 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(c)(ii)	heterogeneous (catalyst)	1
	provides an alternative reaction pathway of lower activation energy	1

Q# 179/ Chem 8 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) (i)			[2]
	M1 – general layout with products below reactants AND both labelled	[1]	
	M2 – E_a and ΔH/ energy change / released labelled with vertical lines	[1]	
(ii)	activation energy is high	[1]	[2]
	so few/no particles with $E \geqslant E_a$	[1]	

Q# 180/ Chem 8 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(c)			[3]
	M1 = correct Boltzmann curve	[1]	
	M2, M3 any 2 from: • line for **both** E_a values or statement in text that catalyst lowers E_a • (catalyst) increases proportion/number of molecules/particles with energy $\geqslant$ activation energy • so more frequent successful collisions	[1] [1]	

Q# 181/ Chem 8 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i) new graph has lower maximum (1)
maximum is to the right of previous maximum (1)

(ii) H is at E_a (1) [3]

(b) the minimum amount of energy molecules must have **or** energy required (1) in order for the reaction to take place (1) [2]

(ii) C is placed to the left of H (1)

(iii) more molecules now have energy $>E_a$ (1) [4]

(d) **reaction 1**
has greater E_a (1)
because energy is needed to break covalent bonds (1)
reaction 2
has lower E_a
or actual reaction is $H^+ + OH^- \rightarrow H_2O$
or reaction involves ions (1)
opposite charges attract (1) [4]

[Total: max 12]

Q# 182/ Chem 9 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(ii)	$AlCl_3$ AND $SiCl_4$ AND PCl_5	1
3(a)(iii)	NaCl	1
3(a)(iv)	$SiCl_4$	1
3(d)(i)	**M1** (structure =) simple / molecular, because it has a low melting / boiling point	1
	M2 (bonding =) covalent, because it is hydrolysed	1

Q# 183/ Chem 9 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(iii)	**M1** water reacts with / hydrolyses PCl_5 **M2** $H_2O + PCl_5 \rightarrow POCl_3 + 2HCl$ OR $4H_2O + PCl_5 \rightarrow H_3PO_4 + 5HCl$	2

Q# 184/ Chem 9 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(f)(i)	white flame / light OR white solid / smoke	1

Q# 185/ Chem 9 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$	1

Q# 186/ Chem 9 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(ii)	$Na_2O + H_2O \rightarrow 2NaOH$	1
2(b)(i)	reacts with both acids and bases / shows both acidic and basic behaviour	1
2(b)(ii)	$Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$	1
2(c)(i)	(structure =) simple/molecular, because it has a low melting/boiling point [1] (bonding =) covalent, because it is hydrolysed [1]	2
2(c)(iv)	$P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	1

Q# 187/ Chem 9 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)(ii)	$PCl_5 + 4H_2O \rightarrow H_3PO_4 + 5HCl$ $P_4O_{10} + 6H_2O \rightarrow 4H_3PO_4$	2

Q# 188/ Chem 9 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(e)(ii)	**M1:** • ($AlCl_3$ / solid) disappears • misty / steamy fumes • temperature increases **M2:** hydrolysis	2
2(f)(i)	simple / molecular **AND** covalent	1
2(f)(ii)	**M1:** 11.54 ÷ 143.4 = 0.0805 **M2:** so ratio Z:Cl is 1:4 / n = 4	2

Q# 189/ Chem 9 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)	$Al(OH)_3$ / aluminium hydroxide	1

Q# 190/ Chem 9 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	$P_4 + 5O_2 \rightarrow P_4O_{10}$	1
2(a)(ii)	any two from: • reacts vigorously • solid disappears / colourless solution forms • hydrolysis • exothermic • acid(ic) (solution) • steamy / misty fumes	2
2(b)(ii)	$SO_2 + H_2O \rightarrow H_2SO_3$	1
2(e)(i)	**M1:** ionic	2
	M2: ions only able / free to move / free to conduct (when liquid / molten)	
2(e)(ii)	**M1:** covalent	2
	M2: hydrolysed (by water)	

Q# 191/ Chem 9 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(c)(i)	$4Ga + 3O_2 \rightarrow 2Ga_2O_3$ **M1** correct formula of Ga_2O_3 **M2** correctly balanced equation based on $Ga + O_2$ and formula of gallium oxide in M1	2
1(c)(ii)	amphoteric	1

Q# 192/ Chem 9 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(e)(i)	reacts with / behaves as both acid and base	1
1(e)(ii)	$BeO + 2OH^- + H_2O \rightarrow Be(OH)_4^{2-}$	1

Q# 193/ Chem 9 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(ii)	**M1:** reacts with both acid and base / alkali **M2:** use any equation with Al_2O_3 and an acid, e.g. $Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$ **M3:** use any equation with Al_2O_3 and a base / alkali, e.g. $Al_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaAl(OH)_4$	3
2(b)(iii)	solid dissolves / disappears OR gets warm / hot	1
2(c)(iii)	$SeO_2 + 2NaOH \rightarrow Na_2SeO_3 + H_2O$	1

Q# 194/ Chem 9 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(f)(i)	**M1** sodium silicate / Na_2SiO_3	1
	M2 water / H_2O	1
2(f)(ii)	acid(ic)	1

Q# 195/ Chem 9 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	oxidation numbers / states of elements (Na-Si) increase from +1 to +4 / by 1 every time	1
	increasing number of valence electrons / NaC*l*, $MgCl_2$, $AlCl_3$, $SiCl_4$ / number of chlorines matches group number	1
	chlorine oxidation number / state –1 in all / stays the same	1
3(c)(ii)	$NaCl \rightarrow Na^+ + Cl^-$	1
	$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$	1
3(c)(iii)	(table below)	2

	structure	bonding
sodium chloride	giant / ionic	ionic
silicon(IV) chloride	simple / molecular	covalent

Q# 196/ Chem 9 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	(**L**=) $MgCl_2$ / magnesium chloride	1
	Any two from (giant) ionic (with strong attractions) $Mg^{2+}(aq)$ / $Mg(H_2O)_6^{2+}(aq)$ is neutral / undergoes (partial) hydrolysis $Mg(OH)_2$ is the white precipitate / solid / insoluble / partially soluble $MgCl_2 + 2NaOH \rightarrow Mg(OH)_2 + 2NaCl$	2
2(b)(ii)	(**M**=) $SiCl_4$ / silicon chloride	1
	Any two from (simple) molecular / simple covalent hydrolysis possible due to available d orbitals forms HC*l* (aq) / hydrochloric acid / solution and / or HC*l* gas / fumes white solid is (hydrated) SiO_2 $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$	2

Q# 197/ Chem 9 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	**A**	1
3(a)(ii)	**H**	1
3(a)(iii)	**G**	1
3(a)(iv)	**B**	1
3(a)(v)	**F**	1

Q# 198/ Chem 9 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	$P_4 + 5O_2 \rightarrow P_4O_{10} / 2P_2O_5$	1
1(b)(ii)	any 2 from: • yellow / green colour (of chlorine gas) disappears • white flame • white solid • solid melts	2
1(b)(iii)	phosphoric(V) acid	1

Q# 199/ Chem 9 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a)	**D** = Ga **G** = Se	[1]	[1]
(b) (i)	$D_2O_3 + 6HCl \rightarrow 2DCl_3 + 3H_2O$ M1 = species; M2 = balancing	[1] [1]	[2]
(ii)	$D_2O_3 + 2NaOH + 7H_2O \rightarrow 2NaD(OH)_4(H_2O)_2$ OR $D_2O_3 + 2NaOH + 3H_2O \rightarrow 2NaD(OH)_4$ OR $D_2O_3 + 2NaOH \rightarrow 2NaDO_2 + H_2O$ OR $D_2O_3 + 2OH^- + 7H_2O \rightarrow 2[D(OH)_4(H_2O)_2]^-$ OR $D_2O_3 + 2OH^- + 3H_2O \rightarrow 2[D(OH)_4]^-$ OR $D_2O_3 + 2OH^- \rightarrow 2DO_2^- + H2O$ M1 = species; M2 = balancing	[1] [1]	[2]
(c)	giant ionic / ionic lattice	[1]	[1]
(d)	$GO_2 + H_2O \rightarrow H_2GO_3$	[1]	[1]
			[7]

Q# 200/ Chem 9 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) (ii)	Covalent **AND** simple / molecular low melting point / reaction with water	[1] [1]	[2]
(iii)	$TeCl_4 + 3H_2O \rightarrow H_2TeO_3 + 4HCl$ **OR** $TeCl_4 + 2H_2O \rightarrow TeO_2 + 4HCl$	[1]	[1]
(d) (i)	Yellow / orange flame White fumes / solid Yellow / green gas disappears	[1] [1] [1]	[max 2]
(ii)	NaC*l* giant / lattice **AND** ionic $SiCl_4$ simple / molecular **AND** covalent For NaC*l* large difference in electronegativity (of sodium / Na and chlorine / C*l* / Cl_2) (indicates electron transfer/ions) For $SiCl_4$ smaller difference (indicates sharing/covalency) with (weak) van der Waals' / IM forces (between molecules) ora	[1] [1] [1] [1]	[4]
			[20]

Q# 201/ Chem 9 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) (i)	$NaCl\ (+\ aq) \rightarrow Na^+ + Cl^-$ $NaCl + H_2O \rightarrow Na^+ + Cl^- + H_2O$ $SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$ $SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$ $SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$ Allow correct equation with other molar amounts of water	1 1	2
(ii)	NaC*l* is ionic **AND** giant / lattice NaC*l* dissolves / does not react $SiCl_4$ is covalent **AND** molecular / simple $SiCl_4$ is hydrolysed / reacts	1 1 1 1	4

Q# 202/ Chem 9 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) **sodium**
burns with a yellow **or** orange flame **or**
forms a white solid
allow – **once only** – colour of chlorine disappears (1)
$2Na + Cl_2 \rightarrow 2NaCl$ (1)

phosphorus
burns with a white **or** yellow flame **or**
colour of chlorine disappears – if **not** given for Na – **or**

for PCl_5 forms a white **or** pale yellow solid

for PCl_3 forms a colourless liquid (1)

$P + 2\frac{1}{2}Cl_2 \rightarrow PCl_5$ **or** $P_4 + 10Cl_2 \rightarrow 4PCl_5$

or

$P + 1\frac{1}{2}Cl_2 \rightarrow PCl_3$ **or** $P_4 + 6Cl_2 \rightarrow 4PCl_3$

equation must refer to compound described (1) [4]

(d) $MgCl_2$ 6.5 to 6.9 (1)

$SiCl_4$ 0 to 3 (1)

$MgCl_2$ dissolves without reaction **or**
slight **or** partial hydrolysis occurs (1)

$SiCl_4$ reacts with water **or**
hydrolysis occurs (1)

$SiCl_4 + 2H_2O \rightarrow SiO_2 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow Si(OH)_4 + 4HCl$ **or**
$SiCl_4 + 4H_2O \rightarrow SiO_2.2H_2O + 4HCl$ (1) [5]

[Total: 16]

Q# 203/ Chem 9 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** penalise (–1) for names of elements

(i) Na **or** K **or** Li (1)

(ii) S **or** C **or** N **or** P (1)

(iii) K (1)

(iv) C (1)

(v) Cl (1)

(vi) Al **or** Si (1) [6]

(b) (i) Al_2O_3 **or** SiO_2 (1)

(ii) Na_2O (1)

(iii) P_2O_3 **or** P_4O_6 **and** P_2O_5 **or** P_4O_{10} **or** SO_2 **and** SO_3 (1+1)

(iv) Al_2O_3 (1) [5]

Q# 204/ Chem 9 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)** $ZnCO_3$ $Zn(OH)_2$ ZnO
not Zn **or** other compounds of Zn (any 2) [2]

Q# 205/ Chem 9 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 **(a)**

Na_2O	MgO	Al_2O_3	SiO_2	P_4O_{10}	SO_2	Cl_2O_7
alkaline	basic	amphoteric	acidic	acidic	acidic	acidic

Na_2O is alkaline – allow basic (1)

MgO is basic – allow alkaline (1)

Al_2O_3 is amphoteric (1)

SiO_2, P_4O_{10}, and SO_2 are **all** acidic (1) [4]

(b) any **two** from:
sodium, phosphorus, sulfur and chlorine
two names required (1) [1]

(c) (i) any **three** from:
floats
vigorous/violent reaction occurs
melts/forms a sphere
moves
disappears – allow dissolves
effervescence/gas produced (any 3)

(ii) $Na + H_2O \rightarrow NaOH + \frac{1}{2}H_2$
or
$2Na + 2H_2O \rightarrow 2NaOH + H_2$ (1) [4]

Q# 206/ Chem 9 ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(d) **(i) and (ii)**

element	Na	Mg	Al	Si	P	S
conductivity	high	high	—	moderate	low	low
melting point	low	high	—	high	low	low
	(1)	(1)		(1)	(1)	(1)

one mark for each correct column [5]

(e) germanium/Ge (1) [1]

Q# 207/ Chem 9 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 **(a)** Accept only symbols.

(i) S or S_8 (1)

(ii) K or K^+ (1)

(iii) Na – allow K or Li (1)

(iv) C*l* or Br or F (1)

(v) Mg or Ca or Li
allow Ni, Cu, or Zn (1) [5]

(b) Accept only formulae.

(i) F_2O (1)

(ii) SO_2 and SO_3
or P_2O_3/P_4O_6 and P_2O_5/P_4O_{10}
or any two from N_2O_3, NO_2/N_2O_4, N_2O_5
or any two from Cl_2O, ClO_2, ClO_3, Cl_2O_7 (1+1) [3]

Q# 208/ Chem 9 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) chlorine is a strong/powerful oxidising agent (1) [1]

(e) covalent/not ionic (1)
simple molecular **or**
mention of weak intermolecular forces **or**
weak van der Waals's forces between molecules (1) [2]

[Total: 14 max]

Q# 209/ Chem 9 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) **(i)** pass chlorine gas (1)
over heated aluminium (1)

(ii) aluminium glows (1)
white/yellow solid formed (1)
chlorine colour disappears/fades (1) (any 2)

Q# 210/ Chem 10 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	reaction 1 = hydrogen / H_2	1
	reaction 2 = carbon dioxide / CO_2 AND water / H_2O	1
2(b)(ii)	$Ba(OH)_2$ is soluble (in aqueous solution) / solubility of Group 2 hydroxides increases down group	1
2(b)(iii)	thermal decomposition	1

Q# 211/ Chem 10 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + ½O_2$	1
1(b)(ii)	radium (nitrate) as thermal stability increases down group / has the greatest thermal stability	1

Q# 212/ Chem 10 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	hydrogen / H_2	1
2(a)(ii)	$Ca(NO_3)_2 \rightarrow CaO + 2NO_2 + ½O_2$	1
2(a)(iii)	(thermal stability) increases	1
2(a)(iv)	$CaCO_3 + H_2O + CO_2 \rightarrow Ca(HCO_3)_2$	1

Q# 213/ Chem 10 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	$CaC_2O_4(s) \rightarrow CaO(s) + CO_2(g) + CO(g)$ **M1** correct formulae	1
	M2 balancing equation AND state symbols.	1
1(b)(ii)	(thermal) decomposition OR disproportionation	1
1(b)(iii)	calcium carbonate / $CaCO_3$	1

Q# 214/ Chem 10 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(ii)	strong triple bond / high activation energy	1

Q# 215/ Chem 10 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	$CaO + H_2O \rightarrow Ca(OH)_2$	1
1(a)(ii)	OH^- / hydroxide	1
1(b)	**M1** (decreasing melting point down the group because) lower forces of attraction / weaker bonds (between cations and anions / oxide / O^{2-}) **M2** larger cations and constant charge OR decreasing charge density of cation (down group)	2
1(c)	high(er) activation energy / heating overcomes activation energy	1

Q# 216/ Chem 10 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	**M1** (one) fewer (inner) shell of electrons / less shielding (effect) *ORA*	1
	M2 smaller distance of the outer electrons (from the nucleus) / stronger nuclear attraction to the (outer) electrons *ORA*	1

Q# 217/ Chem 10 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	$Sr(s) + 2H_2O(l) \rightarrow Sr(OH)_2(aq) + H_2(g)$ **M1** species AND balancing	1
	M2 state symbols	1
1(a)(iii)	**M1** strontium AND forms a more soluble hydroxide	1
	M2 strontium hydroxide is a stronger base / produces more OH^- / it dissociates more	1
1(a)(iv)	(white) solid dissolves / effervescence	1
1(b)(i)	Similarities (any two from the following list) (both have) +2 ion / (+2) same oxidation state / same stoichiometry of oxide / carbonates decompose (on heating)	2
	Difference (X) forms coloured compounds/oxides/ carbonates OR Group 2 elements form white compounds/oxides/carbonates	1
1(b)(ii)	XO	1
1(b)(iii)	$XCO_3 \rightarrow XO + CO_2$	1

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2(d)(iii)	**M1** effervescence / fizzing / bubbling **M2** solid disappears	2
2(d)(iv)	$2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$	1

Q# 219/ Chem 10 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(ii)	$CaSO_4$ does not react (with sulfuric acid)	2
	coating / crust / protective layer / $CaSO_4$ prevents reaction (of sulfuric acid) with calcium	

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3(b)(i)	(strong) heating	1
	(to provide / overcome) high activation energy	1
3(b)(ii)	white flame / white light / white smoke / white solid	1
3(b)(iii)	$Mg(s) + 2H_2O(l) \rightarrow Mg(OH)_2(s) + H_2(g)$	2
3(c)(i)	$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$	1
3(c)(ii)	$CaCO_3 \rightarrow CaO + CO_2$	1
	$CaO + H_2O \rightarrow Ca(OH)_2$	1
3(d)(i)	reduce acidity in soil / increase pH of soil	1
	(both) basic / base(s)	1
3(d)(ii)	$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$ OR $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$	1
	Total:	16

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3(b)(i)	Nitrate / Nitrate(V) / NO_3^-	1	1
3(b)(ii)	Ba / barium OR Sr / Strontium $Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$ OR $Sr^{2+} + SO_4^{2-} \rightarrow SrSO_4$	1	1
3(b)(iii)	$Ba(NO_3)_2$ OR $Sr(NO_3)_2$	1	2
	$2Ba(NO_3)_2 \rightarrow 2BaO + 4NO_2 + O_2$ OR $2Sr(NO_3)_2 \rightarrow 2SrO + 4NO_2 + O_2$	1	
3(c)(i)	$H^+ + OH^- \rightarrow H_2O$ OR $Ca(OH)_2 + 2H^+ \rightarrow Ca^{2+} + 2H_2O$	1	2
	$2H^+ + CO_3^{2-} \rightarrow CO_2 + H_2O$ OR $CaCO_3 + 2H^+ \rightarrow Ca^{2+} + CO_2 + H_2O$ OR $H^+ + CO_3^{2-} \rightarrow HCO_3^-$ OR $CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$	1	
3(c)(ii)	Calcium carbonate is insoluble / less soluble (ora)	1	2
	Calcium carbonate is less likely to be / won't get washed away (ora) OR Calcium carbonate lasts longer (ora) OR Calcium carbonate is less reactive / reacts more slowly (ora)	1	
3(d)	$Mg(OH)_2$	1	2
	MgO	1	
	Total:		14

Q# 222/ Chem 10 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i)	bubbles / effervescence / fizzing	[1]	max [3]
	calcium gets smaller / disappears	[1]	
	water turns cloudy / milky	[1]	
	calcium sinks	[1]	
(ii)	$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$	[1]	[1]
(iii)	faster bubbling / disappearance of Ba OR no / less precipitate forms (owtte)	[1]	[1]

(iii)	high melting / boiling point	[1]	[2]
	strong forces (of attraction / between oppositely charged ions) / strong (ionic) bonding	[1]	
(iv)	MgO is basic / reacts with acid	[1]	[1]
(c) (i)	increases (down the group)	[1]	[1]
(ii)	$MgCO_3 \rightarrow MgO + CO_2$	[1]	[1]
(iii)	$2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$	[1]	[1]
			[15]

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(b) (i)	**A** = $Mg(NO_3)_2$ **B** = H_2 **C** = NO_2 OR O_2 **D** = O_2 OR NO_2	[1] [1] [1] [1]	[4]
(ii)	any Group I carbonate OR ammonium carbonate	[1]	[1]

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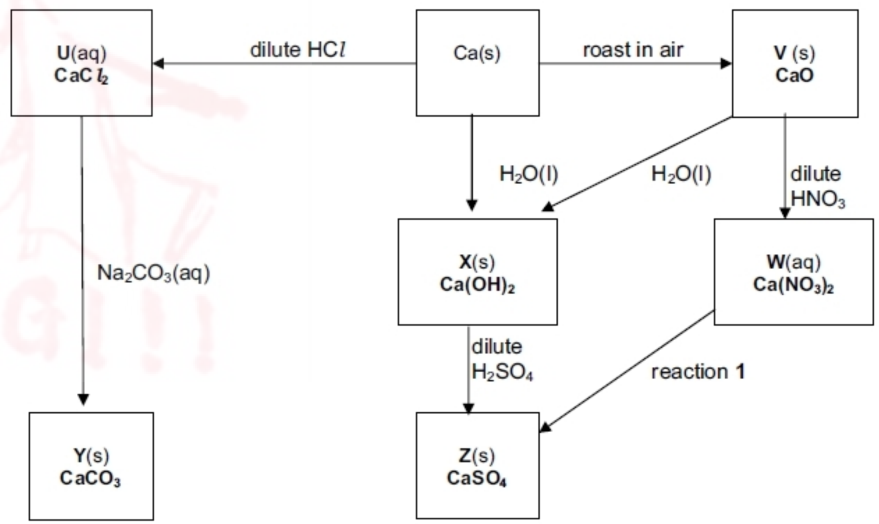
(d) (i)	**X** = $Mg(OH)_2$ **Y** = MgO **Z** = $Mg(NO_3)_2$	1 1 1	[3]
(ii)	reagent = nitric acid	1	
	$MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$	1	[2]
(iii)	Heat / thermal decomposition	1	[1]
(iv)	$Mg + 2H_2O \rightarrow Mg(OH)_2 + H_2$	1	
	$2Mg(NO_3)_2 \rightarrow 2MgO + 4NO_2 + O_2$	1	[2]
			[21]

