IB Diploma Chemistry

Higher Level Paper 1 Exam Questions

From summer 2008 to 2016 winter
1060 marks in total

Name: ____________________________
Graphs and Mark Statistics

PAPER 1
Percentage of all marks awarded for each topic from s2015 to w2016 (TZ 0, 1 & 2) and P1 s2008 to w2014 (red)

<table>
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PAPER 1
Percentage of all marks awarded for each topic from s2008 to w2016, TZ 0, 1 & 2 (green) and Papers 1 and 2 combined (red)

<table>
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<tr>
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Higher Level PAPER 2
Percentage of all marks awarded for each topic from s1999 to w2016 for Paper 2 sections A (compulsory), B (Choose 2 Qs out of 4) and A+B.

From s2016 onwards, all Paper 2 questions are compulsory

Ranked Topics by exam paper

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Frequencies of marks awarded per answer

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(The bias against choosing A, common to multiple choice exam papers, which was worth half a grade 5 years ago, is nearly completely gone)
## Contents

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Topic 1

Topic Chem 1 Q# 1/ IB/Paper 1/2016/w/Time Zone 2/Higher Level/

1. Which volume, in cm$^3$, of 0.20 mol dm$^{-3}$ NaOH(aq) is needed to neutralize 0.050 mol of H$_2$S(g)?

\[ \text{H}_2\text{S}(g) + 2\text{NaOH}(aq) \rightarrow \text{Na}_2\text{S}(aq) + 2\text{H}_2\text{O}(l) \]

A. 0.25
B. 0.50
C. 250
D. 500

2. The complete combustion of 15.0 cm$^3$ of a gaseous hydrocarbon $X$ produces 60.0 cm$^3$ of carbon dioxide gas and 75.0 cm$^3$ of water vapour. What is the molecular formula of $X$? (All volumes are measured at the same temperature and pressure.)

A. $C_4H_8$
B. $C_4H_6$
C. $C_2H_{10}$
D. $C_6H_{10}$

3. 5.0 mol of Fe$_2$O$_3$(s) and 6.0 mol of CO(g) react according to the equation below. What is the limiting reactant and how many moles of the excess reactant remain unreacted?

\[ \text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 2\text{Fe}(s) + 3\text{CO}_2(g) \]

<table>
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<th>Limiting reactant</th>
<th>Moles of excess reactant remaining</th>
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<td>C. Fe$_2$O$_3$</td>
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<td>D. Fe$_2$O$_3$</td>
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Topic Chem 1 Q# 2/ IB/Paper 1/2016/s/Time Zone 0/Higher Level/

1. Which equation represents sublimation?

A. $2\text{Al}(s) + 3\text{I}_2(g) \rightarrow 2\text{AlI}_3(s)$
B. $\text{HgCl}_2(s) \rightarrow \text{HgCl}_2(g)$
C. $\text{I}_2(g) \rightarrow \text{I}_2(s)$
D. $\text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$
1. Which equation represents sublimation?

A. \[2\text{Al}(s) + 3\text{I}_2(g) \rightarrow 2\text{AlI}_3(s)\]

B. \[\text{HgCl}_2(s) \rightarrow \text{HgCl}_2(g)\]

C. \[\text{I}_2(g) \rightarrow \text{I}_2(s)\]

D. \[\text{CaCO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CaCl}_2(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)\]

2. In which mixture is NaOH the limiting reagent?

A. \[0.20\text{mol } \text{NaOH} + 0.10\text{mol } \text{H}_2\text{SO}_4\]

B. \[0.10\text{mol } \text{NaOH} + 0.10\text{mol } \text{H}_2\text{SO}_4\]

C. \[0.20\text{mol } \text{NaOH} + 0.10\text{mol } \text{HNO}_3\]

D. \[0.10\text{mol } \text{NaOH} + 0.10\text{mol } \text{HNO}_3\]

3. Why do gases deviate from the ideal gas law at high pressures?

A. Molecules have finite volume.

B. Cohesive forces increase the volume from the ideal.

C. Increasing pressure increases the temperature of the gas.

D. Collisions between molecules occur more frequently as pressure increases.

---

**Topic Chem 1 Q# 3 / IB/Paper 1/2016/s/Specimen Paper/Higher Level**

2. What is the sum of the coefficients when the equation for the combustion of ammonia is balanced using the smallest possible whole numbers?