Q# 225/ Chem 10 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3



(a) **U** $CaCl_2$ (1)
V CaO (1)
W $Ca(NO_3)_2$ (1)
X $Ca(OH)_2$ (1)
Y $CaCO_3$ (1) [5]

(b) heat strongly in a test-tube or a boiling tube
do not allow 'heat gently' or 'reflux' (1) [1]

(c) (i) Ca to **U**
$Ca + 2HCl \rightarrow CaCl_2 + H_2$ (1)

V to **W**
$CaO + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O$ (1)

U to **Y**
$CaCl_2 + Na_2CO_3 \rightarrow CaCO_3 + 2NaCl$ (1)

(ii) $2Ca(NO_3)_2 \rightarrow 2CaO + 4NO_2 + O_2$ (1) [4]

(d) $Na_2SO_4(aq)/K_2SO_4(aq)$ **or** formula of any **soluble** sulfate (1) [1]

(e) (i) Ca to **X**
colourless gas formed/fizzing/effervescence/bubbles **or**
Ca dissolves **or**
white precipitate/suspension formed (1)

(ii) strongly exothermic/vigorous reaction **or**
steam formed/steamy fumes **or**
surface crumbles (1)
do not allow white ppt. [2

[Total: 13

Q# 226/ Chem 10 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i) configuration ends in s^2
or there are two electrons in outermost/valence shell (1)

(ii) $RaCO_3$/radium carbonate (1) [2]

(c) (i) **water** slow reaction
gas bubbles
gas is colourless any 2 (2)

steam Mg glows
vigorous reaction
white solid formed any 2 (2)

(ii) $Mg + H_2O \rightarrow MgO + H_2$ (1) [5]

(d) (i) $Ra(s) + 2H_2O(l) \rightarrow Ra(OH)_2(aq) + H_2(g)$ eqn. (1)
s.s. (1)

(ii) radium dissolves/disappears
gas evolved
gas is colourless
heat evolved any 2 (2)

(iii) 10–14 (1)

(iv) more – **no mark for this alone**
because reactivity of metals increases down the Group
or electrons are further from nucleus
or IE is lower
or Ra is a stronger reducing agent (1) [6]

[Total: 15]

Q# 227/ Chem 10 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) (i) Ra^{2+} (1)

(ii) less than (502 + 966)
allow answers in the range 1000–1400 kJ mol^{-1} (1)

ionisation energies decrease down the Group
or must be less than IE for $Ba \rightarrow Ba^{2+}$
or size of atom increases down Group/
electrons are further away from nucleus
or there is increased shielding down Group (1)

allow ecf on answer to (i) [3]

[Total: 10]

Q# 228/ Chem 10 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) (i) dissolves (1)
6 – 7 (1)

(ii) does not dissolve/slightly soluble (1)
8 – 11 (1) [4]

Q# 229/ Chem 11 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)	$NaClO$ / sodium hypochlorite / chlorate(I) AND H_2O / water	1

Q# 230/ Chem 11 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)	white ppt / solid /	1
	solid (re)dissolves (on addition of NH_3)	1
2(d)	bromine / Br_2 is not a strong enough / (too) weak as a oxidising agent (to oxidise chloride / Cl^-) owtte / Bromine / Br_2 cannot oxidise chloride (ion) / Cl^-	1

Q# 231/ Chem 11 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)	M1: reaction less vigorous (down the group) M2: *Any two of the following for one mark:* • electronegativity decreases • less attractive to e^- addition • weaker oxidising agent • greater nuclear charge outweighing increased shielding (ENC argument)	2
3(b)(ii)	M1: *All three correct for two marks:* row 1 • acid–base row 2 • acid–base • redox M2: *explanation* H_2SO_4 is strong enough to oxidise / is an oxidising agent with NaBr / HBr / bromide	3
3(c)	H—Cl bond is stronger than H—I / BDE decreases down the group	1

Q# 232/ Chem 11 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(i)	easily vaporised / easily evaporates / turns to gas easily	1

Q# 233/ Chem 11 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)	Br / bromine as the oxidation number of Br decreases / goes from 0 → –1 OR bromine as it causes oxidation number of C (in methanoic acid) to increase / go from (+)2 → (+)4	1
4(b)	(solution) turns (from brown / orange / red to) colourless / decolorises OR brown / orange / red fades	1

Q# 234/ Chem 11 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	$NaCl + H_2SO_4 \rightarrow NaHSO_4 + HCl$ OR $2NaCl + H_2SO_4 \rightarrow Na_2SO_4 + 2HCl$	1
3(a)(ii)	displacement / acid-base (reaction)	1
3(b)(i)	hydrogen iodide / HI	1
3(b)(ii)	dark grey solid I_2 / iodine	1
	other product S / sulfur OR H_2S / hydrogen sulfide OR H_2O / water / steam	1
3(c)	M1 iodide ions are strong(er) reducing agents (than chloride ions) ORA	1
	M2 HI / iodide is oxidised OR HC*l* / chloride is not oxidised	1
3(d)	$2Br^- + 2H^+ + H_2SO_4 \rightarrow Br_2 + 2H_2O + SO_2$	1

Q# 235/ Chem 11 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)	kills bacteria/microbes/micro-organisms	1
2(c)(i)	**M1:** (thermal stability) decreases (down group) **M2:** (H—X) bond energy / strength decreases	2
2(c)(ii)	(+)6, (+)4, –2	1
2(c)(iii)	halides are better / stronger / more able reducing agents / are more easily oxidised **down group**	1
2(d)(i)	when a species is both oxidised and reduced	1
2(d)(ii)	$Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$	1

Q# 236/ Chem 11 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	**M1:** (Volatility) decreases (down the group)	2
	M2: more electrons so greater intermolecular forces / intermolecular attractions OR more electrons so greater VdW **between molecules**	
4(a)(ii)	(HI has the) lowest bond enthalpy	1
4(a)(iii)	**M1:** HF has permanent dipole(-dipole forces) **AND** HI has ((only)) instantaneous dipole / induced dipole (forces) / permanent dipole(-dipole forces)	2
	M2: IMF's in HI are weaker (than IMF's in HF)	
4(a)(iv)	$3I_2 + 6NaOH \rightarrow 5NaI + NaIO_3 + 3H_2O$	1

Q# 237/ Chem 11 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iii)	0 | (+)4 | –1	1

Q# 238/ Chem 11 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)	darker / stronger / deeper down the group	1
2(b)(i)	weaker oxidising agents / (relative reactivity as oxidising agents) decreases **down the group**	1
2(b)(ii)	**M1** (structure =) simple / molecular, because it has a low melting / boiling point **M2** (bonding =) covalent, because it is hydrolysed	2
2(c)(i)	**M1** cream ppt / solid **M2** (ppt / solid) partially dissolves in (aqueous) ammonia	2

2(c)(ii)	**M1** *Acid behaviour of H_2SO_4* H_2SO_4 acts as an acid with Cl^- OR acid / base reaction with Cl^- **M2** *Oxidising behaviour of H_2SO_4* H_2SO_4 acts as an oxidising agent with I^- OR H_2SO_4 does not oxidise Cl^- **M3** *Products formed* (for iodide reaction) I_2 / S / SO_2 / H_2S is formed OR (for chloride reaction) (only) HC*l* is formed OR *Comparison of oxidising strength* H_2SO_4 not strong enough to / cannot oxidise Cl^- (to Cl_2) OR I^- more powerful reducing agent than Cl^-	3
2(d)(i)	**M1** increases (down the group) because of increasing VdW **M2** because of increasing number of electrons	2
2(d)(ii)	**M1** less stable (down the group) / decreases **M2** lower H–Hal bond enthalpy / energy	2

Q# 239/ Chem 11 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)(ii)	It oxidises chlorine from –1 to 0	1
1(a)(ii)	effervescence / fizzing / bubbling OR <u>green</u> gas formed OR solid dissolves / disappears / soluble	1
1(b)	**M1:** decreases (down the group) **M2:** increasing induced dipoles **M3:** greater number of electrons	3
1(c)(i)	**M1:** $Cl_2 + 2NaOH \rightarrow NaCl + NaClO + H_2O$ **M2:** chlorine is oxidised and reduced	2
1(c)(ii)	$NaClO_3$ / sodium chlorate(V)	1
1(d)	**M1:** chloric(I) acid / hypochlorous acid / HC*l*O **M2:** kills bacteria / micro-organisms / microbes	2
1(e)(i)	ultra-violet (light) / sunlight	1
1(e)(ii)	$C_2H_6 + Cl_2 \rightarrow C_2H_5Cl + HCl$	1

Q# 240/ Chem 11 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(c)(ii)	$F_2 + H_2O \rightarrow HF + HOF$	1

Q# 241/ Chem 11 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(b)(ii)	**M1** purple gas / vapour disappears **M2** iodine is not a strong enough oxidising agent ORA	2
2(b)(iii)	**M1** silver nitrate / $AgNO_3$ **M2** yellow	2
2(b)(iv)	(aqueous) ammonia / $NH_3(aq)$ / ammonium hydroxide / $NH_4OH(aq)$	1

Q# 242/ Chem 11 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	bleach	1
3(c)(ii)	$Cl_2 + 2OH^- \rightarrow Cl^- + ClO^- + H_2O$	1
3(c)(iii)	–1 **AND** (+)5	1
3(c)(iv)	gains **AND** loses electrons	1

Q# 243/ Chem 11 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(a)(iii)	thermal stability of the hydrogen halides decreases down group (17)	1
	larger (halogen) atoms / atomic radius (down group) / increased shielding	1
	bond energies decrease / less energy required to break H–X	1
2(b)(ii)	H_2SO_4 is (too strong) an oxidising agent	1
	I_2 would be formed instead	1

Q# 244/ Chem 11 ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(a)	6×10^{-3} (mol)	1	1
1(b)	$NaOH + HCl \rightarrow NaCl + H_2O$	1	1
1(c)	6×10^{-3} (mol)	1	1
1(d)	4×10^{-3} (mol)	1	1
1(e)	4×10^{-3} (mol)	1	1
1(f)	1×10^{-3} (mol)	1	1
1(g)	170	1	1
1(h)	28(.0) Si/silicon	1 1	2
	Total:		9

Q# 245/ Chem 11 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i)	**K** = Cl^- / chloride / F^- / fluoride $H_2SO_4 + 2NaCl \rightarrow Na_2SO_4 + 2HCl$ (or equation with F or **K** for Cl) **OR** $H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl$ (or equation with F or **K** for Cl) ecf from identity of **K** so long as halide **HK** is acidic / **HK** is a gas / an acidic gas is produced	1 1 1	3
(ii)	**L** = I^- /iodide colour = yellow ecf from identity of **L** i.e. Cl^- (white) or Br^- (cream) $Ag^+ + I^- \rightarrow AgI$ (or equation with **L**) $AgNO_3 + NaI \rightarrow AgI + NaNO_3$ (or equation with **L**) ecf from identity of **L** so long as halide	1 1 1	3
(iii)	Br_2/bromine has **fewer electrons** than iodine / **more electrons** than chlorine **intermolecular / van der Waals' forces** (in Br_2 / M_2) **weaker** than in iodine / **stronger** than in chlorine	1 1	2

Q# 246/ Chem 11 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) cold dilute aqueous NaOH

NaOCl (1)
+1 (1)

hot concentrated aqueous NaOH

$NaClO_3$ (1)
+5 (1) [4]

Q# 247/ Chem 11 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i) thermal stability decreases down Group VII (1)

(ii) from Cl to I, atomic size increases **or**
the bonding pair is further from the nucleus of X **or**
H—X bond becomes longer **or**
smaller orbital overlap occurs (1)
hence H—X bond strength decreases down Group VII (1) [3]

Q# 248/ Chem 11 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) NaBr/sodium bromide [1]

(b) Br_2/bromine or SO_2/sulfur dioxide [1]

(c) concentrated sulfuric acid is an oxidising agent
or
phosphoric(V) acid is **not** an oxidising agent [1]

[Total: 3]

Q# 249/ Chem 11 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) chlorine is a strong/powerful oxidising agent (1) [1]

Q# 250/ Chem 12 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	**M1** react with (unburnt) hydrocarbons **M2** (form) PAN / peroxyac(et)yl nitrate	2
2(b)(ii)	$2NO + 2CO \rightarrow 2CO_2 + N_2$ OR $NO_2 + 2CO \rightarrow ½N_2 + 2CO_2$	1
2(c)	any Group 1 hydroxide or $Ca(OH)_2$ / $Sr(OH)_2$ / $Ba(OH)_2$	1

Q# 251/ Chem 12 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(i)	$NO + ½O_2 \rightarrow NO_2$	1
2(d)(ii)	peroxyac(et)ylnitrate / PAN	1

Q# 252/ Chem 12 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(d)(ii)	acid rain	
1(d)(iii)	**M1** $SO_2(g) + 2NaOH(aq) \rightarrow Na_2SO_3(aq) + H_2O(l)$ **AND** correct species and balancing **M2** State symbols	2

Q# 253/ Chem 12 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)	CO / it is a polar molecule / it has a (permanent) dipole (but N_2 is non-polar)	1

Q# 254/ Chem 12 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(iii)	(homogeneous) catalyst	1

Q# 255/ Chem 12 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)	**M1** nitrogen has a triple bond **M2** EITHER high energy is needed to break the bond OR at normal temperatures there is not enough energy to break the bond / to overcome the activation energy	2
3(d)	lightning	1

3(e)(i)	**M1** *define homogeneous* (homogeneous catalyst is) in the same phase / state as the reactants **M2** and **M3** *Define catalyst* *All 3 points scores 2 marks. Any 2 points scores 1 mark* increase the rate **AND** lowers the activation energy **AND** without being chemically altered at the end of the reaction / are regenerated at the end of the reaction	
3(e)(ii)	**M1** $NO_2 + SO_2 \rightarrow NO + SO_3$ **M2** $NO + ½ O_2 \rightarrow NO_2$	2

Q# 256/ Chem 12 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	$C_4H_4S(l) + 6O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l) + SO_2(g)$ • correct species • balancing • state symbols Award one mark for two correct bullet points, award two marks for all three correct.	2

Q# 257/ Chem 12 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(a)	strong triple bond / strong N≡N OR high activation energy / E_a OR non-polar	1
1(c)(i)	(it is used to make) fertilisers	1
1(c)(ii)	**M1** CaO displaces NH_3 (from its salt / NH_4^+) **M2** CaO is a stronger base / more basic (than NH_3)	2
1(d)(i)	NO: (+)2 / (+)II; NO_2: (+)4 / (+)IV	1
1(d)(ii)	**M1** $½N_2 + O_2 \rightarrow NO_2$ **M2** $Mg(NO_3)_2 \rightarrow MgO + 2NO_2 + ½O_2$	2

Q# 258/ Chem 12 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)(i)	1 mark for each bullet, max 2 • triple bond • non-polar / no dipole • needs a lot of energy to break / strong	2
2(b)(i)	(lightning) provides the (high) activation energy	1
2(b)(ii)	**M1** $NO + ½ O_2 \rightarrow NO_2$ **M2** $2NO_2 + H_2O + ½ O_2 \rightarrow 2HNO_3$	2
2(d)(ii)	**M1** ammonia / NH_3 **M2** displaces NH_3	2

Q# 259/ Chem 12 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(c)(i)	**M1** acid rain **M2** • destroys / damages / weathers / erodes / buildings / statues • kills/harms fish / coral / plants / crops / trees / deforestation • leaches salts / ions (aluminium) from soil (into rivers / lakes) • leaches away soil nutrients • breathing difficulties • lowers pH / increases acidity of soil / rivers / oceans / seas	2
1(c)(ii)	balanced equation with $11O_2$ and $8SO_2$ **M1**: O_2 and SO_2 **M2**: 11 and 8	2
1(c)(iii)	**M1** *is for process of calculating number of moles of Fe_2O_3* 33.18 ÷ 159.6 (= 0.2079 mol) **M2** *for correct use of stoichiometry and 120.0 with candidate's* **M1** **M2** (0.2079) × 4 / 2 × 120.0 = 49.89 (g)	2
1(c)(iv)	(0.37/(0.37+49.89)) = 0.74	1

Q# 260/ Chem 12 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(c)	sulfur dioxide would be produced on combustion (which contributes to) acid rain	[1] [1]	[2]

Q# 261/ Chem 12 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(iii)	global dimming / PAN / smog / global warming	[1]	[1]

Q# 262/ Chem 12 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(ii)	(oxides of nitrogen / NO_x / NOs) cause acid rain $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3$ OR $4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$ OR $SO_2 + NO_2 \rightarrow SO_3 + NO$ AND $SO_3 + H_2O \rightarrow H_2SO_4$	[1] [1]	[2]
			[21]

Q# 263/ Chem 12 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) (i)	strong triple bond	[1]	[1]
(ii)	high temperature (needed for reaction between N_2 and O_2)	[1]	[1]
(iii)	$2NO + 2CO \rightarrow N_2 + 2CO_2$ **OR** $2NO + C \rightarrow N_2 + CO_2$	[1]	[1]
(iv)	$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$	[1]	[1]
(v)	$NO + ½O_2 \rightarrow NO_2$ $NO_2 + SO_2 \rightarrow NO + SO_3$ **OR** $NO_2 + SO_2 + H_2O \rightarrow NO + H2SO_4$	[1] [1]	[2]
			[15]

Q# 264/ Chem 12 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a)	$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$	1 1	[2]
(b) (i)	Very exothermic/gets very hot OR creates (acid/H_2SO_4) spray/mist/fog/fumes	1	1
(ii)	$SO_3 + H_2SO_4 \rightarrow H_2S_2O_7$ $H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$	1 1	[2]
(d) (i)	Advantage = higher rate Greater KE/energy/speed/collision frequency/proportion of successful collisions/more particles with E>Ea Disadvantage – reduced yield/less product (Forward reaction) **exothermic AND** (hence in accordance with LCP) equilibrium/reaction **shifts left** (to counteract inc T) ora	1 1 1 1	[4]
(ii)	$K_p = \frac{pSO_3^2}{pSO_2^2 \times pO_2}$	1	[1]
(iii)	$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$ 2 2 0 (–1.8) (–0.9) 0.2 1.1 1.80 $xSO_3 = 1.8/3.1 = 0.581$ $xSO_2 = 0.2/3.1 = 0.065$ $xO_2 = 1.1/3.1 = 0.355$ $K_p = \frac{0.581^2 \times (2 \times 10^5)^2}{0.065^2 \times (2 \times 10^5)^2 \times 0.355 \times 2 \times 10^5} = 1.13 \times 10^{-3}\ Pa^{-1}$	1 1 1 1+1	[5]
			[19]

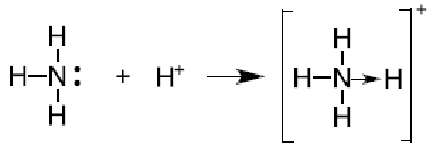
Q# 265/ Chem 12 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(b) (i) carbon allow graphite (1)

(ii) $2C_4H_{10} + 5O_2 \rightarrow 8C + 10H_2O$
allow balanced equations which include CO and/or CO_2 (1) [2]

Q# 266/ Chem 12 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c)



correct displayed eqn.,
with positive charge clearly shown (1)
lone pair on NH_3 (1)
co-ordinate / dative bond clearly shown (1) [3]

[Total: 13]

Q# 267/ Chem 12 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) $(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2H_2O$
correct products (1)
correctly balanced equation (1) [2]

(b) (i) $NaOH + HCl \rightarrow NaCl + H_2O$ (1)

(ii) $n(HCl) = \frac{31.2}{1000} \times 1.00 = 0.0312 = 0.03$ (1)

(iii) $n(NaOH) = \frac{50.0}{1000} \times 2.00 = 0.10$ (1)

(iv) n(NaOH) used up = 0.10 – 0.0312 = 0.0688 = 0.07 (1)

(v) $n[(NH_4)_2SO_4] = \frac{0.0688}{2} = 0.0344 = 0.03$ (1)

(vi) mass of $(NH_4)_2SO_4$ = 0.0344 × 132 = 4.5408 = 4.54 (1)

(vii) percentage purity = $\frac{4.5408 \times 100}{5.00} = 90.816 = 90.8$ (1) [7]

[Total: 9]

Q# 268/ Chem 12 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) (i) combustion of fossil fuels – e.g. from car engines
from car exhausts **or**
during the extraction of metals from sulfide ores or
volcanic eruptions/burning sulfur from volcanoes or
burning biomass (1)

(ii) H_2SO_4
or
SO_3 allow H_2SO_3 **formula required** (1)

(iii) acid rain
or
its consequences e.g. damage to buildings,
damage to crops, plants, marine life
deforestation
or
SO_3 is toxic (1) [3]

Q# 269/ Chem 12 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) (i) $C_2H_5SH + {}^9/_2O_2 \rightarrow 2CO_2 + SO_2 + 3H_2O$ **or**
$2C_2H_5SH + 9O_2 \rightarrow 4CO_2 + 2SO_2 + 6H_2O$
correct products (1)
correct equation which is balanced (1)

(ii) **for CO_2**
enhanced greenhouse effect (1)
global warming (1)

for SO_2
formation of acid rain (1)
damage to stonework of buildings/
dissolving of aluminium ions into rivers/
damage to watercourses or forests/
aquatic life destroyed/
corrosion of metals (1) [6]

(d) help detect leaks of gas (1) [1]

(e) temperature of 450°C (1)
pressure of 1 – 2 atm (1)
V_2O_5/vanadium(V) oxide/vanadium pentoxide catalyst (1) [3]

[Total: 15]

Q# 270/ Chem 12 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(e) (i) CO by incomplete combustion of the hydrocarbon fuel (1)

NO by reaction between N_2 and O_2 in the engine (1)

(ii) CO toxic/effect on haemoglobin (1)

NO toxic/formation of acid rain (1) [4]

(f) (i) platinum/Pt – allow palladium/Pd **or** rhodium/Rh (1)

(ii) $2CO + 2NO \rightarrow 2CO_2 + N_2$ (1) [2]

[Total: 14]

Q# 271/ Chem 12 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(d) CO and HCN both have a dipole **or** N_2 does not have a dipole (1) [1]

Q# 272/ Chem 12 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

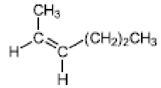
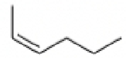
3 (a) $2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$ (1) [1]

(b) SO_2 (1)

NO_x / NO_2 / NO – **not** N_2O (1)
Pb compounds – **not** Pb (1) (any 2)

If more than two answers are given any wrong ones will be penalised. [2]

Q# 273/ Chem 13 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)	C1:  M1 (m.& b.pts are low because) weak intermolecular forces / weak van der Waals	1
	M2 (only) London / dispersion forces / instantaneous dipole-induced dipole	1
4(c)	cis  or 	1

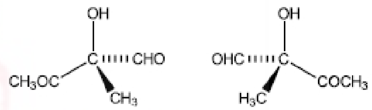
Q# 274/ Chem 13 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(iv)	(molecules / isomers with) the same molecular formula	1
	but different structural formulae	1

Q# 275/ Chem 13 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)	M1 optical M2 one of the C atoms has 4 different groups / atoms attached	2

Q# 276/ Chem 13 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(a)(ii)		2

Q# 277/ Chem 13 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	$C_{18}H_{15}P$	1

Q# 278/ Chem 13 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(iv)	(L has) two identical / two methyl groups attached to one end / one carbon of the C=C / double bond	1

Q# 279/ Chem 13 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6(a)		1

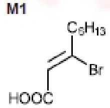
Q# 280/ Chem 13 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(iv)	it does not have four different (groups of) atoms attached to (central) carbon OR it does not have a chiral carbon / centre OR it has two identical / COOH groups attached to (central) carbon OR mirror image is super(im)posable	1

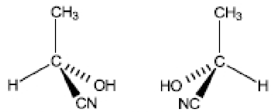
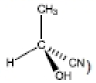
Q# 281/ Chem 13 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	$C_5H_8O_2$	1

Q# 282/ Chem 13 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	M1  M2 (two) different groups on each C atom in the C=C / end of the C=C double bond M3 no / restricted rotation about C=C	3

Q# 283/ Chem 13 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(b)(i)	optical	1
5(b)(ii)	 M1 one 3-D structure of correct molecule shown.	1
	M2 a mirror image of the molecule drawn in M1 OR same profile with two groups swapped (e.g. )	1
	M3 central chiral C shown as *	1

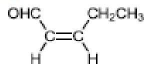
Q# 284/ Chem 13 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)	3-chloroprop-1-ene	1
4(b)	*a* = 109(.5)°	1
	b = 120°	1
4(c)(i)	$C_3H_7ClO_2$	1

Q# 285/ Chem 13 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(a)	3-chloroprop-1-ene	1

Q# 286/ Chem 13 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)	M1 geometric(al) M2 	2

Q# 287/ Chem 13 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(v)	has a carbon / C / atom attached to four different groups / atoms / chains OR has no plane / line of symmetry / has non-superimposable images	1

Q# 288/ Chem 13 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	(different molecules) with same molecular formula / same numbers of atoms of (each type) of element	1
	different structural formulae / displayed formulae	1
	chain / skeletal functional group position(al) / regioisomerism two types correct = 1 mark, all three correct = 2 marks	2
3(d)(i)	(different molecules) with the same (molecular and) structural formula /	1
	with different arrangements of atoms in space / spatial arrangement of atoms	1

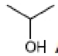
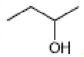
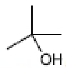
Q# 289/ Chem 13 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(d)(i)	(molecules / isomers with) the same (molecular and) structural formula	1
	Any two of: chiral centre / C attached to four different groups / atoms non-super(im)posable mirror images different spatial / 3D arrangement of atoms (owtte) different rotation of plane-polarised light	1

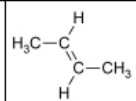
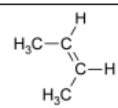
Q# 290/ Chem 13 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	(molecules / isomers with) the same molecular formula / same number of atoms of each element	1
	different structural / displayed formulae / arrangement of bonds	1
4(a)(ii)	sp^2 overlap of (2)s with two (2)p (atomic) orbitals	1
	sp^3 overlap of (2)s with all three (2)p (atomic) orbitals	1
4(a)(iii)	sp^2 = 116° – 124°	1
	sp^3 = 106° – 112°	1

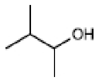
Q# 291/ Chem 13 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(i)	3	1
1(b)(ii)	8	1
1(b)(iii)	$C_3H_8O + 4½O_2 \rightarrow 3CO_2 + 4H_2O$	1
1(b)(iv)	 OH AND propan–2–ol / 2–propanol	1
	 OH AND propan–1–ol / 1–propanol	1
	Alternative answers (any two):  OH AND butan–1–ol / 1–butanol  OH AND butan–2–ol / 2–butanol  OH AND (2–)methylpropan–1–ol / (2–)methyl–1–propanol  OH AND (2–)methylpropan–2–ol / (2–)methyl–2–propanol	
1(b)(v)	correct conversions of data to SI/consistent units p = 100 000 ; V = 20 × 10^{-6} ; T = 393	1
	calculation of *n* (= *pV/RT*) from M1 values $n = \frac{100 \times 10^3 \times 20 \times 10^{-6}}{8.31 \times 393}$	1
	calculation of mass *m* (= *n* × *Mr*) AND answer correct to 3sf *m* = 6.12 × 10^{-4} × 60 = 0.0367 (g) Alternative answer for using $C_4H_{10}O$: *m* = 6.12 × 10^{-4} × 74 = 0.0453 (g)	1
	Total:	10

Q# 292/ Chem 13 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4	(a)	CH_2=$CHCH_2CH_3$ / $CH_2CHCH_2CH_3$ AND CH_3CH=$CHCH_3$ / $CH_3CHCHCH_3$	[1]	[1]
	(b)	CH_2=$CHCH_2CH_3$ / $CH_2CHCH_2CH_3$ AND $(CH_3)_2C$=CH_2 / $(CH3)_2CCH_2$	[1]	[1]
	(c)	  *trans*-but-2-ene (or *E*) *cis*-but-2-ene (or *Z*)	[1] [1]	[2]

Q# 293/ Chem 13 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i)	C_4H_{10}	[1]	[1]
(ii)	C_4H_9	[1]	[1]
(iii)		[1]	[1]

Q# 294/ Chem 13 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i)	structural isomers: (different molecules with) same molecular formula but different structural formulae	[1]	[2]
	chiral: has a carbon/C attached to 4 different groups/atoms/chains OR has no plane/line of symmetry/has non-superimposable mirror images	[1]	

Q# 295/ Chem 13 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) (i)	Stereoisomerism = (molecules with the same molecular formula and) same structural formula but different spatial arrangements of atoms	[1]	
	Chiral centre = atom with four different atoms/groups attached	[1]	[2]

Q# 296/ Chem 13 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) (i)	(Different molecules with) the same (molecular and) structural formula	1	
	different arrangements of atoms (in space)/different displayed formula	1	[2]

Q# 297/ Chem 13 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

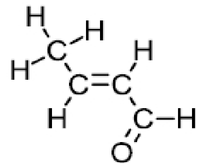
(e) (i) from methane to butane
there are more electrons in the molecule (1)
therefore greater/stronger van der Waals' forces (1)

(ii) straight chain molecules can pack more closely (1)
therefore stronger van der Waals' forces (1)
or reverse argument [4]

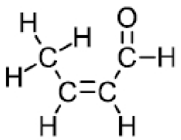
[Total: 15]

Q# 298/ Chem 13 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(b)



trans or E



cis or Z

two correct structures (1)

both correctly labelled (1)

correctly displayed -CHO group (1) [3]

(c)

(1) [1]

Q# 299/ Chem 13 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

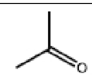
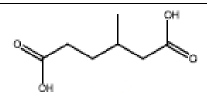
5 (a) (i) same molecular formula
but different structural formula/structure (1)

(ii) asymmetric C atom/chiral centre present (1)
>C=C< bond present (1) [3]

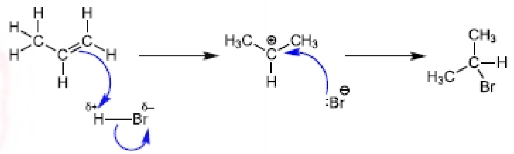
(b) $NaO_2CCH(OH)CH(OH)CO_2Na$ (1) [1]

(c) no **because** there is no chiral carbon atom present (1) [1]

Q# 300/ Chem 14 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(b)	 OR $(CH_3)_2CO$;  OR $HOOC(CH_2)_2CH(CH_3)CH_2COOH$	2

Q# 301/ Chem 14 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(e)(i)	 M1: curly arrow from C=C to H of HBr M2: correct dipole ($^{\delta+}$H—Br$^{\delta-}$) AND curly arrow from H—Br to Br M3: curly arrow from lone pair on :Br$^-$ to carbocation M4: correct intermediate AND product (2-bromopropane)	4

Q# 302/ Chem 14 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(iii)	substitution	1

Q# 303/ Chem 14 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6(a)	addition	1
6(b)	**M1** *catalyst* = sulfuric acid/phosphoric(V) acid	1
	M2 *conditions of reaction* = steam/heat (and pressure)	1
6(c)	(see table below)	2
6(d)(i)	**M1** more stable = $CH_3C^+(H)(CH_3)$ 	1
	M2 less stable = $CH_3CH_2C^+(H_2)$ / 	1
	M3 greater (positive) inductive effect of two alkyl groups OR greater electron donation of two alkyl groups owtte	1
6(d)(ii)	propan-2-ol	1

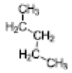
6(c):

	σ	π
C_3H_6	8	1
C_3H_8O	11	0

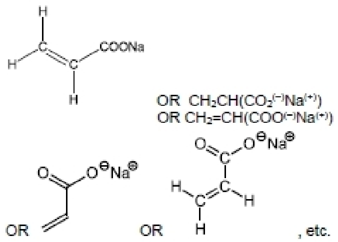
Q# 304/ Chem 14 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(e)(ii)	CO/hydrocarbons **AND** toxic/poisonous/harmful to health/(catalyses formation of) photochemical smog	1

Q# 305/ Chem 14 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(a)(i)	(compounds / molecules) containing only / entirely carbon and hydrogen (atoms)	1
5(a)(ii)	crude oil	1
5(b)(i)	(thermal) cracking	1
5(b)(ii)	*structure of W*  OR $CH_3(CH_2)_3CH_3$ OR 	1

Q# 306/ Chem 14 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(c)(i)	CO_2H / carboxylic acid	1
5(c)(ii)	**M1** (add) $Br_2(aq)$ / bromine water	1
	M2 (solution) turns (from brown / orange / red to) colourless / decolorises OR brown / orange / red fades	1
5(d)	 OR $CH_2CH(CO_2^{(-)}Na^{(+)})$ OR $CH_2{=}CH(COO^{(-)}Na^{(+)})$ OR … OR …, etc.	1

Q# 307/ Chem 14 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(d)(iii)	ethene	1

Q# 308/ Chem 14 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(g)(i)	(free-)radical substitution	1
2(g)(ii)	ultraviolet (UV) light / sunlight	1
2(g)(iii)	$(1s^2)\ 2s^2\ 2p^6\ 3s^2\ 3p^5$	1
2(g)(iv)	$Cl^{\bullet}$ AND CH_2Cl_2	1
2(g)(v)	termination	1
2(g)(vi)	$CHCl_3$ OR $(CH_2Cl)_2$	1

Q# 309/ Chem 14 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(v)	ethanoic acid / CH_3COOH	1

Q# 310/ Chem 14 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6(b)(i)	hot AND concentrated	1
6(b)(ii)	oxidation	1
6(c)	*Structural formula of X:* HCO_2H OR $HCOOH$	1
6(d)	**M1** *reagent* (2,4–) DNPH / (2,4)-dinitrophenylhydrazine **M2** *observation* yellow / orange / red precipitate	2

Q# 311/ Chem 14 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(a)(i)	Cl	1
5(b)(i)	ultraviolet light / uv	1
5(b)(ii)	homolytic fission (of chlorine (gas) / Cl_2)	1

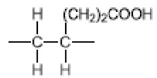
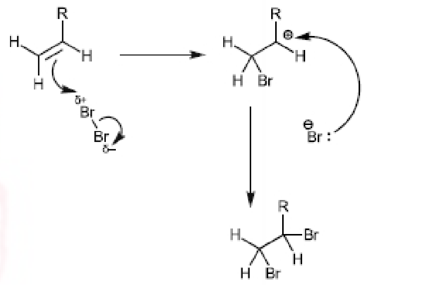
Q# 312/ Chem 14 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(d)(i)	*Two structures representing the intermediate* **M1** $C_2H_5C^+HCH_3$ **M2** $CH_3CH_2CH_2C^+H_2$	2
5(d)(ii)	*Identify the most stable intermediate* **M1** $C_2H_5C^+HCH_3$ *explanation* **M2** (more / 2 alkyl groups attached so) it has the greater inductive / electron donating effect	2

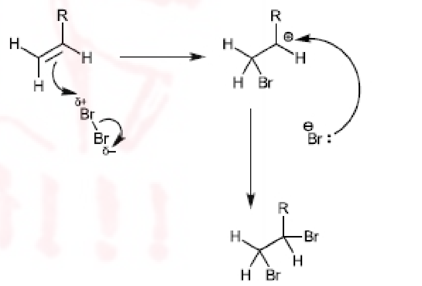
Q# 313/ Chem 14 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(ii)	H_2 / hydrogen	1

Q# 314/ Chem 14 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(ii)		1
3(c)(iii)	 **M1** curly arrow from C=C double bond to Br **M2** correct dipole in Br_2 AND curly arrow from Br—Br to $Br^{\delta-}$ **M3** correct intermediate AND curly arrow from lone pair on Br^- to C^+ **M4** correct product	4

Q# 315/ Chem 14 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(iii)	 **M1** curly arrow from C=C double bond to Br **M2** correct dipole in Br_2 AND curly arrow from Br—Br to $Br^{\delta-}$ **M3** correct intermediate AND curly arrow from lone pair on Br^- to C^+ **M4** correct product	4

Q# 316/ Chem 14 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	cracking	1
3(a)(ii)	enthalpy change of combustion / ΔH_c is high / large energy release (per mole / per unit mass) OR combust / burn easily	1
3(a)(iii)	$C_4H_8 + 4O_2 \rightarrow 4CO + 4H_2O$	1

Q# 317/ Chem 14 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(ii)	oxidation	1

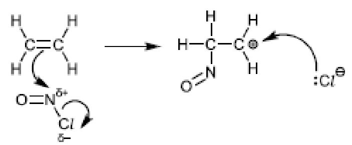
Q# 318/ Chem 14 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(b)(i)	ultra-violet (light) / sun(light)	1
4(b)(ii)	$CH_2{=}CHCH_3 + Cl\bullet \rightarrow CH_2{=}CHCH_2\bullet + HCl$ OR $C_3H_6 + Cl\bullet \rightarrow C_3H_5\bullet + HCl$	1
4(b)(iii)	free-radical (substitution) reactions are uncontrolled OR further chlorination / substitution occurs	1

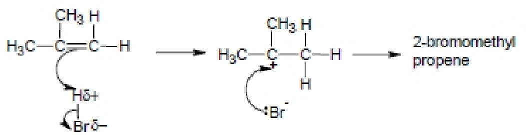
Q# 319/ Chem 14 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(c)(i)	cold, dilute acidified $KMnO_4$ / potassium manganate(VII)	1
4(d)	**M1** major product formed from more stable intermediate / carbocation OR (intermediate has) 2°carbocation which is (more) stable **M2** (positive) inductive effect / (+)I of alkyl groups (on the intermediate)	2

Q# 320/ Chem 14 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(e)	 **M1** curly arrow from C=C to $N^{\delta+}$ AND curly arrow from N—Cl to $Cl^{\delta-}$ **M2** intermediate AND curly arrow from lone pair on Cl^- to C(+)	2

Q# 321/ Chem 14 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(d)(i)		
	curly arrow from C=C to H	1
	correct dipole on HBr and curly arrow from bond of HBr to Br	1
	tertiary intermediate cation	1
	Br^- with curly arrow from lone pair	1
4(d)(ii)	(carbo)cation / tertiary ion / tertiary intermediate (more) stable (than primary)	1
	due to electron-releasing / (positive) inductive effect of more alkyl / methyl groups	1

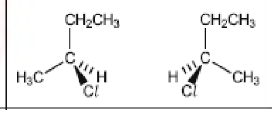
Q# 322/ Chem 14 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(a)	Different (hydrocarbon) molecules have different numbers of electrons	1
	so different strengths / numbers / amount of VdW / IMFs / id-id	1
2(b)	Produces more useful / more valuable / higher demand substances / alkanes / alkenes	1
2(c)(i)	$C_{12}H_{26} \rightarrow 2C_2H_4 + C_8H_{18}$	1

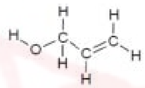
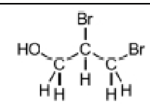
Q# 323/ Chem 14 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(c)(i)	acidified AND $KMnO_4$ hot AND c(oncentrated)	2

Q# 324/ Chem 14 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(ii)	mirror images are super(im)posable / no chiral carbon / no chiral centre / it is achiral	1
	(one) C of double bond has identical groups / H (atoms) (attached) OR (one) end of double bond has identical groups / 2 H (atoms) (attached)	1
3(d)(iii)	X = 2-chlorobutane	1
	Y = 1-chlorobutane	1
3(d)(iv)	optical (isomerism)	1
3(d)(v)	one acceptable 3D structure of 2-chlorobutane	1
	the 2nd optical isomer EITHER drawn as a mirror image of the first OR the same bond pattern is shown but two of the groups swap positions. 	1

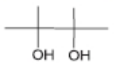
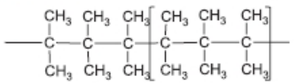
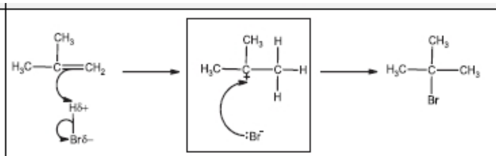
Q# 325/ Chem 14 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)(i)		1
4(b)(ii)	(electrophilic) addition	1
	bromine decolourises / turns colourless / fades (from orange / brown)	1
4(b)(iii)	$HOCH_2CHBrCH_2Br$ OR 	1
4(b)(iv)	CO_2 / carbon dioxide	1

Q# 326/ Chem 14 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	(electrophilic) addition	1
3(c)(ii)	**S** has CH_3CHOH **OR** methyl / CH_3 group next to CHOH	1
3(c)(iii)	positive inductive effect of more alkyl groups / more alkyl groups donate electron density	1
	secondary carbocation / secondary intermediate is more stable (than primary)	1

Q# 327/ Chem 14 ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	4-methylhex-2-ene	1	1
4(a)(ii)	(Molecules with the) same structural formula (and same molecular formula) with different arrangement of atoms/groups (in space)	1	1
4(a)(iii)	4 double-bond / alkene (2) different groups on each double-bonded carbon (one) chiral carbon (centre) / (one) carbon atom has 4 different groups attached / is asymmetric / is chiral	1 1 1 1	4
4(b)(i)	2,3-dimethylbut-2-ene	1	1
4(b)(ii)		1	1
4(b)(iii)	Propanone	1	1
4(b)(iv)		1	1
4(c)(i)	(2-)methylprop(-1-)ene	1	1
4(c)(ii)		4	4
4(c)(iii)	(tertiary carbocat)ion / (tertiary) intermediate is / C+ with least number of hydrogen atoms bonded to it is more stable (than primary) due to (positive) inductive effect of three/more methyl groups (cf one) / three / more electron releasing methyl groups three / more electron donating methyl groups reducing charge (density) on C+	1 1 1	3
	Total:		18

Q# 328/ Chem 14 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(e) (i)	**V** = $CH_3CH_2CHCHCH_2CH_3$ / $CH_3CH_2CH{=}CHCH_2CH_3$ **T** = $CH_3CH_2CH(OH)CH(OH)CH_2CH_3$	[1] [1]	[2]
(ii)	**V** = geometric(al) / *cis-trans* / *E–Z* **T** = optical	[1] [1]	[2]
			[15]

Q# 329/ Chem 14 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(d)	**B** is $CH_2{=}CHCH_2CH_3$ OR $CH_3CH{=}CHCH_3$ OR $(CH_3)_2C{=}CH_2$ distinguished by addition of bromine brown/red/orange/yellow to colourless/decolourises with **B** (but not **A**)	[1] [1] [1]	[3]
			[7]

Q# 330/ Chem 14 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(b)	$C_8H_{18} + 12\frac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$	[1]	[1]

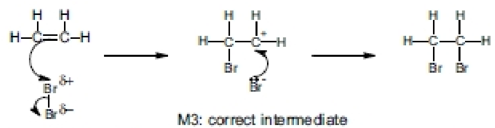
Q# 331/ Chem 14 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

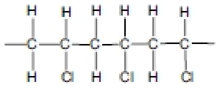
(ii)	$CH_3CH_2CH(CH_3)CH_2CH_2CH_3$ 3-methylhexane $CH_3CH(CH_3)CH(CH_3)CH_2CH_3$ / $(CH_3)_2CHCH(CH_3)CH_2CH_3$ 2,3-dimethylpentane	[1] [1] [1] [1]	[4]
(b) (i)	$C_7H_{16} + 11O_2 \rightarrow 7CO_2 + 8H_2O$	[1]	[1]
(ii)	$C_7H_{16} + 4O_2 \rightarrow 7C + 8H_2O$	[1]	[1]
(c) (i)	(Free) Radical Substitution	[1]	[1]
(ii)	$Cl_2 \rightarrow 2Cl\bullet$ OR $Cl_2 \rightarrow Cl\bullet + Cl\bullet$ $C_7H_{16} + Cl\bullet \rightarrow \bullet C_7H_{15} + HCl$ $\bullet C_7H_{15} + Cl_2 \rightarrow C_7H_{15}Cl + Cl\bullet$ $\bullet C_7H_{15} + Cl\bullet \rightarrow C_7H_{15}Cl$ OR $\bullet C_7H_{15} + \bullet C_7H_{15} \rightarrow C_{14}H_{30}$ Initiation; Propagation; Termination (used correctly)	[1] [1] [1] [1] [1]	[5]
			[15]