\[\underline{\text{\_\_\_\_}} \text{NH}_3(g) + \underline{\text{\_\_\_\_}} \text{O}_2(g) \rightarrow \underline{\text{\_\_\_\_}} \text{N}_2(g) + \underline{\text{\_\_\_\_}} \text{H}_2\text{O}(g)\]

A. 6

B. 12

C. 14

D. 15
3. 5.00 g of calcium carbonate, when heated, produced 2.40 g of calcium oxide. Which is the correct expression for the percentage yield of calcium oxide? \( M_r(\text{CaCO}_3) = 100; M_r(\text{CaO}) = 56. \)

\[ \text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g) \]

\[ \text{A.} \quad \frac{56 \times 5.00 \times 100}{2.40} \]

\[ \text{B.} \quad \frac{2.40 \times 100 \times 100}{56 \times 5.00} \]

\[ \text{C.} \quad \frac{56 \times 5.00 \times 100}{2.40 \times 100} \]

\[ \text{D.} \quad \frac{2.40 \times 100}{56 \times 5.00} \]

Topic Chem 1 Q# 4/ IB/Paper 1/2015/w/Time Zone 2/Higher Level/

1. Which compound’s molecular formula is the same as its empirical formula?

A. \( \text{C}_2\text{H}_5\text{OH} \)

B. \( \text{CH}_3\text{COOH} \)

C. \( \text{C}_6\text{H}_5 \)

D. \( \text{C}_6\text{H}_{12} \)

2. The equation for the complete combustion of propene, \( \text{C}_3\text{H}_6 \), is shown below.

\[ 2\text{C}_3\text{H}_6(g) + 9\text{O}_2(g) \rightarrow 6\text{CO}_2(g) + 6\text{H}_2\text{O}(l) \]

Which mixture, when ignited, will lead to incomplete combustion and the formation of \( \text{CO}(g) \)?

A. 2 dm\(^3\) of propene and 10 dm\(^3\) of oxygen

B. 0.5 dm\(^3\) of propene and 2.3 dm\(^3\) of oxygen

C. 1 dm\(^3\) of propene and 4 dm\(^3\) of oxygen

D. 3 dm\(^3\) of propene and 14 dm\(^3\) of oxygen
3. What is the percentage yield when 1.1 g of ethanal, CH₃CHO, is obtained from 4.6 g of ethanol, CH₃CH₂OH? $M_r(\text{CH}_3\text{CH}_2\text{OH}) = 46, \ M_r(\text{CH}_3\text{CHO}) = 44$

\[ \text{CH}_3\text{CH}_2\text{OH}(l) + [\text{O}] \rightarrow \text{CH}_3\text{CHO}(l) + \text{H}_2\text{O}(l) \]

A. \[
\frac{1.1 \times 46 \times 100}{44 \times 4.6}
\]
B. \[
\frac{1.1 \times 100}{4.6}
\]
C. \[
\frac{4.6 \times 44 \times 100}{4.6 \times 1.1}
\]
D. \[
\frac{1.1 \times 46}{44 \times 4.6}
\]

Topic Chem 1 Q# 5/ IB/Paper 1/2015/s/Time Zone 2/Higher Level/

1. What is the total number of protons and electrons in one mole of hydrogen gas?

A. 2
B. 4
C. $1.2 \times 10^{24}$
D. $2.4 \times 10^{24}$

2. Which expression gives the sum of all the coefficients for the general equation for the complete combustion of hydrocarbons?

\[
\_\_\_ \text{C}_x\text{H}_y(g) + \_\_\_ \text{O}_2(g) \rightarrow \_\_\_ \text{CO}_2(g) + \_\_\_ \text{H}_2\text{O}(l)
\]

A. $1 + x + \frac{y}{4}$
B. $1 + x + \frac{y}{2}$
C. $1 + 2x + \frac{3y}{4}$
D. $1 + 2x + \frac{3y}{2}$

3. A gas with a molar mass (M) of 44 g mol⁻¹ occupies a volume of $2.00 \times 10^3$ cm³ at a pressure of $1.01 \times 10^5$ Pa and a temperature of 25 °C. Which expression is correct for the calculation of the mass of the gas, in g? \( R = 8.31 \text{ JK}^{-1} \text{ mol}^{-1} \)

A. \[
\frac{44 \times 1.01 \times 10^5 \times 2.00 \times 10^{-3}}{8.31 \times 298}
\]
B. \[
\frac{44 \times 1.01 \times 10^5 \times 2.00 \times 10^3}{8.31 \times 25}
\]
C. \[
\frac{1.01 \times 10^5 \times 2.00 \times 10^{-3}}{44 \times 8.31 \times 298}
\]
D. \[
\frac{44 \times 1.01 \times 10^5 \times 2.00 \times 10^3}{8.31 \times 298}
\]
1. 4.0 g of solid sodium hydroxide is added to 0.10 dm$^3$ of 1.0 mol dm$^{-3}$ aqueous sulfuric acid.

$$2\text{NaOH}(s) + \text{H}_2\text{SO}_4(aq) \rightarrow \text{Na}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l)$$

Which statement is correct?
A. Neither reactant is in excess.
B. 0.10 mol Na$_2$SO$_4$ is formed.
C. Excess H$_2$SO$_4$ remains in solution.
D. Excess NaOH remains in solution.

2. Which compound has the highest percentage of carbon by mass?
A. CH$_4$
B. C$_2$H$_4$
C. C$_4$H$_{10}$
D. C$_6$H$_6$

3. Which solution contains the biggest amount, in mol, of chloride ions?
A. 20 cm$^3$ of 0.50 mol dm$^{-3}$ NH$_4$Cl
B. 60 cm$^3$ of 0.20 mol dm$^{-3}$ MgCl$_2$
C. 70 cm$^3$ of 0.30 mol dm$^{-3}$ NaCl
D. 100 cm$^3$ of 0.30 mol dm$^{-3}$ CICl$_2$COOH

Topic Chem 1 Q# 7 / IB/Paper 1/2014/w/Time Zone 0/Higher Level/

1. 0.040 mol of (NH$_4$)$_2$Ni(SO$_4$)$_2$•6H$_2$O is dissolved in water to give 200 cm$^3$ of aqueous solution. What is the concentration, in mol dm$^{-3}$, of ammonium ions?
A. 0.00040
B. 0.0080
C. 0.20
D. 0.40
2. When sodium bromate(V), \( \text{NaBrO}_3 \), is heated, it reacts according to the equation below.

\[
2\text{NaBrO}_3(s) \rightarrow 2\text{NaBr}(s) + 3\text{O}_2(g)
\]

What amount, in mol, of \( \text{NaBrO}_3 \) produces 2.4 dm\(^3\) of oxygen gas, measured at room temperature and pressure? (Molar volume of gas = 24 dm\(^3\)mol\(^{-1}\) at room temperature and pressure.)

A. 0.017
B. 0.067
C. 0.10
D. 0.15

3. At which temperature, in K, assuming constant pressure, is the volume of a fixed mass of gas at 127 °C doubled?

A. 200 K
B. 254 K
C. 400 K
D. 800 K

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1. What is the mass, in g, of one mole of hydrated copper(II) sulfate, \( \text{CuSO}_4\cdot5\text{H}_2\text{O} \), given the following relative atomic mass values?

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<th>S</th>
<th>H</th>
<th>O</th>
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<tbody>
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<td>Relative atomic mass</td>
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<td>32</td>
<td>1</td>
<td>16</td>
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</table>

A. 160
B. 178
C. 186
D. 250
2. An excess of calcium carbonate is added to a solution containing 0.10 \text{ mol} \text{ of HCl(aq)}. What mass of calcium carbonate reacts, and what mass of carbon dioxide is formed?