Q# 332/ Chem 14 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(b) (i)	but-1-ene / 1-butene but-2-ene / 2-butene	[1] [1]	[2]
(ii)	but-2-ene **AND** two different groups on each carbon (of C=C) double bond means no free rotation	[1] [1]	[2]
(iii)	 and (either way round)	[1+1]	[2]
			[13]

Q# 333/ Chem 14 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a)	decolourisation with an alkene at room conditions / quickly / easily / **OR** alkane needs higher temp / UV / is slow at room conditions double / π / pi bond / C=C present in alkenes	1 1	2
(c) (i)	Electrophilic Addition	1 1	2
(ii)	 M1: 2 correct curly arrows M2: correct dipole M3: correct intermediate M4: curly arrow from lone pair on Br^- to C^+		4

(d)	 minimum of three repeat units	2	2

Q# 334/ Chem 14 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(b) (i)	UV light/ sunlight/ high temperature	1	1
(ii)	(Free) radical Substitution	1 1	2
(iii)	$\bullet C_2H_5$ + $\bullet C_2H_5$ → C_4H_{10}	1	1
(iv)	C_2H_5Br + $Br\bullet$ → $\bullet C_2H_4Br$ + HBr **OR** $\bullet C_2H_4Br$ + Br_2 → $C_2H_4Br_2$ + $Br\bullet$	1	1

Q# 335/ Chem 14 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) (i) alkanes **or** paraffins **not** hydrocarbons (1)

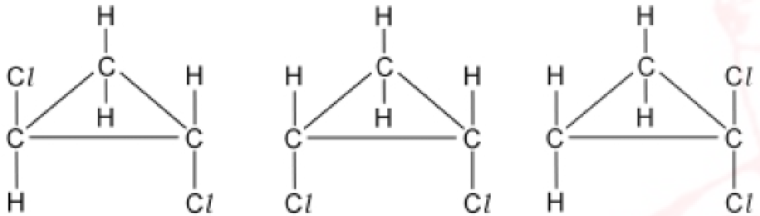
(ii) $2C_4H_{10} + 13O_2 \rightarrow 8CO_2 + 10H_2O$ (1) [2]

Q# 336/ Chem 14 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) 117° to 120° (1) [1]

(b) (i) electrophilic addition (1)

(ii)



1 mark for each correct structure
allow correctly drawn optical isomers of the first structure (3 × 1) [4]

[Total: 5]

3 (a) (i) **anode** $Cl^-(aq) \rightarrow \frac{1}{2} Cl_2(g) + e^-$ (1)

cathode $H^+(aq) + e^- \rightarrow \frac{1}{2}H_2(g)$ **or**
$2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$ (1)

(ii) because iron in steel will react with chlorine (1) [3]

(b) **sodium**
burns with a yellow **or** orange flame **or**
forms a white solid
allow – **once only** – colour of chlorine disappears (1)
$2Na + Cl_2 \rightarrow 2NaCl$ (1)

phosphorus
burns with a white **or** yellow flame **or**
colour of chlorine disappears – if **not** given for Na – **or**

for PCl_5 forms a white **or** pale yellow solid

for PCl_3 forms a colourless liquid (1)

$P + 2\frac{1}{2}Cl_2 \rightarrow PCl_5$ **or** $P_4 + 10Cl_2 \rightarrow 4PCl_5$

or

$P + 1\frac{1}{2}Cl_2 \rightarrow PCl_3$ **or** $P_4 + 6Cl_2 \rightarrow 4PCl_3$

equation must refer to compound described (1) [4]

Q# 337/ Chem 14 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

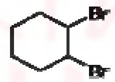
(b)

	with HBr	**with MnO_4^-**
colour at start	colourless	purple **or** pink
colour after reaction	colourless	colourless **or** decolourised
structural formula of product	CH_3CH_2Br	$HOCH_2CH_2OH$

with hydrogen bromide
from colourless to colourless both colours required
do not allow 'clear' instead of colourless (1)
CH_3CH_2Br (1)
with potassium manganate(VII)
from purple/pink to colourless/decolourised both colours required (1)
$HOCH_2CH_2OH$ (1) [4]

(c) (i) C_6H_{10} (1)

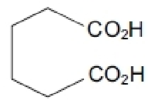
(ii)



accept answers which have $-CH_2-$ in the ring (1)

(iii) electrophilic (1)
addition (1)

(iv)



or

$HO_2C(CH_2)_4CO_2H$ **or**
$HO_2CCH_2CH_2CH_2CH_2CO_2H$ (1)
accept answers which have $-CH_2-$ in the ring [5]

Q# 338/ Chem 14 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) (i) break large hydrocarbons into smaller hydrocarbons **or** break down large hydrocarbons (1)

smaller hydrocarbons are more useful **or** smaller hydrocarbons are more in demand (1)

(ii) using high temperatures/thermal cracking **or** using catalysts/catalytic cracking (1)

(iii) $C_{14}H_{30} \rightarrow C_7H_{16} + C_7H_{14}$ **or**
$C_{14}H_{30} \rightarrow C_7H_{16} + C_2H_4 + C_5H_{10}$ **or**
$C_{14}H_{30} \rightarrow C_7H_{16} + C_3H_6 + C_4H_8$ **or**
$C_{14}H_{30} \rightarrow C_7H_{16} + 2C_2H_4 + C_3H_6$ (1)

do not allow any equation with H_2 [4]

Q# 339/ Chem 14 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) alkanes/paraffins
not hydrocarbon (1) [1]

(b) **2 $C_{14}H_{30}$ + 43 $O_2 \rightarrow$ 28 CO_2 + 30 H_2O or**

$C_{14}H_{30}$ + $^{43}/_2O_2 \rightarrow$ **14** CO_2 + **15** H_2O (1) [1]

(c) (i) mass of $C_{14}H_{30}$ burnt

$\frac{8195 \times 10.8}{1000} = 88.506 = 88.5$ t (1)

(ii) mass of CO_2 produced

M_r of $C_{14}H_{30}$ = (14 x 12 + 30 x 1) = 198 (1)

2 x 198 t of $C_{14}H_{30} \rightarrow$ 28 x 44 t of CO_2

88.5 t of $C_{14}H_{30} \rightarrow \frac{28 \times 44 \times 88.5}{2 \times 198}$ (1)

= 275.3 t of CO_2 (1)

allow 275.4 t if candidate has used 88.506
allow ecf on wrong value for M_r of $C_{14}H_{30}$ [4]

Q# 340/ Chem 14 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i) a compound which contains **only** carbon and hydrogen (1)

(ii) separation of compounds by their boiling points (1) [2]

(b) (i) high temperature **and** high pressure (1)

high temperature **and** catalyst (1)

(ii) $C_{11}H_{24} \rightarrow C_5H_{12} + C_6H_{12}$ **or**

$C_{11}H_{24} \rightarrow C_5H_{12} + 2C_3H_6$ **or**

$C_{11}H_{24} \rightarrow C_5H_{12} + 3C_2H_4$ (1) [3]

(c) (i)

$CH_3CH_2CH_2CH_2CH_3$	$CH_3CH_2CH(CH_3)CH_3$	$CH_3C(CH_3)_2CH_3$
isomer **B**	isomer **C**	isomer **D**
(1)	(1)	(1)

(ii) the straight chain isomer (isomer **B** above) (1)

it has the greatest van der Waals' forces (1)

because unbranched molecules have greater area of contact/ can pack more closely together (1) [6]

Q# 341/ Chem 14 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(e) (i) heat released = m c δT = 200 x 4.18 x 27.5 (1)

= 22990 J = 23.0 kJ (1)

(ii) 23.0 kJ produced from 0.47 g of **E**

2059 kJ produced from $\frac{0.47 \times 2059}{23.0}$ g of **E** (1)

= 42.08 g of **E** (1)

allow ecf in **(i)** or **(ii)** on candidate's expressions [4]

(f) C_3H_6 = 42

E is C_3H_6

for ecf, **E** must be unsaturated and be no larger than C_5 (1) [1]

Q# 342/ Chem 14 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(b) $C_xH_y + \left(x+\frac{y}{4}\right)O_2 \longrightarrow xCO_2 + \frac{y}{2}H_2O$

xCO_2 (1)

$\frac{y}{2}H_2O$ (1) [2]

(c) (i) oxygen/O_2 (1)

(ii) carbon dioxide/CO_2 (1)

(iii) 10 cm^3 (1)

(iv) 20 cm^3 (1) [4]

(d) $C_xH_y + \left(x+\frac{y}{4}\right)O_2 \longrightarrow xCO_2 + \frac{y}{2}H_2O$

10 cm^3 20 cm^3 10 cm^3

1 mol of C_xH_y gives 1 mol of CO_2

whence x = 1 (1)

1 mol of C_xH_y reacts with 2 mol of O_2

whence $\left(x+\frac{y}{4}\right) = 2$

and $y = 4$ (1)

molecular formula is CH_4 (1) [3]

[Total: 11]

Q# 343/ Chem 14 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(b) (i) initiation (1)

Cl_2 + uvl $\rightarrow$ 2Cl (1)

propagation (1)

$CH_4 + Cl \rightarrow CH_3 + HCl$

$CH_3 + Cl_2 \rightarrow CH_3Cl + Cl$ both needed (1)

termination (1)

$CH_3 + CH_3 \rightarrow C_2H_6$ **or**

$CH_3 + Cl \rightarrow CH_3Cl$ **or**

$Cl + Cl \rightarrow Cl_2$ (1)

(ii) CH_3/methyl radical (1) [7]

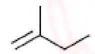
Q# 344/ Chem 15 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(e)(iii)	M1: (water solvent)	$CH_3CH_2CH_2OH$ / propan-1-ol	**AND** NaBr / sodium bromide	2
	M2: (ethanol solvent)	CH_3CHCH_2 / propene	**AND** H_2O / water **AND** NaBr / sodium bromide	

Q# 345/ Chem 15 ALvl Chemistry/2021/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6(e)(i)	elimination	1
6(e)(ii)	**M1** NaOH / KOH	1
	M2 ethanolic solution / ethanol / alcohol + heat	1

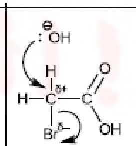
Q# 346/ Chem 15 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)(i)	HI(g) / PI_3 / P and I_2	1
4(c)(i)	2(-)iodo(-)2(-)methylbutane	1
4(c)(ii)	Nucleophilic substitution / S_N	1
4(c)(iii)		1

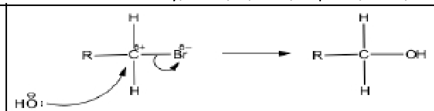
Q# 347/ Chem 15 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(c)(iii)	nucleophilic substitution / S_N2	1

Q# 348/ Chem 15 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

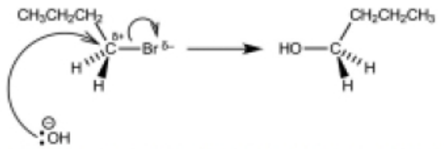
4(b)(v)	 **M1** lone pair on $^-$OH **AND** curly arrow from lone pair to C of C—Br **M2** correct dipole on C—Br **AND** curly arrow from bond to Br	2

Q# 349/ Chem 15 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

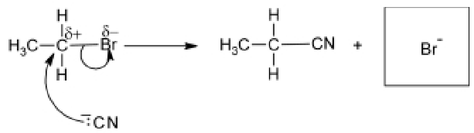
3(b)	 M1 lone pair on O of $^-$OH AND curly arrow from lone pair to C(—Br) M2 correct dipole on $C^{\delta+}$—$Br^{\delta-}$ AND curly arrow from bond to Br	2

3(c)(ii)	S_N / nucleophilic substitution	1
	$((CH_3)_3CBr$ / tertiary halogenoalkane) forms a stable (carbo)cation / stable intermediate (as charge density on cation is reduced) OR (in) 1-bromobutane / primary halogenoalkane there is no (stable) (carbo)cation / intermediate formed	1
	(because) there are (3 /more) alkyl / methyl groups AND (+) I / (greater) inductive effect OR (because) there is only one / fewer alkyl / methyl group(s) (compared to reaction with 2-bromo-2-methyl propane / tertiary halogenoalkane) AND limited (+) I / (less) inductive effect	1

Q# 350/ Chem 15 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)	 lone pair on O **AND** curly arrow from O to C of C–Br dipole on C–Br **AND** curly arrow from C–Br to Br product (butan-1-ol)	1 1 1	3

Q# 351/ Chem 15 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a)			[2]
	M1 = lone pair on C of CN– AND curly arrow from lone pair to C of C—Br	[1]	
	M2 = correct dipole on C—Br, curly arrow from C—Br bond to Br AND Br^-	[1]	
(c) (i)	sodium/potassium hydroxide aqueous	[1] [1]	[2]
(ii)	ethanol	[1]	[1]

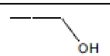
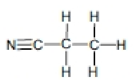
Q# 352/ Chem 15 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

(e)	NaOH(aq)	[1]	[1]

Q# 353/ Chem 15 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(ii)	NaOH / KOH warm / heat / reflux AND aqueous	[1] [1]	[2]
(b) (i)	CH_2=CH_2 / ethane / C_2H_4 / CH_2CH_2	[1]	[1]
(ii)	White ppt / solid / suspension	[1]	[1]
(iii)	$Ag^+(aq) + Cl^-(aq) \rightarrow AgCl(s)$	[1]	[1]

Q# 354/ Chem 15 ALvl Chemistry/2014/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(e) (i)	NaOH/KOH	1	
	ethanolic / alcoholic **AND** heat / reflux	1	2
(ii)		1	1
(iii)		1	
	Propanenitrile / propanonitrile / propionitrile / ethyl cyanide / cyanoethane	1	2
			20

Q# 355/ Chem 15 ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) reaction 1 reagent NaOH/KOH (1)

solvent H_2O/water/aqueous (1)

reaction 2 reagent NH_3/ammonia (1)

solvent ethanol/C_2H_5OH/alcohol (1)

reaction 3 reagent NaOH/KOH (1)

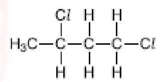
solvent ethanol/C_2H_5OH/alcohol (1) [6]

(b) with $CH_3CH_2CH_2CH_2I$ rate would be faster (1)

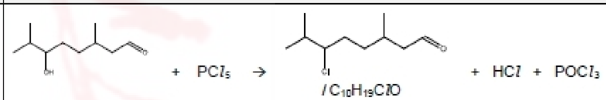
C-I bond is weaker than C-Br bond (1)

C-I bond energy is 240 kJ mol^{-1}, C-Br bond energy is 280 kJ mol^{-1}
data **must** be quoted for this mark (1) [3]

Q# 356/ Chem 16 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	substitution	1
3(c)(ii)		1

Q# 357/ Chem 16 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	**M1** Q orange → green **M2** R orange → green **M3** –CHO / aldehyde (in both) (and 2° / secondary alcohol in R) reacts / oxidised	3
3(d)(ii)	 **M1** correct formula of organic product **M2** correct inorganic products	2

Q# 358/ Chem 16 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	potassium/sodium dichromate [(VI)] / $K_2Cr_2O_7$ / $Na_2Cr_2O_7$ acidified AND (heat) under reflux	2
4(a)(ii)	$C_2H_5OH + 2[O] \rightarrow CH_3CO_2H + H_2O$	1

Q# 359/ Chem 16 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(iii)	*Construct an equation* $(CH_2OH)_2 + SOCl_2 \rightarrow (CH_2Cl)_2 + SO_2 + H_2O$	1
4(d)	Forms hydrogen bonds with water	1

Q# 360/ Chem 16 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(c)(ii)	**M1:** (excess dichromate and) heat under reflux **M2:** to allow full oxidation (of alcohol and aldehyde groups)	2

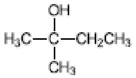
Q# 361/ Chem 16 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	**M1:** potassium dichromate[(VI)] **M2:** acid(ified) AND (heat under) **reflux**	2

Q# 362/ Chem 16 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(i)	**M1** acidified / H^+ $Cr_2O_7^{2-}$ / (potassium / sodium) dichromate OR manganate(VII) / MnO_4^- / $KMnO_4$ **M2** (heat under) reflux	2

Q# 363/ Chem 16 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(e)(ii)	$C_2H_5CH(OH)C_2H_5 + HCl \rightarrow C_2H_5CH(Cl)C_2H_5 + H_2O$	1
2(e)(iii)		1
2(e)(iv)	substitution	1

Q# 364/ Chem 16 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(iii)	see table below	1

	alcohol group present in Z
primary	✓
secondary	✓
tertiary	

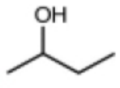
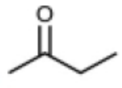
Q# 365/ Chem 16 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(b)(iv)	$SOCl_2$ OR PCl_5 OR PCl_3 OR c(oncentrated) HCl	1

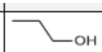
Q# 366/ Chem 16 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	Iodoform / triiodomethane	1
4(a)(ii)	butan-2-ol	1
4(b)	$CH_3CH_2CH_2CH_2OH$ $(CH_3)_3COH$ $(CH_3)_2CHCH_2OH$	2
4(c)(i)	oxidation / redox	1
4(c)(ii)	acidified / H^+ AND potassium / sodium dichromate((VI)) or formulae	1
4(c)(iii)	*In any order:*	
	but-1-ene	1
	but-2-ene	1
	cis / *Z*- AND *trans* / *E*-	1

Q# 367/ Chem 16 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(iv)	**S** = 	1
	T = 	1
	U = 	1
3(c)(v)	$CH_3CHOHCH_2CH_3 + [O] \rightarrow CH_3COCH_2CH_3 + H_2O$	1
3(d)(i)	methyl pentanoate	1

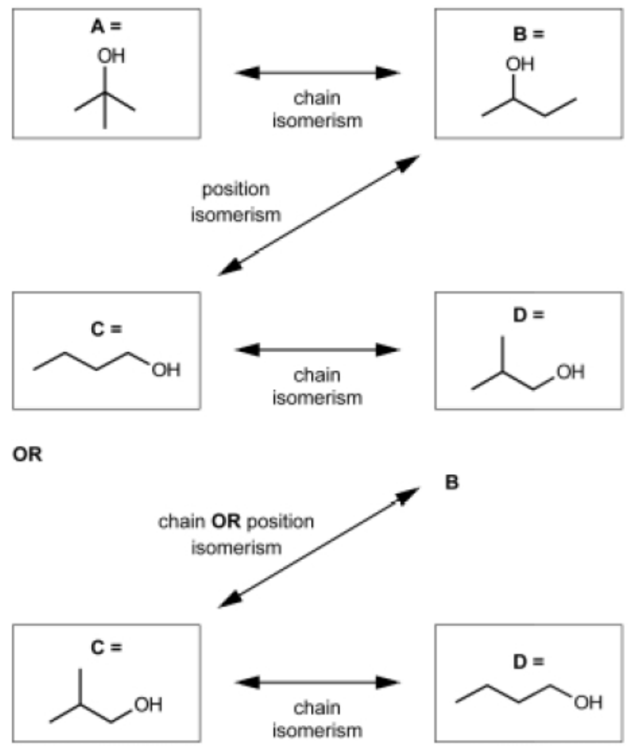
Q# 368/ Chem 16 ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(a)		1	1
5(b)	$H^+ / Cr_2O_7^{2-}$	1	2
	(heat under) reflux	1	
5(c)	$H^+ / Cr_2O_7^{2-}$	1	2
	(heat and) distil	1	

Q# 369/ Chem 16 ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i)	$CH_3CH_2OH + HCl \rightarrow CH_3CH_2Cl + H_2O$ or $CH_3CH_2OH + PCl_5 \rightarrow CH_3CH_2Cl + HCl + POCl_3$ or $CH_3CH_2OH + SOCl_2 \rightarrow CH_3CH_2Cl + HCl + SO_2$	[1+1]	[2]
(c) (i)	CH_3CHO / ethanal	[1]	[1]
(ii)	CH_3CH_2OH higher bpt than CH_3CHO ora	[1]	
	due to hydrogen bonding in ethanol/ stronger IMFs	[1]	[3]
	prevents further oxidation owtte	[1]	
			[11]

Q# 370/ Chem 16 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a)		[1] [1] [1] [1] [1] [1] [1]	[7]

Q# 371/ Chem 16 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(b) (i)	Oxidation	1	[1]
(ii)	Sodium/potassium dichromate or correct formula H^+/acidified and (heat under) reflux	1 1	[2]

Q# 372/ Chem 16 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i) $C_2H_5OH \rightarrow C_2H_4 + H_2O$ (1)

(ii) elimination **or** dehydration (1)

(iii) phosphoric acid **or** concentrated sulfuric acid
sulfuric acid must be 'concentrated'
allow aluminium oxide (1) [3]

Q# 373/ Chem 17 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(i)	carbonyl	1
4(c)(ii)	CHI_3	1
4(c)(iii)	M1 / M2  M3 chain (isomerism)	3

Q# 374/ Chem 17 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	red / orange / yellow precipitate / ppt / solid [1] silver mirror / silver / grey solid / precipitate / ppt [1] effervescence / bubbling / fizzing [1]	3

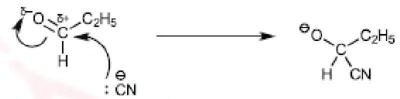
Q# 375/ Chem 17 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(b)	**M1:** red / orange / yellow ppt / solid **M2:** silver mirror OR silver / grey / black / brown ppt / solid	2
4(d)(i)	$CH_2OHCHO + 2[H] \rightarrow (CH_2OH)_2$	1
4(d)(ii)	$NaBH_4$ / $LiAlH_4$	1