Mass of one mole of $\text{CaCO}_3 = 100 \text{ g}$

Mass of one mole of $\text{CO}_2 = 44 \text{ g}$

$$\text{CaCO}_3(s) + 2\text{HCl(aq)} \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O(l)} + \text{CO}_2(\text{g})$$

<table>
<thead>
<tr>
<th>$\text{CaCO}_3(\text{s}) / \text{g}$</th>
<th>$\text{CO}_2(\text{g}) / \text{g}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>5.0</td>
</tr>
<tr>
<td>D</td>
<td>5.0</td>
</tr>
</tbody>
</table>

3. For which compounds is the empirical formula the same as the molecular formula?

I. Methane
II. Ethene
III. Ethanol

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

Topic Chem 1 Q# 10/ IB/Paper 1/2014/s/Time Zone 1/Higher Level/

1. The structural formula of a dioxin is shown below.

What is its empirical formula?

A. $\text{C}_6\text{O}$
B. $\text{C}_6\text{H}_4\text{O}$
C. $\text{C}_6\text{H}_6\text{O}$
D. $\text{C}_{12}\text{H}_8\text{O}_2$
2. Under which conditions does \( \text{CH}_4 \) have the same number of molecules as \( 100 \text{ cm}^3 \) of \( \text{O}_2 \) at \( 27 \degree \text{C} \) and \( 1.0 \times 10^5 \text{ Pa} \)?

<table>
<thead>
<tr>
<th>Volume / cm(^3)</th>
<th>Temperature / °C</th>
<th>Pressure / (10^5) Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 50</td>
<td>54</td>
<td>1.0</td>
</tr>
<tr>
<td>B. 50</td>
<td>327</td>
<td>1.0</td>
</tr>
<tr>
<td>C. 100</td>
<td>54</td>
<td>2.0</td>
</tr>
<tr>
<td>D. 100</td>
<td>327</td>
<td>2.0</td>
</tr>
</tbody>
</table>

3. 100.0 cm\(^3\) of a 0.50 mol dm\(^{-3}\) solution of \( \text{BaCl}_2 \) is added to 50.0 cm\(^3\) of a 0.10 mol dm\(^{-3}\) solution of \( \text{Na}_2\text{SO}_4 \). A precipitate of \( \text{BaSO}_4 \) is formed according to the equation below.

\[
\text{BaCl}_2 (\text{aq}) + \text{Na}_2\text{SO}_4 (\text{aq}) \rightarrow \text{BaSO}_4 (s) + 2\text{NaCl(aq)}
\]

What is the amount, in mol, of \( \text{BaSO}_4 \) produced?

A. 0.0050
B. 0.010
C. 0.050
D. 0.10
2. What are the coefficients of $H_2SO_4(aq)$ and $H_2PO_4(aq)$ when the following equation is balanced using the smallest possible whole numbers?

$$\text{Ca}_2(PO_4)_{2(s)} + \text{H}_2SO_4(aq) \rightarrow \text{CaSO}_4(s) + \text{H}_3PO_4(aq)$$

<table>
<thead>
<tr>
<th>Coefficient of $H_2SO_4(aq)$</th>
<th>Coefficient of $H_3PO_4(aq)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>1</td>
</tr>
<tr>
<td>B.</td>
<td>2</td>
</tr>
<tr>
<td>C.</td>
<td>3</td>
</tr>
<tr>
<td>D.</td>
<td>3</td>
</tr>
</tbody>
</table>

3. 7.102 g of $Na_2SO_4(M = 142.04 \, g \, mol^{-1})$ is dissolved in water to prepare 0.5000 dm$^3$ of solution. What is the concentration of $Na_2SO_4$ in mol dm$^{-3}$?

A. $2.500 \times 10^{-2}$
B. $1.000 \times 10^{-1}$
C. 1.000 × 10
D. $1.000 \times 10^2$

Topic: Chem 1 Q# 12/ IB/Paper 1/2013/s/Time Zone 2/Higher Level/

1. How many atoms are present in 0.10 mol of $PtCl_4(NH_3)_2$?

A. $6.0 \times 10^{23}$
B. $3.0 \times 10^{23}$
C. $6.6 \times 10^{23}$
D. $6.6 \times 10^{24}$

2. What mass of carbon dioxide, $CO_2(g)$, in g, is produced when 5.0 g of calcium carbonate, $CaCO_3(s)$, reacts completely with hydrochloric acid, $HCl(aq)$?

$$CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$$

A. 0.050
B. 2.2
C. 4.4
D. 5.0
3. The volume occupied by one mole of an ideal gas at 273 K and 1.01×10^5 Pa is 22.4 dm^3 mol\(^{-1}\). What volume of hydrogen, in dm^3, is produced when excess magnesium ribbon reacts with 100 cm^3 of 2.00 mol dm\(^{-3}\) hydrochloric acid?

\[ \text{Mg (s) + 2HCl (aq) → MgCl}_2 (aq) + \text{H}_2 (g) \]

A. 0.100
B. 2.24
C. 4.48
D. 22.4

Topic Chem 1 Q# 13/ IB/Paper 1/2013/s/Time Zone 1/Higher Level/

1. What is the whole number ratio of the coefficients of ammonia to oxygen when the following equation is balanced correctly?

\[ \underline{\text{____ NH}_3 (g) + \text{____ O}_2 (g) → \text{____ NO (g) + ____ H}_2\text{O (l)}} \]

A. 1 : 2
B. 2 : 1
C. 4 : 5
D. 5 : 4

2. When 50 cm^3 of a hydrocarbon, C\(_x\)H\(_y\), was burned in excess oxygen, 200 cm^3 of carbon dioxide and 250 cm^3 of steam were produced (all volumes were measured under the same conditions). What is the molecular formula of the hydrocarbon?

A. C\(_2\)H\(_4\)
B. C\(_3\)H\(_4\)
C. C\(_4\)H\(_4\)
D. C\(_4\)H\(_{10}\)
3. Which graph represents the relationship between volume and pressure for a fixed mass of gas at constant temperature?

A. 

B. 

C. 

D. 

1. What is the number of ions in 0.20 mol of (NH₄)₂PO₄?

A. 8.0 × 10⁻¹

B. 1.2 × 10²³

C. 4.8 × 10²³

D. 2.4 × 10²⁴
2. The equation for the reduction of iron(III) oxide is:

\[ \text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 2\text{Fe}(s) + 3\text{CO}_2(g) \]

What mass of carbon dioxide, in g, is produced by the complete reduction of 80 g of iron(III) oxide?

A. 44
B. 66
C. 88
D. 132

3. 3.0 dm$^3$ of ethyne, C$_2$H$_2$, is mixed with 3.0 dm$^3$ of hydrogen and ignited. The equation for the reaction that occurs is shown below.

\[ \text{C}_2\text{H}_2(g) + 2\text{H}_2(g) \rightarrow \text{C}_2\text{H}_6(g) \]

Assuming the reaction goes to completion and all gas volumes are measured at the same temperature and pressure, what volume of ethane, C$_2$H$_6$, in dm$^3$, is formed?

A. 1.5
B. 2.0
C. 3.0
D. 6.0

Topic Chem 1 Q# 15/ IB/Paper 1/2012/s/Time Zone 2/Higher Level /

1. What is the total number of atoms in 0.100 mol of [Pt(NH$_3$)$_2$Cl$_2$]? 

A. 11
B. $6.02 \times 10^{23}$
C. $3.01 \times 10^{23}$
D. $6.62 \times 10^{23}$
2. Nitroglycerine, $\text{C}_3\text{H}_5\text{N}_3\text{O}_9$, can be used in the manufacture of explosives. What is the coefficient of $\text{C}_3\text{H}_5\text{N}_3\text{O}_9(\text{l})$ when the equation for its decomposition reaction is balanced using the lowest whole numbers?

$$\text{C}_3\text{H}_5\text{N}_3\text{O}_9(\text{l}) \rightarrow \_\_\_\text{CO}_2(\text{g}) + \_\_\_\text{H}_2\text{O}(\text{l}) + \_\_\_\text{N}_2(\text{g}) + \_\_\_\text{O}_2(\text{g})$$

A. 2  
B. 4  
C. 20  
D. 33

3. The volume occupied by one mole of an ideal gas at 273 K and $1.01\times10^5$ Pa is 22.4 dm$^3$. What volume, in dm$^3$, is occupied by 3.20 g $\text{O}_2(\text{g})$ at 273 K and $1.01\times10^5$ Pa?

A. 2.24  
B. 4.48  
C. 22.4  
D. 71.7

4. What volume, in m$^3$, is occupied by 2.00 mol of gas at 27 °C and 2.00 atm pressure? Assume: 1.00 atm = $1.01\times10^5$ Pa and $R = 8.31$ J K$^{-1}$ mol$^{-1}$.