Q# 376/ Chem 17 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(vi)	$CH_3COCH_3 + 3I_2 + 4OH^- \rightarrow (1)CH_3COO^- + 3H_2O + 3I^- + \mathbf{CHI_3}$ **M1:** correctly balanced **M2:** CHI_3 product	2
4(c)(vii)	yellow ppt / yellow solid	1

Q# 377/ Chem 17 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	**M1:** potassium dichromate[(VI)] **M2:** acid(ified) AND (heat under) **reflux**	2
3(c)(ii)	(**M1:** *correct identity of R and statement re: reaction 3 ONLY ketone reduced*) R (is 2-hydroxybutanoic acid) AND as (only) C=O / ketone reduced (**M2:** *correct explanation re: strength of reducing agents*) $NaBH_4$ cannot reduce the COOH / **carboxylic acid** OR $LiAlH_4$ can reduce the COOH / **carboxylic acid**	2
3(c)(iii)	 **M1:** Presence of :CN (if bonding shown, must be unambiguous triple bond) **M2:** curly arrow from :CN lone pair to carbonyl carbon **M3:** correct dipole AND curly arrow from double bond to oxygen **M4:** correct intermediate drawn	4
3(c)(iv)	$C_2H_5CH(OH)CN + \mathbf{HCl + 2H_2O} \rightarrow C_2H_5CH(OH)COOH + \mathbf{NH_4Cl}$	1
3(c)(v)	Any two of three absorption references: • absorption 2200–2250 (cm^{-1}) shows presence of C≡N • lack of absorption at 1680–1730 (cm^{-1}) shows lack of C=O • lack of absorption at 2500–3000 (cm^{-1}) shows lack of RCO_2–H / O–H in RCO_2H	2

Q# 378/ Chem 17 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

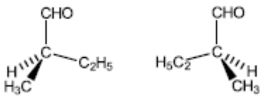
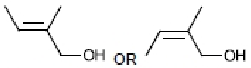
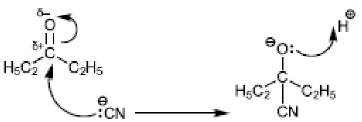
5(c)(i)	carbonyl / aldehyde / ketone	1
5(c)(ii)	tertiary halogenoalkane	1

Q# 379/ Chem 17 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(ii)	nucleophilic addition	1
3(a)(iii)	yellow / orange / red ppt / solid	1

Q# 380/ Chem 17 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	(2,2–)dimethylpropanal	1
4(a)(ii)	sp^2	1
4(b)(i)	acidified potassium dichromate**[(VI)] AND** heat under reflux	1
4(b)(iii)	$(CH_3)_3CCHO + 2[H] \rightarrow (CH_3)_3CCH_2OH$	1

4(c)(i)	• orange / red / yellow precipitate • orange / red / yellow precipitate	1
4(c)(ii)	Aldehyde	1
4(c)(iii)	has a carbon / atom attached / bonded to four different atoms / groups / groups of atoms / chains	1
4(c)(iv)	 **M1:** Correct 3D representation **M2:** Correct 3D representation of drawn enantiomer	2
4(c)(vi)	 **M1:** skeletal alkene group AND C5 structure **M2:** one alcohol group **M3:** branched chain AND capable of geometrical isomerism	3
4(c)(vii)	**M1:** Correct structure of **X** and correct dipole on C=O **M2:** curly arrow from C=O bond to O AND intermediate with CN attached and –ve charge on the O **M3:** curly arrow from lone pair on CN^- to C(=O) in **X** AND curly arrow from lone pair in the intermediate to H^+ 	3
4(c)(viii)	catalyst	1

Q# 381/ Chem 17 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(a)	**M1** a lone pair / electron pair donor	1
	M2 (:)CN^- / $^-$(:)CN / cyanide ion	1

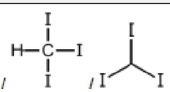
Q# 382/ Chem 17 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

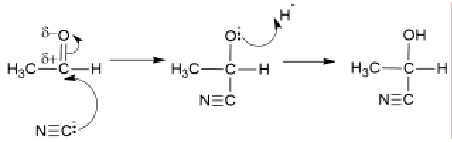
3(b)	$C_5H_{10}O + 2[H] \rightarrow C_5H_{12}O$	1

Q# 383/ Chem 17 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(i)	reducing agent / reductant	1
4(c)(ii)	$C_2H_2O_3 + 2[H] \rightarrow C_2H_4O_3$ **M1** for correct molecular formulae $C_2H_2O_3$ and $C_2H_4O_3$ **M2** for balancing	2

Q# 384/ Chem 17 ALvl Chemistry/2017/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

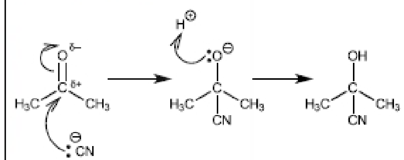
4(c)(i)	P = propanal	1
	Q = propanone	1
4(c)(ii)	tr(i)iodomethane / CHI_3 / 	1

4(d)(ii)		
	curly arrow from lone pair on :C≡N to $C^{(\delta+)}$	1
	correct dipole on carbonyl $^{\delta+}C=O^{\delta-}$ AND curly arrow from bond to $O^{(\delta-)}$	1
	correct intermediate, including C–O^- AND curly arrow from lone pair to H^+	1
	Total:	19

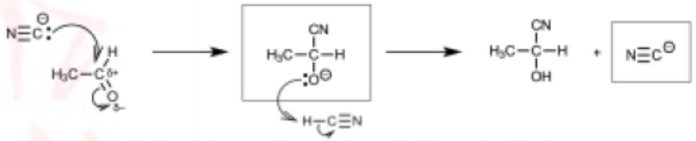
Q# 385/ Chem 17 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5/www.SmashingScience.org

(ii)	pent-3-en(e)-2-one OR 3-penten-2-one	[1]	[1]
(iii)	red / orange / yellow precipitate / solid	[1]	[1]

Q# 386/ Chem 17 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

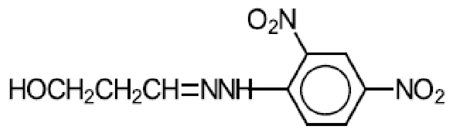
(d) (i)	nucleophilic addition	[1]	[1]
(ii)	 correct dipole on carbonyl curly arrow from lone pair on CN^- AND from C=O to O correct intermediate curly arrow from lone pair on O^- to H^+ correct product	[1] [1] [1] [1] [1]	[5]
			[17]

Q# 387/ Chem 17 ALvl Chemistry/2015/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(ii)	(Planar) carbonyl so (equal chance of nucleophile) attacking either side	[1]	[1]
3 (c) (i)	 M1 = lone pair **AND** curly arrow from lone pair to carbonyl C M2 = partial charges on C=O **AND** curly arrow from bond (=) to $O^{\delta-}$ M3 = structure of intermediate including charge M4 = lone pair **AND** two correct curly arrows (from lone pair to H **AND** from H—C to C) M5 = CN^-	[1] [1] [1] [1] [1]	[5]
(ii)	(CN^- regenerated so) catalyst	[1]	[1]
			[12]

Q# 388/ Chem 17 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(b) (i)



(1)

(ii) red **or** orange (1) [2]

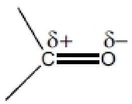
[Total: 12]

Q# 389/ Chem 17 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i) nucleophilic addition
both words are necessary (1)

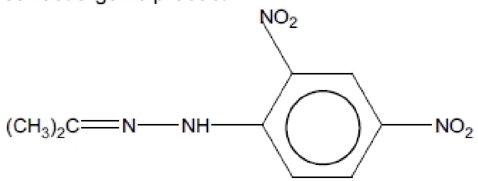
(ii) NaCN and H_2SO_4 **or**
HCN plus CN^-
do not allow HCN on its own (1)

(iii) correct δ+ **and** δ-, i.e.



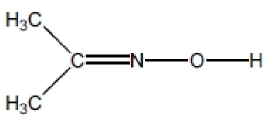
(1) [3]

(b) (i) correct organic product



C=N bond must be clearly shown (1)
H_2O formed/ equation balanced (1) [2]

(ii)

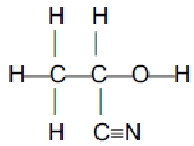


(1) [1]

[Total: 6]

Q# 390/ Chem 17 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

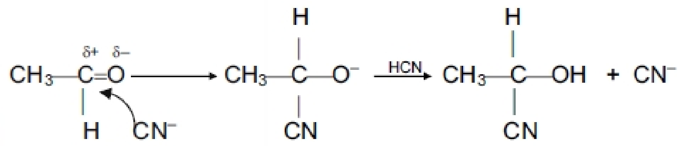
(e) (i)



C≡N must be shown (1)

(ii) nucleophilic addition (1)

(iii)



C=O dipole correctly shown **or** correct curly arrow on C=O (1)
attack on $C^{\delta+}$ by C of CN^- (1)
correct intermediate (1)
CN^- regenerated (1) [5 max]

[Total: 13]

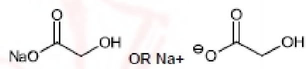
Q# 391/ Chem 18 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)(i)	**M1** (add) group 1 carbonate / group 1 bicarbonate / Na_2CO_3 / $NaHCO_3$ etc. **M2** effervescence / fizzing / bubbling	2

Q# 392/ Chem 18 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(b)(i)	L = CH_3OH / methanol [1] conditions = acid(ic) / H^+ / H_2SO_4 **AND** (heat under) reflux [1]	2

Q# 393/ Chem 18 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(i)		1
4(c)(ii)	Not a strong (enough) reducing agent	1

Q# 394/ Chem 18 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(ii)	(**M1:** *correct identity of R and statement re: reaction 3 ONLY ketone reduced*) R (is 2-hydroxybutanoic acid) **AND** as (only) C=O / ketone reduced	2
	(**M2:** *correct explanation re: strength of reducing agents*) $NaBH_4$ cannot reduce the COOH / carboxylic acid OR $LiAlH_4$ can reduce the COOH / carboxylic acid	

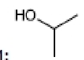
Q# 395/ Chem 18 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6(c)	*Structural formula of X:* HCO_2H OR HCOOH	1
6(d)	**M1** *reagent* (2,4–) DNPH / (2,4)-dinitrophenylhydrazine **M2** *observation* yellow / orange / red precipitate	2
6(e)	*Predict two differences, with reasons, between spectra of **Y**, $CH_3CH_2COCH_3$ and 2-methylbut-1-ene (shown)* *first difference* **M1** absence of peak/ absorption at 3100 (cm^{-1}) as no longer any =C–H present (in Y) *second difference* **M2** peak at 1650 (cm^{-1}) moves to the left to any value / range of values between 1670 and 1740) due to disappearance of C=C (in Y) and appearance of C=O (in Y) OR absence of peak at 1650 (cm^{-1}) as no longer any C=C present (in Y) AND appearance of peak (in Y) at (any value / range of values) between 1670-1740(cm^{-1}) due to C=O	2
6(f)(i)	$CH_3CH_2CO_2H + 4[H] \rightarrow CH_3CH_2CH_2OH + H_2O$	1
6(f)(ii)	propan-1-ol ALLOW propan-2-ol as error carried forward from **6f(i)**	1
6(g)(i)	*Molecular formula of W* $C_3H_6O_2$	1
6(g)(ii)	*Possible structure of W* CH_3COOCH_3 OR $HCOOCH_2CH_3$	1

Q# 396/ Chem 18 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(v)	**M1** hydrolysis **M2** esterification / condensation	2

Q# 397/ Chem 18 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)(ii)	**M1:** A has **H-bonding** (between molecules) **M2:** B only has dipole–dipole / VdW forces (between molecules) **M3:** H-bonding is stronger / requires more energy to overcome	3
4(b)(iv)	**M1:**  / $CH_3CH(OH)CH_3$ **M2:** H_2SO_4 / sulfuric acid	2

Q# 398/ Chem 18 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(iii)	(see table below)	1
4(d)(i)	A and B	1
4(d)(ii)	(see tables below)	2, 3, 3

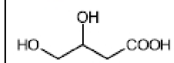
4(c)(iii):

	alcohol group present in Z
primary	✓
secondary	✓
tertiary	

4(d)(ii):

	Compound(s)	Observation	Marks
Reaction with Tollens' reagent	B ✓	silver mirror OR grey / black / brown / silver precipitate ✓	2
Reaction with alkaline aq. iodine	A ✓ and C ✓	(Pale) yellow precipitate /solid ✓	3
Reaction with sodium metal	C ✓ and D✓	Effervescence / sodium/solid disappears ✓	3

Q# 399/ Chem 18 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(c)(ii)	**M1** catalyst **M2** ethanoic acid / CH_3CO_2H	2
4(c)(iii)	nucleophilic substitution / S_N2	1
4(c)(iv)	 **M1** hydrolysed nitrile on straight-chain 4C backbone **M2** 3,4-diol	2

Q# 400/ Chem 18 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	carbon dioxide **AND** water	1

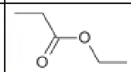
Q# 401/ Chem 18 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	methyl pentanoate	1

Q# 402/ Chem 18 ALvl Chemistry/2016/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(d)	(1-)propyl propanoate	1	1
	Total:		6

Q# 403/ Chem 18 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(d) (i)	(conc) H$^+$ / (conc) acid / (conc)H_2SO_4 / (conc)H_3PO_4	[1]	[1]
(ii)		[1]	[1]
(iii)	ethyl propanoate	[1]	[1]

Q# 404/ Chem 18 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a)	$CH_3CH_2CO_2H + 4[H] \rightarrow CH_3CH_2CH_2OH + H_2O$	1+1	[2]
(c)	$2\ CH_3CH_2CO_2H + CaCO_3 \rightarrow (CH_3CH_2CO_2)_2Ca + H_2O + CO_2$	1+1	[2]
(d) (i)	CH_3CO_2H warm / hot / high temperature / heat / reflux **AND** concentrated sulfuric acid	1 1	[2]
(ii)	water (or hydrogen chloride or ethanoic acid)	1	[1]
			[10]

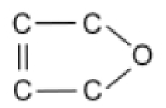
Q# 405/ Chem 18 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(e)

cis **or** Z   *trans* **or** E

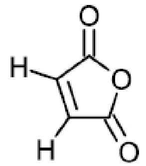
two correct structures (1)
correct labels (1) [2]

(f) correct ring of C and O atoms, i.e.



(1)

correct compound, i.e.



(hydrogen atoms do not need to be shown) (1) [2]

[Total: 18]

Q# 406/ Chem 18 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 **(a)** carboxylic acid **or** $-CO_2H$ **or** $-COOH$ (1) [1]

Q# 407/ Chem 18 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(b) $NaO_2CCH(OH)CH(OH)CO_2Na$ (1) [1]

(d) (i) $C:H:O = \frac{35.8}{12} : \frac{4.5}{1} : \frac{59.7}{16}$ this mark is for correct use of A_r values (1)

$C:H:O = 2.98 : 4.5 : 3.73$

$C:H:O = 1 : 1.5 : 1.25$ this mark is for evidence of correct calculation (1)

gives empirical formula of **W** is $C_4H_6O_5$

(ii) $C_4H_6O_5 = 12 \times 4 + 1 \times 6 + 16 \times 5 = 134$

molecular formula of **W** is $C_4H_6O_5$ (1) [3]

(e) (i) $n(OH^-) = \frac{29.4 \times 100}{1000} = 0.0294$ (1)

$n(W) = \frac{1.97}{134} = 0.0147$ (1)

no. of $-CO_2H$ groups present in one molecule of **W** $= \frac{0.0294}{0.0147} = 2$ (1)

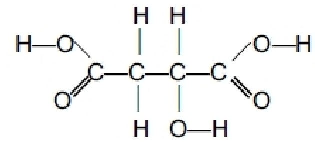
or $n(OH^-) = \frac{29.4 \times 1.00}{1000} = 0.0294$ (1)

1.97 g **W** ≡ 0.0294 mol NaOH

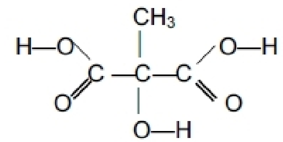
134 g **W** $\equiv \frac{0.0294 \times 134}{1.97} = 1.999 \approx 2$ mol NaOH (1)

no. of $-CO_2H$ groups present in 1 molecule of **W** = 2 (1) [3]

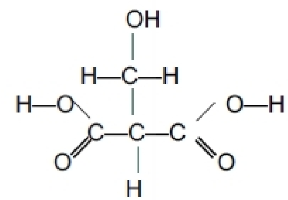
(ii)



or



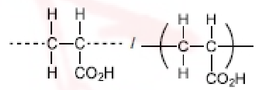
or



one correct structure (1)
correctly displayed (1)
allow any correct ether [2]

[Total: 13]

Q# 408/ Chem 19 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	addition polymerisation	1
3(d)(ii)		1
3(d)(iii)	propan-1-amine / 1-aminopropane	1
3(d)(iv)	alcoholic / ethanolic solution AND high pressure / heat in a sealed container	1

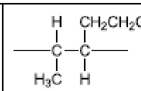
Q# 409/ Chem 19 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(iv)	$C_2H_5CH(OH)CN + HCl + 2H_2O \rightarrow C_2H_5CH(OH)COOH + NH_4Cl$	1

Q# 410/ Chem 19 ALvl Chemistry/2019/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(c)	$CH_3CH(OH)CO_2H$ OR $HO_2CCH(OH)CH_3$	1

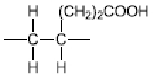
Q# 411/ Chem 20 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(d)(i)	addition	1
4(d)(ii)	 correct carbon backbone including 'dangling' bonds for ONE repeat unit	1
	rest of structure correct	1

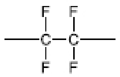
Q# 412/ Chem 20 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	addition polymerisation	1

Q# 413/ Chem 20 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)(ii)		1

Q# 414/ Chem 20 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(i)	addition	1
3(c)(ii)		1
3(c)(iii)	molecule unreactive / inert	1
3(c)(iv)	non-biodegradable creates toxic / harmful gases / HF / CO_2 / CO if burnt	2

Question	Answer	Marks
4(a)	see table below 1 mark for each in column 2 (obs) 1 mark for COOH and OH	4

reagent	observation with glycolic acid	does a reaction occur? ✓ / ×	functional group
Na_2CO_3(aq)	effervescence / fizzing / bubbling	✓	COOH / carboxylic acid
2,4–DNPH	no visible reaction owtte	×	(no group required)
acidified $Cr_2O_7^{2-}$	orange to green	✓	–OH / alcohol

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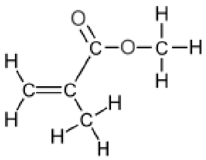
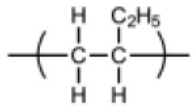
Q# 415/ Chem 20 ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)(ii)	addition polymerisation	1
2(c)(iii)	*two from* save space in landfill avoid litter prevent eyesore non-biodegradable conserves non-renewable resources harmful incineration products harmful to wildlife	2
2(c)(iv)		
	correct monomer	1
	fully displayed	1

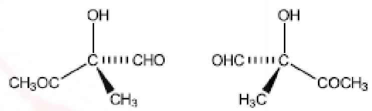
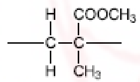
Q# 416/ Chem 20 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(a)(iii)	 C–C backbone with dangling bonds 1 rest of structure 1	2

Q# 417/ Chem 21 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)	$K_2Cr_2O_7$ OR $KMnO_4$ OR Na	A2 make solution turn (orange to) green OR turn colourless OR effervescence	2
	alkaline I_2(aq) / OR 2,4-DNPH	B1 gives yellow/orange ppt OR B1 gives red/yellow/orange ppt	2
	Br_2(aq)	C2 turns it (orange to) colourless	
	Na_2CO_3 $NaHCO_3$	D2 gives effervescence	

Q# 418/ Chem 21 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	red / orange / yellow precipitate / ppt / solid [1] silver mirror / silver / grey solid / precipitate / ppt [1] effervescence / bubbling / fizzing [1]	3
4(a)(ii)		2
4(b)(i)	L = CH_3OH / methanol [1] conditions = acid(ic) / H^+ / H_2SO_4 AND (heat under) reflux [1]	2
4(b)(ii)	 carbon backbone with 'dangling' bonds [1] rest of structure correct [1]	2
4(b)(iii)	Perspex® would not have absorption 1500–1680 cm^{-1} AND Perspex® does not have C=C	1
4(b)(iv)	step 1 KCN / HCN OR NaCN / H_2SO_4 [1] addition [1] step 2 H^+ / H_2SO_4(aq) [1] hydrolysis / substitution [1] step 3 elimination / dehydration [1]	5

Q# 419/ Chem 21 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(b)(iv)	step 1 KCN / HCN OR NaCN / H_2SO_4 [1] addition [1] step 2 H^+ / H_2SO_4(aq) [1] hydrolysis / substitution [1] step 3 elimination / dehydration [1]	5

Q# 420/ Chem 21 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(ii)	stage 1 = reduction stage 2 = substitution		2
3(c)(iii)	G = $C_2H_5CH_2OH$	H = $C_2H_5CH=CHC_2H_5$	2
3(d)	$CH_3CH_2CO_2H$	CH_3COCH_3	2

Q# 421/ Chem 21 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(d)(ii)	CH_3CH_2CN; $CH_3CH_2CO_2H$; $CH_3C(OH)(CN)CH_3$	3

Q# 422/ Chem 21 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(a)(iii)	**M1** CO_3^{2-} **M2** propanoic acid – effervesce. (Propan-1-ol – no reaction)	2
5(d)(i)	*Two structures representing the intermediate* **M1** $C_2H_5C^+HCH_3$ **M2** $CH_3CH_2CH_2C^+H_2$	2
5(d)(ii)	*Identify the most stable intermediate* **M1** $C_2H_5C^+HCH_3$ *explanation* **M2** (more / 2 alkyl groups attached so) it has the greater inductive / electron donating effect	2

Q# 423/ Chem 21 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(e) [3]

	P	Q	R
Na(s)	effervescence	no reaction	no reaction
2,4-DNPH	no reaction	orange ppt	orange ppt
acidified $K_2Cr_2O_7$(aq)	no reaction	no reaction	(turns) green

Q# 424/ Chem 21 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a) [4]

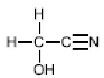
reagent	observation with glycolic acid	does a reaction occur? ✓ / ×	functional group
Na_2CO_3(aq)	effervescence / fizzing / bubbling	✓	COOH / carboxylic acid
2,4–DNPH	no visible reaction owtte	×	(no group required)
acidified $Cr_2O_7^{2-}$	orange to green	✓	–OH / alcohol

1 mark for each in column 2 (obs)

1 mark for COOH and OH

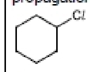
Q# 425/ Chem 21 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)(i) [1]



4(b)(ii)	hydrochloric / sulfuric / nitric / phosphoric acid	1
4(b)(iii)	free-radical substitution	1
4(b)(iv)	UV (light) / sunlight	1

Q# 426/ Chem 21 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(a)(i)	ultraviolet / UV light	1
4(a)(ii)	initiation HC*l* propagation 	4
4(b)	elimination	1

Q# 427/ Chem 21 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i) carbon dioxide AND water [1]

3(d)(ii) [4]

reaction	reagent(s) and condition(s)
1	HCN ✓ NaCN ✓
3	☐ $K_2Cr_2O_7$ ☐ H_2SO_4 / acid / H^+ ☐ (heat under) reflux

3(d)(iii)	hydrolysis	1
3(d)(iv)	reducing agent	1

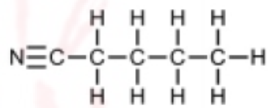
Q# 428/ Chem 21 ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a) [6]

reaction	reagent(s) and conditions	reaction type(s)
1	aqueous / aq / dilute NaOH / KOH OR water	substitution OR hydrolysis
2	alcoholic / ethanolic NaOH / KOH	elimination
3	NaCN / KCN in ethanol / alcohol	substitution
4	aqueous /dilute H_2SO_4 / H^+(aq)	hydrolysis OR substitution OR addition-elimination
5	acidified / H^+ (with) $K_2Cr_2O_7$ / $Cr_2O_7^{2-}$ (and distil) NOT reflux	oxidation OR elimination
6	acidified / H^+ $K_2Cr_2O_7$ / $Cr_2O_7^{2-}$ Fehling's / Tollens' / Benedict's (reagent)	oxidation

Q# 429/ Chem 21 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

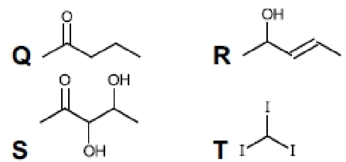
3(a)(i) [1]



3(a)(ii)	reaction **1** = HC*l*(aq)	1
	reaction **2** = (conc.) NaOH / KOH **AND** ethanol	1

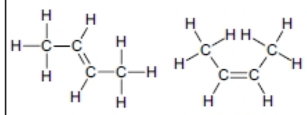
Q# 430/ Chem 21 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5/www.SmashingScience.org

5 (a) (i)



[1] [1] [1] [1] [4]

Q# 431/ Chem 21 ALvl Chemistry/2014/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a)	**P**; $CH_2 = C(CH_3)_2$ **Q**; $CH_3CH_2CH = CH_2$ **R**; $CH_3CH = CHCH_3$ **S**; $(CH_3)_2CO$	1 1 1 1	[4]
(ii)	 trans-but-2-ene cis-but-2-ene	1 1	[2]
(c)	reagent; $NaBH_4$ or $LiAlH_4$ or names product; propan-2-ol	1 1	[2]
			[10]

Q# 432/ Chem 21 ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

(c) **S** into **T**
conc. H_2SO_4 **followed by** H_2O
or H_3PO_4 **followed by** H_2O **or**
steam and H_3PO_4 catalyst (1 + 1)

S into **U**
$KMnO_4$ (1)
cold dilute acidified **or** cold dilute alkaline (1)

T into **S**
P_4O_{10} **or conc.** H_2SO_4 **or** conc. H_3PO_4 **or** Al_2O_3
and heat in each case (1) [5]

(d) **T** reacting with an excess of Na

$NaO_2CCH(ONa)CH_2CO_2Na$ (1)

U reacting with an excess of Na_2CO_3

$NaO_2CCH(OH)CH(OH)CO_2Na$ (1) [2]

Q# 433/ Chem 21 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a)

reaction	reagent	product
A	Br_2 in an inert organic solvent	$CH_3CHBrCHBrCHO$
B	PCl_3	NO REACTION
C	H_2 and Ni catalyst	$CH_3CH_2CH_2CH_2OH$
D	$NaBH_4$	$CH_3CH=CHCH_2OH$
E	$K_2Cr_2O_7/H^+$	$CH_3CH=CHCO_2H$

one mark for each correct answer [5]

(d) (i) $CH_3CH(OH)CH(OH)CO_2H$ (1)

(ii) CH_3CO_2H (1)
HO_2CCO_2H (1) [3]

allow ecf on candidate's answer to E in **(a)**

[Total: 12]

Q# 434/ Chem 21 ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Types of reaction used must come from the list in the question.

organic reaction	type of reaction	reagent(s)
$CH_3CH_2CH_2CH_2Br \rightarrow CH_3CH_2CH_2CH_2NH_2$	nucleophilic (1) substitution (1)	NH_3 (1)
$CH_3CH_2CH_2CH_2OH \rightarrow BrCH_2CH_2CH_2CH_2OH$	free radical (1) substitution (1)	Br_2 **or** Br_2 in an organic solvent (1) **not** $Br_2(aq)$
$CH_3COCH_3 \rightarrow CH_3C(OH)(CN)CH_3$	nucleophilic (1) addition (1)	HCN **or** HCN and CN^- **or** NaCN/KCN + H^+ (1)
$CH_3CH(OH)CH_2CH_3 \rightarrow CH_3CH{=}CHCH_3$	elimination (1) **not** dehydration	conc. H_2SO_4 **or** P_4O_{10} **or** Al_2O_3 **or** H_3PO_4 (1)

[Total: 11]

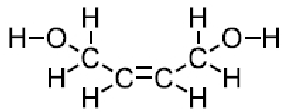
Q# 435/ Chem 21 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) (i) carboxylic acid **or** alcohol present **or** carboxylic acid **and** alcohol present **not** acid **or** carboxyl **or** hydroxyl (1)

(ii) carboxylic acid **not** present **or** only alcohol present (1)

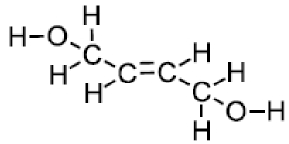
(iii) alkene **or** >C=C< present (1) [3]

(b) (i)



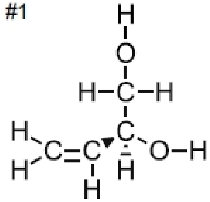
each correct structure gets (1) (4 × 1)

(ii) **pair 1** geometrical **or** *cis-trans* **or** *E/Z* isomerism (1)

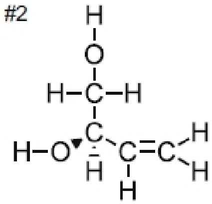


pair 2 optical isomerism – accept chiral compounds (1) [6]

#1



#2



[Total: 9]

Q# 436/ Chem 21 ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i)

reaction	organic compound	reagent	structural formulae of organic products
A	$(CH_3)_3COH$	$Cr_2O_7^{2-}/H^+$ heat under reflux	no reaction
B	CH_3CH_2CHO	Fehling's reagent warm	$CH_3CH_2CO_2H$ **or** $CH_3CH_2CO_2^-$
C	$HCO_2CH(CH_3)_2$	NaOH(aq) warm	HCO_2Na **or** HCO_2^- $(CH_3)_2CHOH$
D	$CH_2{=}CHCHO$	$NaBH_4$	$CH_2{=}CHCH_2OH$
E	$(CH_3)_3COH$	$NaBH_4$	no reaction
F	$CH_3CH_2COCH_3$	MnO_4^-/H^+ heat under reflux	no reaction

each correct answer gets (1) (7 × 1)

(ii)

reaction	colour at the beginning of the reaction	colour at the end of the reaction
B	blue	brick red

each correct answer gets 1 (1 +1 + 1) [10]

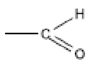
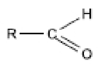
Q# 437/ Chem 21 ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(b) (i) alcohol (1)

(ii) $n(H_2) = \frac{160}{24000} = 6.67 \times 10^{-3}$ mol (1)
n(H atoms) $= 2 \times 6.67 \times 10^{-3}$ mol $= 1.33 \times 10^{-2}$ mol (1)

(iii) $n(\mathbf{X}) = \frac{0.600}{90} = 6.67 \times 10^{-3}$ mol
$n(\mathbf{X}) : n$(H atoms) $= 6.67 \times 10^{-3} : 1.33 \times 10^{-2}$
$= 1 : 2$
since each –OH group produces one H atom
there are two –OH groups (1) [4]

(c) (i)

 **or**  (1)

(ii) $HOCH_2CH(OH)CHO$ as the minimum
allow the *gem* diols $(HO)_2CHCH_2CHO$ **or** $CH_3C(OH)_2CHO$ (1)

(iii) $HOCH_2CH(OH)CO_2H$ or $HOCH_2CH(OH)CO_2^-$ (1) [3]

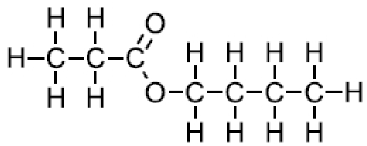
(d) (i) $HOCH_2CH(OH)CH_2OH$ (1)

(ii) HO_2CCOCO_2H (1) [2]

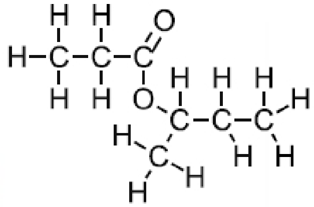
[Total: 10]

Q# 438/ Chem 21 ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(b) T + U



or



correct structures (1)
correctly displayed ester group (1) [2]

[Total: 7]

5 (a) (i) 1 primary (1)
alcohol **not** hydroxyl (1)

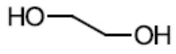
2 aldehyde **not** carbonyl (1)

(ii)

test 1			
reagent	Na	$PCl_3/PCl_5/PBr_3$	RCO_2H/H^+
observation	gas/H_2/effervescence/ fizzing	HCl/HBr steamy fumes	fruity smell
test 2			
reagent	Tollens' reagent	Fehling's reagent	2,4-dinitro-phenylhydrazine
observation	Ag mirror/silver/ black ppt	brick-red ppt red ppt	orange/red/yellow ppt/solid

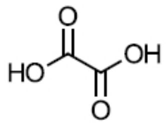
only award the observation mark if reagent is correct (4) [7]

(b) (i)



(1)

(ii)



(1) [2]

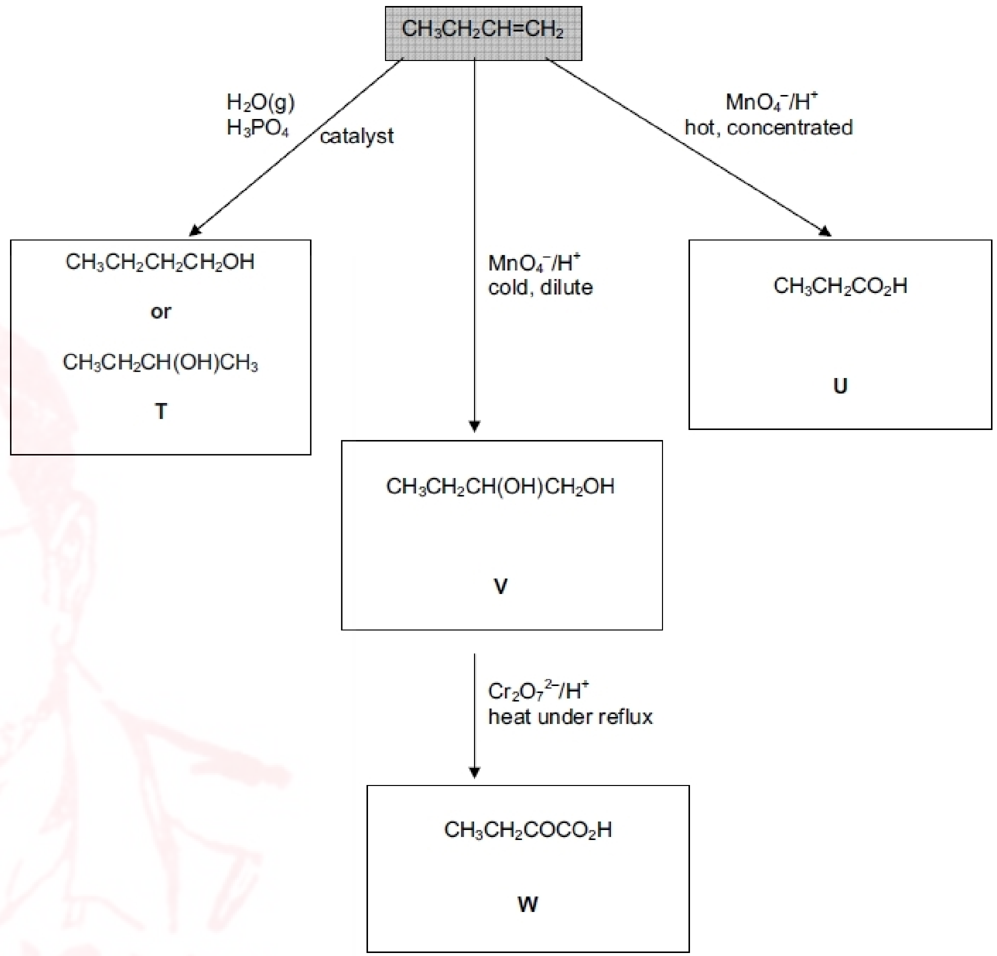
5 (c)

route	starting compound	first reagent	intermediate X	second reagent	intermediate Y	third reagent	final compound
A/1	$HOCH_2CHO$	PCl_3 PCl_5 $SOCl_2$ etc.	$ClCH_2CHO$	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$ClCH_2CO_2H$	NH_3	$H_2NCH_2CO_2H$
A/2	$HOCH_2CHO$	HBr P/Br_2 etc.	$BrCH_2CHO$	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$BrCH_2CO_2H$	NH_3	$H_2NCH_2CO_2H$
B/1	$HOCH_2CHO$	PCl_3 PCl_5 $SOCl_2$ etc.	$ClCH_2CHO$	NH_3	H_2NCH_2CHO	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$H_2NCH_2CO_2H$
B/2	$HOCH_2CHO$	HBr P/Br_2 etc.	$BrCH_2CHO$	NH_3	H_2NCH_2CHO	$K_2Cr_2O_7/H^+$ $KMnO_4/H^+$ $KMnO_4/OH^-$ Tollens' or Fehling's reagents	$H_2NCH_2CO_2H$
C	$HOCH_2CHO$	Tollens' or Fehling's reagents	$HOCH_2CO_2H$	KBr/conc. H_2SO_4	$BrCH_2CO_2H$	NH_3	$H_2NCH_2CO_2H$
mark		(1)	(1)	(1)	(1)	(1)	

[5]

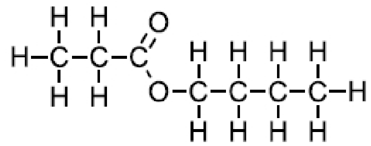
[Total: 14]

4 (a)

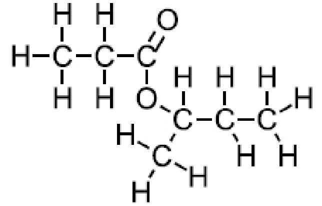


correct **T** (1)
correct **U** (1)
correct **V** (1)
correct > CO group in **W** (1)
correct –CO_2H group in **W** (1) [5]

(b) T + U



or



correct structures (1)
correctly displayed ester group (1) [2]

[Total: 7]

Q# 440/ Chem 21 ALvl Chemistry/2011/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) (i) mass of C = $\frac{12 \times 0.352}{44}$ = 0.096g (1)

n(C) = $\frac{0.096}{12}$ = 0.008 (1)

(ii) mass of H = $\frac{2 \times 0.144}{18}$ = 0.016g (1)

n(H) = $\frac{0.016}{1}$ = 0.016 (1)

(iii) mass of oxygen = 0.240 – (0.096 + 0.016) = 0.128g (1)

n(O) = $\frac{0.128}{16}$ = 0.008 (1)

allow ecf at any stage [6]

(b) C : H : O = 0.008: 0.016 : 0.008 = 1:2:1

allow C : H : O = $\frac{0.096}{12} : \frac{0.016}{1} : \frac{0.128}{16}$ = 1:2:1

gives CH_2O (1) [1]

(c) (i) $M_r = \frac{mRT}{pV} = \frac{0.148 \times 8.31 \times 333}{1.01 \times 10^5 \times 67.7 \times 10^{-6}}$ (1)

= 59.89

allow 59.9 or 60 (1)

(ii) $C_2H_4O_2$ (1) [3]

(d) CH_3CO_2H (1)

HCO_2CH_3 (1) [2]

(e) the only products of the reaction are the two oxides H_2O and CO_2 and copper (1) [1]

[Total: 13]

Q# 441/ Chem 21 ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) $CaC_2 + 2H_2O \rightarrow Ca(OH)_2 + C_2H_2$ (1) [1]

(b) (i) step 1 electrophilic (1)
addition (1)
step 2 elimination **or** dehydrohalogenation (1)

(ii) reagent $NaOH/KOH/OH^-$ (1)
conditions in alcohol/ethanol (1)
only allow conditions mark if reagent is correct [5]

(c) (i) **Q** is CH_3CHO (as minimum) (1)
R is CH_3CO_2H (as minimum) (1)

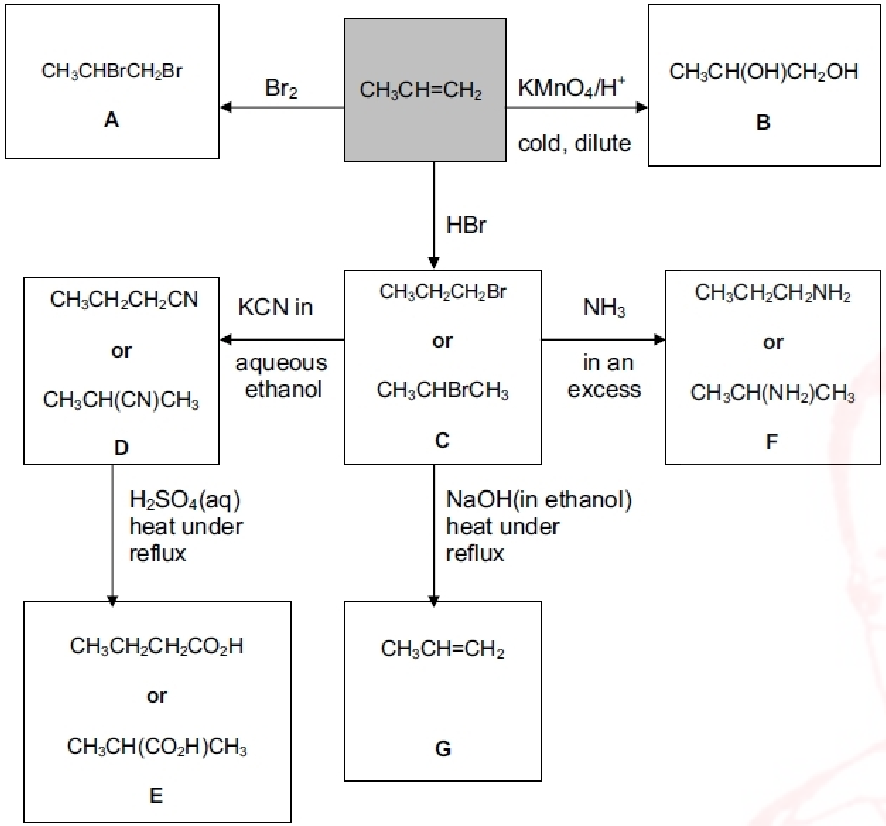
(ii) step 3 is addition (1)
step 4 is oxidation/redox (1) [4]

(d) (i) **combustion**
$C_2H_2(g) + {}^5/_2O_2(g) \rightarrow 2CO_2(g) + H_2O(l)$ **or**
equation must be for the combustion of one mole of C_2H_2
H_2O must be shown as liquid (1)
correct state symbols in this equation (1)

formation
$2C(s) + H_2(g) \rightarrow C_2H_2(g)$
no mark for state symbols here (1)

Q# 442/ Chem 21 ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a)



give 1 for each correct structure (7 × 1) [7]

(b) (i) ester (1)

(ii) heat under reflux (1)
trace of conc. H_2SO_4 **or** presence of HC*l* (g) (1) [3]

[Total: 10]

Q# 443/ Chem 21 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) **G** is HCHO/methanal (1) [1]

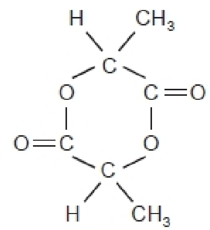
(b) (i) carboxylic acid/carboxyl/–CO_2H
not acid (1)

(ii) **H** is CH_3CO_2H/ethanoic acid (1)

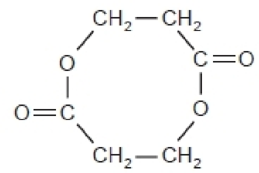
(iii) **J** is $CH_3CH(OH)CO_2H$/2-hydroxypropanoic acid
allow $HOCH_2CH_2CO_2H$/3-hydroxypropanoic acid (1) [3]

(c) **K** is CH_3COCO_2H (1) [1]

(d) (i) **L** is



allow as ecf on $HOCH_2CH_2CO_2H$/3-hydroxypropanoic acid



(1)

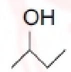
(ii) esterification
allow elimination/dehydration/condensation (1) [2]

[Total: 7]

Q# 444/ Chem 21 ALvl Chemistry/2009/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i) C_2H_5O (1)

(ii)



(1)

(iii)

compound	type of isomerism
A	*cis-trans* **or** geometrical
D	optical

allow one mark if **both A and D** are correctly identified
but in **both** cases, the type of isomerism is incorrect

(1 + 1) [4]

(b) (i) dehydration/elimination (1)

(ii) conc. $H_2SO_4/P_4O_{10}/Al_2O_3$/pumice etc. (1)

(iii) $CH_2{=}CHCH{=}CH_2$/butadiene/buta-1,3-diene (1) [3]

(c) (i) $CH_3CH_2CH(OH)CH_3$ (1)

(ii) steam with H_3PO_4 catalyst **or** conc. H_2SO_4 then water (1 + 1)

(iii) $Cr_2O_7^{2-}/H^+$ (1) [4]

(d) functional group isomerism
or structural isomerism
not positional isomerism (1) [1]

[Total: 12]

Q# 445/ Chem 21 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5 (a) $CH_3COCH_2C(CH_3)_2$ (with OH on the C(CH₃)₂ carbon) **or** (by addition of one molecule of $(CH_3)_2CO$ across the >C=O bond of another)

$CH_3COCHCH(CH_3)_2$ (with OH on the CH carbon) (by working backwards from **G** and adding one molecule of H_2O across the C=C bond)

(1) [1]

(b)

functional group in **G**	reagent used in test	what would be seen
alkene	Br_2 **or** $KMnO_4$(aq)	decolourised
or carbonyl	**or** 2,4-dinitro-phenylhydrazine/ Brady's reagent	**or** yellow/orange/red colour or ppt.
(1)	(1)	(1)

[3]

(c) (i) dehydration/elimination (1)

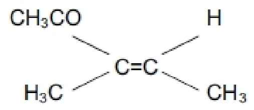
(ii) Al_2O_3 / P_4O_{10} / conc. H_2SO_4/ conc.H_3PO_4 (1) [2]

(d) $NaBH_4$ **or** $LiAlH_4$ (1)

in water **or** methanol/ethanol **or** mixture of alcohol and water **or** in **dry** ether (1) [2]

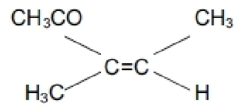
not ether
Solvent mark is only awarded if reagent is correct.