A. $\frac{8.31\times27}{1.01\times10^5}$  
B. $\frac{2.00\times8.31\times27}{1.01\times10^5}$  
C. $\frac{2.00\times8.31\times300}{2.00\times1.01\times10^5}$  
D. $\frac{2.00\times8.31\times300}{1.01\times10^5}$
1. How many atoms of hydrogen are in 0.500 mol of CH$_3$OH molecules?
   A. $1.20 \times 10^{23}$
   B. $3.01 \times 10^{23}$
   C. $6.02 \times 10^{23}$
   D. $1.20 \times 10^{24}$

2. Calcium carbonate reacts with hydrochloric acid according to the following equation.

   \[
   \text{CaCO}_3(s) + 2\text{HCl(aq)} \rightarrow \text{CaCl}_2(\text{aq}) + \text{CO}_2(\text{g}) + \text{H}_2\text{O(l)}
   \]

   What is the theoretical yield, in mol, of calcium chloride if 0.10 mol CaCO$_3$ is added to 100 cm$^3$ of 1.0 mol dm$^{-3}$ HCl?
   A. 0.050
   B. 0.10
   C. 0.20
   D. 0.50

3. A fixed mass of an ideal gas at 27.0 °C and 1.01×10$^5$ Pa has a volume of 100 cm$^3$. Which change doubles the volume of the gas?
   A. Heating the gas at constant pressure to 54.0 °C.
   B. Heating the gas at constant pressure to 327 °C.
   C. Increasing the pressure on the gas to 2.02×10$^5$ Pa at constant temperature.
   D. Heating the gas to 54.0 °C and increasing the pressure to 2.02×10$^5$ Pa.
1. How many oxygen atoms are in 0.100 mol of CuSO₄·5H₂O?

A. $5.42 \times 10^{22}$
B. $6.02 \times 10^{22}$
C. $2.41 \times 10^{23}$
D. $5.42 \times 10^{23}$

2. What is the sum of the coefficients when the following equation is balanced using whole numbers?

$$\underline{\text{___}} \text{Fe}_2\text{O}_3(s) + \underline{\text{___}} \text{CO(g)} \rightarrow \underline{\text{___}} \text{Fe(s)} + \underline{\text{___}} \text{CO}_2(g)$$

A. 5
B. 6
C. 8
D. 9

3. Four identical containers under the same conditions are filled with gases as shown below. Which container and contents will have the highest mass?

A. Nitrogen
B. Oxygen
C. Ethane
D. Neon
4. 1.0 dm$^3$ of an ideal gas at 100 kPa and 25 °C is heated to 50 °C at constant pressure. What is the new volume in dm$^3$?

A. 0.50  
B. 0.90  
C. 1.1  
D. 2.0

5. What is the amount, in moles, of sulfate ions in 100 cm$^3$ of 0.020 mol dm$^{-3}$ FeSO$_4$(aq) ?

A. $2.0 \times 10^{-2}$  
B. $2.0 \times 10^{-3}$  
C. $2.0 \times 10^{-2}$  
D. 2.0

Topic Chem 1 Q# 18/IB/Paper 1/2011/s/Time Zone 2/Higher Level/

1. What is the total number of hydrogen atoms in 1.0 mol of benzamide, C$_6$H$_5$CONH$_2$? 

A. 7  
B. $6.0 \times 10^{23}$  
C. $3.0 \times 10^{24}$  
D. $4.2 \times 10^{24}$

2. Chloroethene, C$_2$H$_5$Cl, reacts with oxygen according to the equation below.

$$2C_2H_5Cl(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(g) + 2HCl(g)$$

What is the amount, in mol, of H$_2$O produced when 10.0 mol of C$_2$H$_5$Cl and 10.0 mol of O$_2$ are mixed together, and the above reaction goes to completion?

A. 4.00  
B. 8.00  
C. 10.0  
D. 20.0
3. What is the concentration of NaCl, in mol dm$^{-3}$, when 10.0 cm$^3$ of 0.200 mol dm$^{-3}$ NaCl solution is added to 30.0 cm$^3$ of 0.600 mol dm$^{-3}$ NaCl solution?