(e)



*cis**

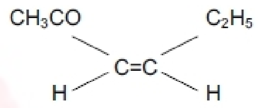
* allow this to be called Z



*trans***

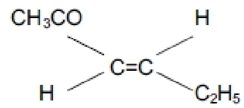
** allow this to be called E

or



*cis**

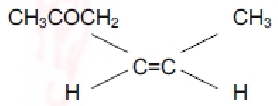
* allow this to be called Z



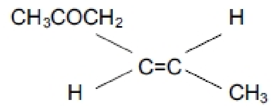
*trans***

** allow this to be called E

or



cis or Z



trans or E

two structures (1)
correct *cis* and *trans* (1)
explanation (1) [3]

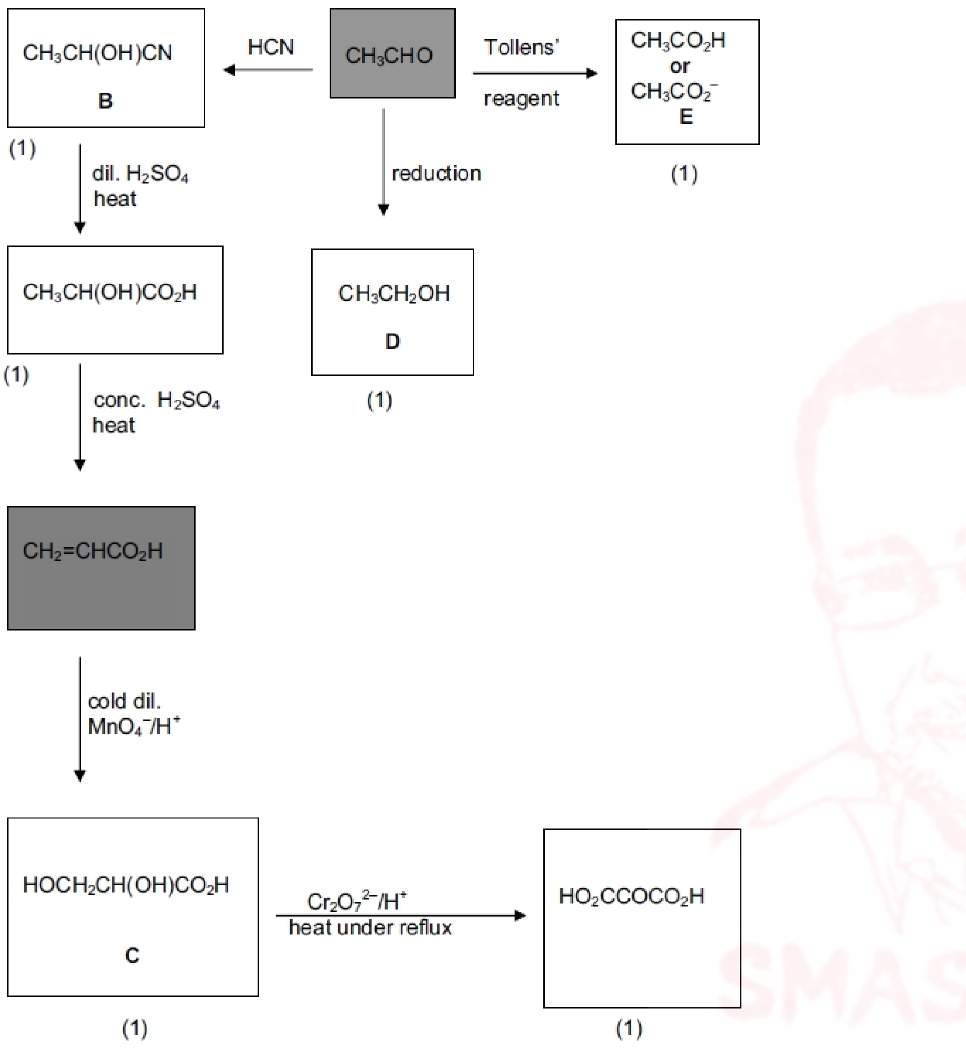
For *cis* and *trans* answers, the explanation should be in terms of the methyl groups (first pair of isomers) or hydrogen atoms (second and third pairs of isomers) being on the same or opposite sides relative to the C=C bond.

For E/Z answers, the explanation will need to involve the relative sizes of the CH_3C- group and the CH_3- group. This really only affects the first pair of isomers.

[Total: 11]

Q# 446/ Chem 21 ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a)



one mark for each correct structure [6]

(b) **C** + **D**

$HOCH_2CH(OH)CO_2C_2H_5$ as minimum or

$HOCH_2C(H)(OH)CO_2C_2H_5$ (1)

Allow e.c.f on candidate's **C** and/or **D**.

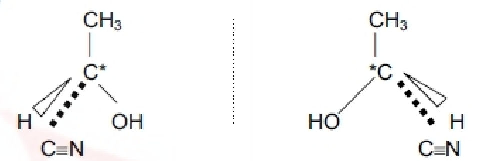
C + **E**

CH_2OCOCH_3 – $CHOCOCH_3$ – CO_2H

Allow either monoester. (1) [2]

Allow e.c.f on candidate's **C** and/or **E**.

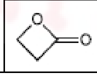
(c)



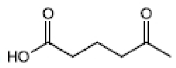
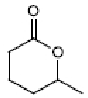
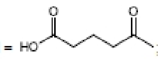
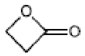
correct chiral carbon atom indicated (1)
one structure drawn fully displayed with C≡N (1)
mirror object/mirror image pair correctly drawn in 3D (1) [3]

[Total: 11]

Q# 447/ Chem 22 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(c)	100 / 1.1 ÷ 95.5 / 3.15 = 3 carbon atoms	1
		1

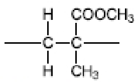
Q# 448/ Chem 22 ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

5(a)(i)	N = 	1
5(a)(ii)	$C_6H_{10}O_3 + 2[H] \rightarrow C_6H_{12}O_3$	1
5(a)(iii)	**M1** (ketone in) N is planar (so can be attacked from either side)	1
	M2 because different stereoisomers / optical isomers form	1
5(a)(iv)		1
5(b)	N =  ; 5-hh  **M1** absorptions will overlap / be similar / the same / indistinguishable	1
	M2 both have some bonds in similar environments owtte	1
5(c)	100 / 1.1 ÷ 95.5 / 3.15 = 3 carbon atoms	1
		1

Q# 449/ Chem 22 ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(d)	29 $C_2H_5^+$ 57 $COCH_2CH_3^+$ OR $C_3H_5O^+$ OR $CH_2COCH_3^+$ identity of Z: pentan-3-one / $CH_3CH_2COCH_2CH_3$; pentan-2-one / $CH_3COCH_2CH_2CH_3$	3

Q# 450/ Chem 22 ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(b)(ii)	 carbon backbone with 'dangling' bonds [1] rest of structure correct [1]	2
4(b)(iii)	Perspex® would not have absorption 1500–1680 cm^{-1} AND Perspex® does not have C=C	1

Q# 451/ Chem 22 ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(b)	**M1** ester **M2** 1100 cm^{-1} linked to C—O AND 1720 cm^{-1} linked to C=O **M3** No COOH / carboxylic acid and No OH / alcohol in D (but present in C) OR COOH / carboxylic acid and OH / alcohol reacted /lost (in C to form D)	3

Q# 452/ Chem 22 ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(c)	**M1:** 2150–2250 (cm^{-1}) AND C≡C **M2:** 2200–2250 (cm^{-1}) AND C≡N	2

Q# 453/ Chem 22 ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(c)(v)	Any two of three absorption references: • absorption 2200–2250 (cm^{-1}) shows presence of C≡N • lack of absorption at 1680–1730 (cm^{-1}) shows lack of C=O • lack of absorption at 2500–3000 (cm^{-1}) shows lack of RCO_2–H / O–H in RCO_2H	2

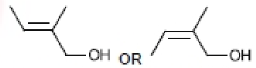
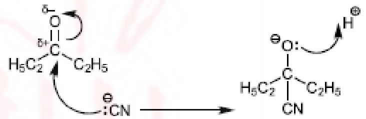
Q# 454/ Chem 22 ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 6/www.SmashingScience.org

6(e)	*Predict two differences, with reasons, between spectra of **Y**, $CH_3CH_2COCH_3$ and 2-methylbut-1-ene (shown)* *first difference* **M1** absence of peak/ absorption at 3100 (cm^{-1}) as no longer any =C–H present (in **Y**) *second difference* **M2** peak at 1650 (cm^{-1}) moves to the left to any value / range of values between 1670 and 1740) due to disappearance of C=C (in **Y**) and appearance of C=O (in **Y**) OR absence of peak at 1650 (cm^{-1}) as no longer any C=C present (in **Y**) AND appearance of peak (in **Y**) at (any value / range of values) between 1670-1740(cm^{-1}) due to C=O	2

Q# 455/ Chem 22 ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(iii)	**M1** / **M2** *absorptions seen in both spectra (any two):* (same) both show an absorption at 1680–1730 (cm^{-1}) because of C=O (same) both show an absorption at 1040–1300 (cm^{-1}) because of C–O (same) both show an absorption at 2500–3000 (cm^{-1}) because of RCO_2–H / O–H in RCO_2H / carboxyl(ic acid) **M3** *absorption only seen in spectrum of* **T**: (different) **T** shows an absorption at 1500–1680 (cm^{-1}) because of C=C (different) **T** shows an absorption at 3000–3100 (cm^{-1}) because of (C=)C–H	3

Q# 456/ Chem 22 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(c)(vi)	 **M1:** skeletal alkene group **AND** C5 structure **M2:** one alcohol group **M3:** branched chain **AND** capable of geometrical isomerism	3
4(c)(vii)	**M1:** Correct structure of **X** and correct dipole on C=O **M2:** curly arrow from C=O bond to O AND intermediate with CN attached and –ve charge on the O **M3:** curly arrow from lone pair on CN^- to C(=O) in **X** **AND** curly arrow from lone pair in the intermediate to H^+ 	3
4(c)(viii)	catalyst	1

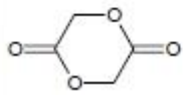
Q# 457/ Chem 22 ALvl Chemistry/2019/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3(a)(iv)	**M1:** infrared spectroscopy **M2:** Compare / measure (characteristic) wavelengths	2

Q# 458/ Chem 22 ALvl Chemistry/2019/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)	**M1** compound P **M2** (absorption at) 2250 cm^{-1} **AND** C≡N (stretch) **M3** (absorption at) 3100–3700 cm^{-1} **AND** O—H (stretch)	3

Q# 459/ Chem 22 ALvl Chemistry/2018/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(d)(i)	**EITHER** Glycolic acid would have: **M1** 2500–3000 due to RCO_2-H **M2** range within 3200–3650 due to RO–H OR Spectrum Y would NOT have: **M1** 2500–3000 due to RCO_2-H **M2** range within 3200–3650 due to RO–H	2
4(d)(ii)	 **M1** ANY ester group **AND** valid $C_4H_4O_4$ molecule **M2** correct cyclic structure	2

Q# 460/ Chem 22 ALvl Chemistry/2018/m/TZ 2/Paper 4/Q# 4/www.SmashingScience.org

4(c)(ii)	cyclohexene would have absorption at 1500–1680 (cm^{-1}) because of C=C (and adipic acid would not) cyclohexene would have absorption at 3000–3100 (cm^{-1}) because of =C—H/C—H in alkene (and adipic acid would not) adipic acid would have absorption at 2500–3000 (cm^{-1}) because of O—H/CO_2—H (and cyclohexene would not) adipic acid would have absorption at 1040–1300 (cm^{-1}) because of C—O (and cyclohexene would not) adipic acid would have absorption at 1640–1750 (cm^{-1}) because of C=O (and cyclohexene would not)	max 3

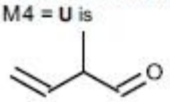
Q# 461/ Chem 22 ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(ii)	(compound **V** is) spectrum X	1
	spectra X and Z show a C=O (stretch) at 1730 (cm^{-1})	1
	spectra Y and Z show O–H (stretches) above 2500 (cm^{-1})	1
	V has a C=O (bond) and no O–H (bond)	1

Q# 462/ Chem 22 ALvl Chemistry/2016/s/TZ 1/Paper 4/Q# 5/www.SmashingScience.org

(ii)	disappearance of peak / dip / trough / absorption at 1680–1730	[1]	[2]
	due to (loss of) C=O	[1]	
	OR		
	peak at 3200–3650	[1]	
	due to (alcohol) O—H (formation)	[1]	

Q# 463/ Chem 22 ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 5/www.SmashingScience.org

(b)	*This question was discounted.* M1 = decolourises bromine / 1500–1600 cm^{-1} = alkene M2 = absorption at 1700 cm^{-1} is C=O AND (very) broad absorption at 2500–3000 cm^{-1} is O—H = carboxylic acid M3 = no cis-trans so terminal alkene OR chiral so contains a carbon atom with 4 different groups attached M4 = **U** is 	[1] [1] [1] [1]	[4]
			[10]

2016 Data Booklet and Periodic Table

The Data Booklet was used for all Paper 1, 2 and 4 exams until and including winter 2021.

Two Data Booklets cover the time period of this Work Book, one for exams after 2009 and the other for exam safter 2016. Only the data booklet for 2016 is given here, but for exam questions for years 2009 to 2015 care should be taken checking the mark schemes, sometimes constants change from one edition of a Data Booklet to another, so **answers to calculations using data from an unintended Data Booklet might be a little out** as a result. If unsure, check out the earlier data booklet for questions 2015 and before (Google: "2009 data booklet 9701").

Contents: Tables of Chemical Data

1 Important values, constants and standards

molar gas constant	$R = 8.31\ J\,K^{-1}\,mol^{-1}$
the Faraday constant	$F = 9.65 \times 10^{4}\ C\,mol^{-1}$
the Avogadro constant	$L = 6.02 \times 10^{23}\ mol^{-1}$
the Planck constant	$h = 6.63 \times 10^{-34}\ J\,s$
speed of light in a vacuum	$c = 3.00 \times 10^{8}\ m\,s^{-1}$
rest mass of proton, $^{1}_{1}H$	$m_p = 1.67 \times 10^{-27}\ kg$
rest mass of neutron, $^{1}_{0}n$	$m_n = 1.67 \times 10^{-27}\ kg$
rest mass of electron, $^{0}_{-1}e$	$m_e = 9.11 \times 10^{-31}\ kg$
electronic charge	$e = -1.60 \times 10^{-19}\ C$
molar volume of gas	$V_m = 22.4\ dm^3\,mol^{-1}$ at s.t.p. $V_m = 24.0\ dm^3\,mol^{-1}$ under room conditions (where s.t.p. is expressed as 101 kPa, approximately, and 273 K [0 °C])
ionic product of water	$K_w = 1.00 \times 10^{-14}\ mol^2\,dm^{-6}$ (at 298 K [25 °C])
specific heat capacity of water	$= 4.18\ kJ\,kg^{-1}\,K^{-1}$ ($= 4.18\ J\,g^{-1}\,K^{-1}$)

2 Ionisation energies (1st, 2nd, 3rd and 4th) of selected elements, in kJ mol^{-1}

	Proton number	First	Second	Third	Fourth
H	1	1310	–	–	–
He	2	2370	5250	–	–
Li	3	519	7300	11800	–
Be	4	900	1760	14800	21000
B	5	799	2420	3660	25000
C	6	1090	2350	4610	6220
N	7	1400	2860	4590	7480
O	8	1310	3390	5320	7450
F	9	1680	3370	6040	8410
Ne	10	2080	3950	6150	9290
Na	11	494	4560	6940	9540
Mg	12	736	1450	7740	10500
Al	13	577	1820	2740	11600
Si	14	786	1580	3230	4360
P	15	1060	1900	2920	4960
S	16	1000	2260	3390	4540
Cl	17	1260	2300	3850	5150
Ar	18	1520	2660	3950	5770
K	19	418	3070	4600	5860
Ca	20	590	1150	4940	6480
Sc	21	632	1240	2390	7110
Ti	22	661	1310	2720	4170
V	23	648	1370	2870	4600
Cr	24	653	1590	2990	4770
Mn	25	716	1510	3250	5190
Fe	26	762	1560	2960	5400
Co	27	757	1640	3230	5100
Ni	28	736	1750	3390	5400
Cu	29	745	1960	3350	5690
Zn	30	908	1730	3828	5980
Ga	31	577	1980	2960	6190
Br	35	1140	2080	3460	4850
Rb	37	403	2632	3900	5080
Sr	38	548	1060	4120	5440
Ag	47	731	2074	3361	5000
I	53	1010	1840	3000	4030
Cs	55	376	2420	3300	4400
Ba	56	502	966	3390	4700

3 Bond Energies

3(a) Bond energies in diatomic molecules (these are exact values)

Homonuclear

Bond	Energy / kJ mol^{-1}
H—H	436
D—D	442
N≡N	944
O=O	496
P≡P	485
S=S	425
F—F	158
Cl—Cl	242
Br—Br	193
I—I	151

Heteronuclear

Bond	Energy / kJ mol^{-1}
H—F	562
H—Cl	431
H—Br	366
H—I	299
C≡O	1077

3(b) **Bond energies in polyatomic molecules (these are average values)**

Homonuclear

Bond	**Energy / kJ mol^{-1}**
C—C	350
C=C	610
C≡C	840
C⋯C (benzene)	520
N—N	160
N=N	410
O—O	150
Si—Si	225
P—P	200
S—S	265

Heteronuclear

Bond	**Energy / kJ mol^{-1}**
C—H	410
C—Cl	340
C—Br	280
C—I	240
C—N	305
C=N	610
C≡N	890
C—O	360
C=O	740
C=O in CO_2	805
N—H	390
N—Cl	310
O—H	460
Si—Cl	360
Si—H	320
Si—O (in SiO_2(s))	460
Si=O (in SiO_2(g))	640
P—H	320
P—Cl	330
P—O	340
P=O	540
S—H	340
S—Cl	250
S—O	360
S=O	500

4 Standard electrode potential and redox potentials, $E^{\ominus}$ at 298 K (25°C)

For ease of reference, two tables are given:

(a) an extended list in alphabetical order;
(b) a shorter list in decreasing order of magnitude, i.e. a redox series.

(a) $E^{\ominus}$ in alphabetical order

Electrode reaction			$E^{\ominus}$/V
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+0.80
$Al^{3+} + 3e^-$	$\rightleftharpoons$	Al	–1.66
$Ba^{2+} + 2e^-$	$\rightleftharpoons$	Ba	–2.90
$Br_2 + 2e^-$	$\rightleftharpoons$	$2Br^-$	+1.07
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	Ca	–2.87
$Cl_2 + 2e^-$	$\rightleftharpoons$	$2Cl^-$	+1.36
$2HOCl + 2H^+ + 2e^-$	$\rightleftharpoons$	$Cl_2 + 2H_2O$	+1.64
$ClO^- + H_2O + 2e^-$	$\rightleftharpoons$	$Cl^- + 2OH^-$	+0.89
$Co^{2+} + 2e^-$	$\rightleftharpoons$	Co	–0.28
$Co^{3+} + e^-$	$\rightleftharpoons$	Co^{2+}	+1.82
$[Co(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Co + 6NH_3$	–0.43
$Cr^{2+} + 2e^-$	$\rightleftharpoons$	Cr	–0.91
$Cr^{3+} + 3e^-$	$\rightleftharpoons$	Cr	–0.74
$Cr^{3+} + e^-$	$\rightleftharpoons$	Cr^{2+}	–0.41
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	$\rightleftharpoons$	$2Cr^{3+} + 7H_2O$	+1.33
$Cu^+ + e^-$	$\rightleftharpoons$	Cu	+0.52
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$Cu^{2+} + e^-$	$\rightleftharpoons$	Cu^+	+0.15
$[Cu(NH_3)_4]^{2+} + 2e^-$	$\rightleftharpoons$	$Cu + 4NH_3$	–0.05
$F_2 + 2e^-$	$\rightleftharpoons$	$2F^-$	+2.87
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	–0.44
$Fe^{3+} + 3e^-$	$\rightleftharpoons$	Fe	–0.04
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+0.77
$[Fe(CN)_6]^{3-} + e^-$	$\rightleftharpoons$	$[Fe(CN)_6]^{4-}$	+0.36
$Fe(OH)_3 + e^-$	$\rightleftharpoons$	$Fe(OH)_2 + OH^-$	–0.56
$2H^+ + 2e^-$	$\rightleftharpoons$	H_2	0.00
$2H_2O + 2e^-$	$\rightleftharpoons$	$H_2 + 2OH^-$	–0.83
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$	+0.54
$K^+ + e^-$	$\rightleftharpoons$	K	–2.92
$Li^+ + e^-$	$\rightleftharpoons$	Li	–3.04
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg	–2.38
$Mn^{2+} + 2e^-$	$\rightleftharpoons$	Mn	–1.18
$Mn^{3+} + e^-$	$\rightleftharpoons$	Mn^{2+}	+1.49
$MnO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Mn^{2+} + 2H_2O$	+1.23
$MnO_4^- + e^-$	$\rightleftharpoons$	MnO_4^{2-}	+0.56
$MnO_4^- + 4H^+ + 3e^-$	$\rightleftharpoons$	$MnO_2 + 2H_2O$	+1.67
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	+1.52
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$	$NO_2 + H_2O$	+0.81
$NO_3^- + 3H^+ + 2e^-$	$\rightleftharpoons$	$HNO_2 + H_2O$	+0.94
$NO_3^- + 10H^+ + 8e^-$	$\rightleftharpoons$	$NH_4^+ + 3H_2O$	+0.87

Electrode reaction			$E^{\ominus}$/V
$Na^+ + e^-$	$\rightleftharpoons$	Na	–2.71
$Ni^{2+} + 2e^-$	$\rightleftharpoons$	Ni	–0.25
$[Ni(NH_3)_6]^{2+} + 2e^-$	$\rightleftharpoons$	$Ni + 6NH_3$	–0.51
$H_2O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	$2H_2O$	+1.77
$HO_2^- + H_2O + 2e^-$	$\rightleftharpoons$	$3OH^-$	+0.88
$O_2 + 4H^+ + 4e^-$	$\rightleftharpoons$	$2H_2O$	+1.23
$O_2 + 2H_2O + 4e^-$	$\rightleftharpoons$	$4OH^-$	+0.40
$O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	H_2O_2	+0.68
$O_2 + H_2O + 2e^-$	$\rightleftharpoons$	$HO_2^- + OH^-$	–0.08
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	–0.13
$Pb^{4+} + 2e^-$	$\rightleftharpoons$	Pb^{2+}	+1.69
$PbO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Pb^{2+} + 2H_2O$	+1.47
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2 + 2H_2O$	+0.17
$S_2O_8^{2-} + 2e^-$	$\rightleftharpoons$	$2SO_4^{2-}$	+2.01
$S_4O_6^{2-} + 2e^-$	$\rightleftharpoons$	$2S_2O_3^{2-}$	+0.09
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	Sn	–0.14
$Sn^{4+} + 2e^-$	$\rightleftharpoons$	Sn^{2+}	+0.15
$V^{2+} + 2e^-$	$\rightleftharpoons$	V	–1.20
$V^{3+} + e^-$	$\rightleftharpoons$	V^{2+}	–0.26
$VO^{2+} + 2H^+ + e^-$	$\rightleftharpoons$	$V^{3+} + H_2O$	+0.34
$VO_2^+ + 2H^+ + e^-$	$\rightleftharpoons$	$VO^{2+} + H_2O$	+1.00
$VO_3^- + 4H^+ + e^-$	$\rightleftharpoons$	$VO^{2+} + 2H_2O$	+1.00
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn	–0.76

All ionic states refer to aqueous ions but other state symbols have been omitted.

(b) $E^{\ominus}$ in decreasing order of oxidising power

(a selection only – see also the extended alphabetical list on the previous pages)

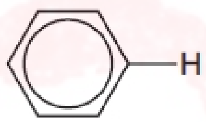
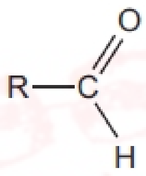
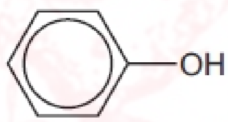
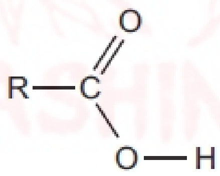
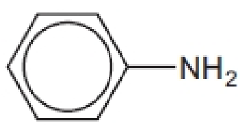
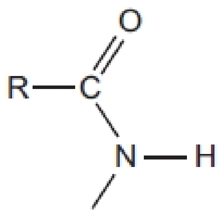
Electrode reaction			$E^{\ominus}$/V
$F_2 + 2e^-$	$\rightleftharpoons$	$2F^-$	+2.87
$S_2O_8^{2-} + 2e^-$	$\rightleftharpoons$	$2SO_4^{2-}$	+2.01
$H_2O_2 + 2H^+ + 2e^-$	$\rightleftharpoons$	$2H_2O$	+1.77
$MnO_4^- + 8H^+ + 5e^-$	$\rightleftharpoons$	$Mn^{2+} + 4H_2O$	+1.52
$PbO_2 + 4H^+ + 2e^-$	$\rightleftharpoons$	$Pb^{2+} + 2H_2O$	+1.47
$Cl_2 + 2e^-$	$\rightleftharpoons$	$2Cl^-$	+1.36
$Cr_2O_7^{2-} + 14H^+ + 6e^-$	$\rightleftharpoons$	$2Cr^{3+} + 7H_2O$	+1.33
$O_2 + 4H^+ + 4e^-$	$\rightleftharpoons$	$2H_2O$	+1.23
$Br_2 + 2e^-$	$\rightleftharpoons$	$2Br^-$	+1.07
$ClO^- + H_2O + 2e^-$	$\rightleftharpoons$	$Cl^- + 2OH^-$	+0.89
$NO_3^- + 10H^+ + 8e^-$	$\rightleftharpoons$	$NH_4^+ + 3H_2O$	+0.87
$NO_3^- + 2H^+ + e^-$	$\rightleftharpoons$	$NO_2 + H_2O$	+0.81
$Ag^+ + e^-$	$\rightleftharpoons$	Ag	+0.80
$Fe^{3+} + e^-$	$\rightleftharpoons$	Fe^{2+}	+0.77
$I_2 + 2e^-$	$\rightleftharpoons$	$2I^-$	+0.54
$O_2 + 2H_2O + 4e^-$	$\rightleftharpoons$	$4OH^-$	+0.40
$Cu^{2+} + 2e^-$	$\rightleftharpoons$	Cu	+0.34
$SO_4^{2-} + 4H^+ + 2e^-$	$\rightleftharpoons$	$SO_2 + 2H_2O$	+0.17
$Sn^{4+} + 2e^-$	$\rightleftharpoons$	Sn^{2+}	+0.15
$S_4O_6^{2-} + 2e^-$	$\rightleftharpoons$	$2S_2O_3^{2-}$	+0.09
$2H^+ + 2e^-$	$\rightleftharpoons$	H_2	0.00
$Pb^{2+} + 2e^-$	$\rightleftharpoons$	Pb	–0.13
$Sn^{2+} + 2e^-$	$\rightleftharpoons$	Sn	–0.14
$Fe^{2+} + 2e^-$	$\rightleftharpoons$	Fe	–0.44
$Zn^{2+} + 2e^-$	$\rightleftharpoons$	Zn	–0.76
$2H_2O + 2e^-$	$\rightleftharpoons$	$H_2 + 2OH^-$	–0.83
$V^{2+} + 2e^-$	$\rightleftharpoons$	V	–1.20
$Mg^{2+} + 2e^-$	$\rightleftharpoons$	Mg	–2.38
$Ca^{2+} + 2e^-$	$\rightleftharpoons$	Ca	–2.87
$K^+ + e^-$	$\rightleftharpoons$	K	–2.92

5 Atomic and ionic radii

(a)	**Period 1**	**atomic / nm**		**ionic / nm**			
	single covalent	H	0.037	H^-	0.208		
	van der Waals	He	0.140				
(b)	**Period 2**	**atomic / nm**		**ionic / nm**			
	metallic	Li	0.152	Li^+	0.060		
		Be	0.112	Be^{2+}	0.031		
	single covalent	B	0.080	B^{3+}	0.020		
		C	0.077	C^{4+}	0.015	C^{4-}	0.260
		N	0.074			N^{3-}	0.171
		O	0.073			O^{2-}	0.140
		F	0.072			F^-	0.136
	van der Waals	Ne	0.160				
(c)	**Period 3**	**atomic / nm**		**ionic / nm**			
	metallic	Na	0.186	Na^+	0.095		
		Mg	0.160	Mg^{2+}	0.065		
		Al	0.143	Al^{3+}	0.050		
	single covalent	Si	0.117	Si^{4+}	0.041	Si^{4-}	0.271
		P	0.110			P^{3-}	0.212
		S	0.104			S^{2-}	0.184
		Cl	0.099			Cl^-	0.181
	van der Waals	Ar	0.190				
(d)	**Group 2**	**atomic / nm**		**ionic / nm**			
	metallic	Be	0.112	Be^{2+}	0.031		
		Mg	0.160	Mg^{2+}	0.065		
		Ca	0.197	Ca^{2+}	0.099		
		Sr	0.215	Sr^{2+}	0.113		
		Ba	0.217	Ba^{2+}	0.135		
		Ra	0.220	Ra^{2+}	0.140		

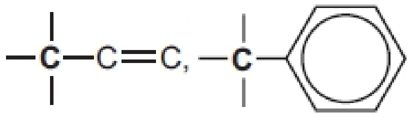
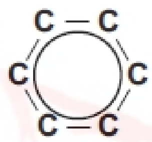
(e)	**Group 14**	**atomic / nm**		**ionic / nm**			
	single covalent	C	0.077				
		Si	0.117	Si^{4+}	0.041		
		Ge	0.122	Ge^{2+}	0.093		
	metallic	Sn	0.162	Sn^{2+}	0.112		
		Pb	0.175	Pb^{2+}	0.120		
(f)	**Group 17**	**atomic / nm**		**ionic / nm**			
	single covalent	F	0.072	F^{-}	0.136		
		C*l*	0.099	Cl^{-}	0.181		
		Br	0.114	Br^{-}	0.195		
		I	0.133	I^{-}	0.216		
		At	0.140				
(g)	**First row transition elements**	**atomic / nm**		**ionic / nm**			
	metallic	Sc	0.164			Sc^{3+}	0.081
		Ti	0.146	Ti^{2+}	0.090	Ti^{3+}	0.067
		V	0.135	V^{2+}	0.079	V^{3+}	0.064
		Cr	0.129	Cr^{2+}	0.073	Cr^{3+}	0.062
		Mn	0.132	Mn^{2+}	0.067	Mn^{3+}	0.062
		Fe	0.126	Fe^{2+}	0.061	Fe^{3+}	0.055
		Co	0.125	Co^{2+}	0.078	Co^{2+}	0.053
		Ni	0.124	Ni^{2+}	0.070	Ni^{3+}	0.056
		Cu	0.128	Cu^{2+}	0.073		
		Zn	0.135	Zn^{2+}	0.075		

6 Typical proton (^{1}H) chemical shift values (δ) relative to TMS = 0

type of proton	environment of proton	example structures	chemical shift range (δ)
C–H	alkane	$–CH_3$, $–CH_2–$, >CH–	0.9–1.7
	alkyl next to C=O	$CH_3–C=O$, $–CH_2–C=O$, >CH–C=O	2.2–3.0
	alkyl next to aromatic ring	$CH_3–Ar$, $–CH_2–Ar$, >CH–Ar	2.3–3.0
	alkyl next to electronegative atom	$CH_3–O$, $–CH_2–O$, $–CH_2–Cl$, >CH–Br	3.2–4.0
	attached to alkyne	≡C–H	1.8–3.1
	attached to alkene	$=CH_2$, =CH–	4.5–6.0
	attached to aromatic ring		6.0–9.0
	aldehyde		9.3–10.5
O-H (see note below)	alcohol	RO–H	0.5–6.0
	phenol		4.5–7.0
	carboxylic acid		9.0–13.0
N-H (see note below)	alkyl amine	R–NH–	1.0–5.0
	aryl amine		3.0–6.0
	amide		5.0–12.0

Note: δ values for –O-H and –N-H protons can vary depending on solvent and concentration

7 Typical carbon (^{13}C) chemical shift values (δ) relative to TMS = 0

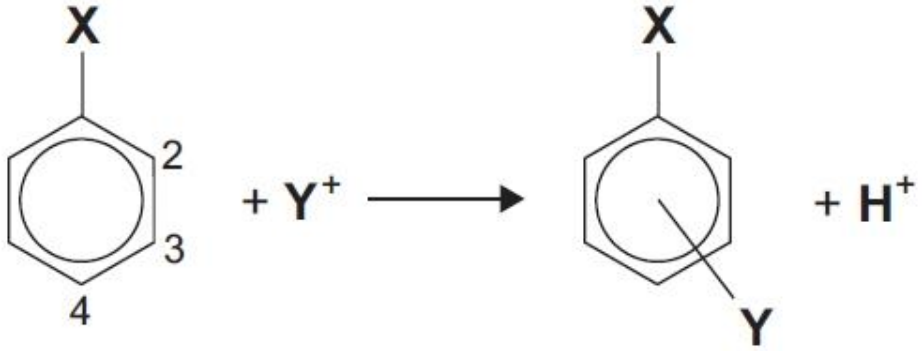
hybridisation of the carbon atom	environment of carbon atom	example structures	chemical shift range (δ)
sp^3	alkyl	CH_3–, –CH_2–, –CH<, >C<	0–50
sp^3	next to alkene/arene		10–40
sp^3	next to carbonyl/carboxyl	–C–COR, –C–CO_2R,	25–50
sp^3	next to nitrogen	–C–NH_2, –C–NR_2, –C–NHCO	30–65
sp^3	next to chlorine (-CH_2-Br and -CH_2-I are in the same range as alkyl)	–C–Cl	30–60
sp^3	next to oxygen	–C–OH, –C–O–CO–	50–70
sp^2	alkene or arene	>C=C<, 	110–160
sp^2	carboxyl	R–CO_2H, R–CO_2R	160–185
sp^2	carbonyl	R–CHO, R–CO–R	190–220
sp	alkyne	R–C≡C–	65–85
sp	nitrile	R–C≡N	100–125

8 Characteristic infra-red absorption frequencies for some selected bonds

bond	functional groups containing the bond	absorption range (in wavenumbers) /cm^{-1}	appearance of peak (*s* = strong, *w* = weak)
C–O	alcohols, ethers, esters	1040–1300	*s*
C=C	aromatic compounds, alkenes	1500–1680	*w* unless conjugated
C=O	amides, ketones and aldehydes, carboxylic acids, esters	1640–1690 1670–1740 1680–1730 1710–1750	*s* *s* *s* *s*
C≡C	alkynes	2150–2250	*w* unless conjugated
C≡N	nitriles	2200–2250	*w*
C–H	alkanes, CH_2–H alkenes/arenes, =C–H	2850–2950 3000–3100	*s* *w*
N–H	amines, amides	3300–3500	*w*
O–H	carboxylic acids, RCO_2–H H–bonded alcohol, RO–H free alcohol, RO–H	2500–3000 3200–3600 3580–3650	*s* and very broad *s* *s* and sharp

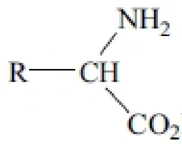
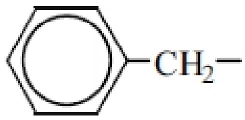
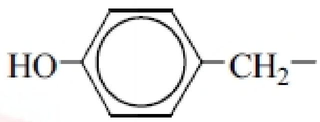
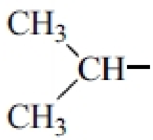
9 The orientating effect of groups in aromatic substitution reactions.

The position of the incoming group, **Y**, is determined by the nature of the group, **X**, already bonded to the ring, and not by the nature of the incoming group **Y**.



X- groups that direct the incoming **Y** group to the 2- or 4- positions	**X**- groups that direct the incoming **Y** group to the 3- position
$-NH_2$, $-NHR$ or $-NR_2$	$-NO_2$
–OH or –OR	$-NH_3^+$
–NHCOR	–CN
$-CH_3$, –alkyl	–CHO, –COR
–*Cl*	$-CO_2H$, $-CO_2R$

10 Names, structures and abbreviations of some amino acids

name	3-letter abbreviation	1-letter symbol	structure of side chain R- in 
alanine	Ala	A	CH_3–
aspartic acid	Asp	D	HO_2CCH_2–
cysteine	Cys	C	$HSCH_2$–
glutamic acid	Glu	E	$HO_2CCH_2CH_2$–
glycine	Gly	G	H–
lysine	Lys	K	$H_2NCH_2CH_2CH_2CH_2$–
phenylalanine	Phe	F	
serine	Ser	S	$HOCH_2$–
tyrosine	Tyr	Y	
valine	Val	V	

Important values, constants and standards (2022 and after)

Important values, constants and standards

molar gas constant	$R = 8.31\ J\,K^{-1}\,mol^{-1}$
Faraday constant	$F = 9.65 \times 10^4\ C\,mol^{-1}$
Avogadro constant	$L = 6.022 \times 10^{23}\ mol^{-1}$
electronic charge	$e = -1.60 \times 10^{-19}\ C$
molar volume of gas	$V_m = 22.4\ dm^3\,mol^{-1}$ at s.t.p. (101 kPa and 273 K) $V_m = 24.0\ dm^3\,mol^{-1}$ at room conditions
ionic product of water	$K_w = 1.00 \times 10^{-14}\ mol^2\,dm^{-6}$ (at 298 K (25 °C))
specific heat capacity of water	$c = 4.18\ kJ\,kg^{-1}\,K^{-1}$ ($4.18\ J\,g^{-1}\,K^{-1}$)

9701/41/O/N/23

The Periodic Table of Elements

Key

atomic number
atomic symbol
name
relative atomic mass

Group 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
							1 H hydrogen 1.0										2 He helium 4.0
3 Li lithium 6.9	4 Be beryllium 9.0											5 B boron 10.8	6 C carbon 12.0	7 N nitrogen 14.0	8 O oxygen 16.0	9 F fluorine 19.0	10 Ne neon 20.2
11 Na sodium 23.0	12 Mg magnesium 24.3											13 Al aluminium 27.0	14 Si silicon 28.1	15 P phosphorus 31.0	16 S sulfur 32.1	17 Cl chlorine 35.5	18 Ar argon 39.9
19 K potassium 39.1	20 Ca calcium 40.1	21 Sc scandium 45.0	22 Ti titanium 47.9	23 V vanadium 50.9	24 Cr chromium 52.0	25 Mn manganese 54.9	26 Fe iron 55.8	27 Co cobalt 58.9	28 Ni nickel 58.7	29 Cu copper 63.5	30 Zn zinc 65.4	31 Ga gallium 69.7	32 Ge germanium 72.6	33 As arsenic 74.9	34 Se selenium 79.0	35 Br bromine 79.9	36 Kr krypton 83.8
37 Rb rubidium 85.5	38 Sr strontium 87.6	39 Y yttrium 88.9	40 Zr zirconium 91.2	41 Nb niobium 92.9	42 Mo molybdenum 95.9	43 Tc technetium –	44 Ru ruthenium 101.1	45 Rh rhodium 102.9	46 Pd palladium 106.4	47 Ag silver 107.9	48 Cd cadmium 112.4	49 In indium 114.8	50 Sn tin 118.7	51 Sb antimony 121.8	52 Te tellurium 127.6	53 I iodine 126.9	54 Xe xenon 131.3
55 Cs caesium 132.9	56 Ba barium 137.3	57–71 lanthanoids	72 Hf hafnium 178.5	73 Ta tantalum 180.9	74 W tungsten 183.8	75 Re rhenium 186.2	76 Os osmium 190.2	77 Ir iridium 192.2	78 Pt platinum 195.1	79 Au gold 197.0	80 Hg mercury 200.6	81 Tl thallium 204.4	82 Pb lead 207.2	83 Bi bismuth 209.0	84 Po polonium –	85 At astatine –	86 Rn radon –
87 Fr francium –	88 Ra radium –	89–103 actinoids	104 Rf rutherfordium –	105 Db dubnium –	106 Sg seaborgium –	107 Bh bohrium –	108 Hs hassium –	109 Mt meitnerium –	110 Ds darmstadtium –	111 Rg roentgenium –	112 Cn copernicium –	113 Nh nihonium –	114 Fl flerovium –	115 Mc moscovium –	116 Lv livermorium –	117 Ts tennessine –	118 Og oganesson –

lanthanoids	57 La lanthanum 138.9	58 Ce cerium 140.1	59 Pr praseodymium 140.9	60 Nd neodymium 144.4	61 Pm promethium –	62 Sm samarium 150.4	63 Eu europium 152.0	64 Gd gadolinium 157.3	65 Tb terbium 158.9	66 Dy dysprosium 162.5	67 Ho holmium 164.9	68 Er erbium 167.3	69 Tm thulium 168.9	70 Yb ytterbium 173.1	71 Lu lutetium 175.0
actinoids	89 Ac actinium –	90 Th thorium 232.0	91 Pa protactinium 231.0	92 U uranium 238.0	93 Np neptunium –	94 Pu plutonium –	95 Am americium –	96 Cm curium –	97 Bk berkelium –	98 Cf californium –	99 Es einsteinium –	100 Fm fermium –	101 Md mendelevium –	102 No nobelium –	103 Lr lawrencium –