A. 0.450  
B. 0.300  
C. 0.500  
D. 0.800

1. 1.7 g of NaNO$_3$ ($M_r = 85$) is dissolved in water to prepare 0.20 dm$^3$ of solution. What is the concentration of the resulting solution in mol dm$^{-3}$?

A. 0.01  
B. 0.1  
C. 0.2  
D. 1.0

2. What mass, in g, of hydrogen is formed when 3 mol of aluminium react with excess hydrochloric acid according to the following equation?

$$2\text{Al}(s) + 6\text{HCl}(aq) \rightarrow 2\text{AlCl}_3(aq) + 3\text{H}_2(g)$$

A. 3.0  
B. 4.5  
C. 6.0  
D. 9.0

3. The relative molecular mass of a gas is 56 and its empirical formula is CH$_2$. What is the molecular formula of the gas?

A. CH$_3$  
B. C$_2$H$_4$  
C. C$_3$H$_6$  
D. C$_4$H$_8$
4. What is the sum of all coefficients when the following equation is balanced using the smallest possible whole numbers?

\[ \text{C}_2\text{H}_6 + \_\text{O}_2 \rightarrow \_\text{CO}_2 + \_\text{H}_2\text{O} \]

A. 5  
B. 7  
C. 11  
D. 13

1. On analysis, a compound with molar mass 60 g mol\(^{-1}\) was found to contain 12 g of carbon, 2 g of hydrogen and 16 g of oxygen. What is the molecular formula of the compound?

A. CH\(_2\)O  
B. CH\(_4\)O  
C. C\(_2\)H\(_4\)O  
D. C\(_2\)H\(_4\)O\(_2\)

2. 300 cm\(^3\) of water is added to a solution of 200 cm\(^3\) of 0.5 mol dm\(^{-3}\) sodium chloride. What is the concentration of sodium chloride in the new solution?

A. 0.05 mol dm\(^{-3}\)  
B. 0.1 mol dm\(^{-3}\)  
C. 0.2 mol dm\(^{-3}\)  
D. 0.3 mol dm\(^{-3}\)
3. The graph below represents the relationship between two variables in a fixed amount of gas.

Which variables could be represented by each axis?

<table>
<thead>
<tr>
<th></th>
<th>x-axis</th>
<th>y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>pressure</td>
<td>temperature</td>
</tr>
<tr>
<td>B.</td>
<td>volume</td>
<td>temperature</td>
</tr>
<tr>
<td>C.</td>
<td>pressure</td>
<td>volume</td>
</tr>
<tr>
<td>D.</td>
<td>temperature</td>
<td>volume</td>
</tr>
</tbody>
</table>

1. What is the mass, in g, of one molecule of ethane, C₂H₆?

   A. 3.0×10⁻²³
   B. 5.0×10⁻²³
   C. 30
   D. 1.8×10²⁵

2. 6.0 mol of aluminium reacts with oxygen to form aluminium oxide. What is the amount of oxygen, in mol, needed for complete reaction?

   \[ 4\text{Al}(s) + 3\text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s) \]

   A. 1.5
   B. 3.0
   C. 4.5
   D. 6.0
3. Which of the following is consistent with Avogadro's law?
   A. \( \frac{P}{T} = \text{constant} (V, n \text{ constant}) \)
   B. \( \frac{V}{T} = \text{constant} (P, n \text{ constant}) \)
   C. \( Vn = \text{constant} (P, T \text{ constant}) \)
   D. \( \frac{V}{n} = \text{constant} (P, T \text{ constant}) \)

4. A sample of element X contains 69% of \(^{65}\text{X}\) and 31% of \(^{65}\text{X}\). What is the relative atomic mass of X in this sample?
   A. 63.0
   B. 63.6
   C. 65.0
   D. 69.0

1. What is the approximate molar mass, in g mol\(^{-1}\), of MgSO\(_4\)·7H\(_2\)O?
   A. 120
   B. 130
   C. 138
   D. 246

2. Which is both an empirical and a molecular formula?
   A. \( \text{C}_5\text{H}_{12} \)
   B. \( \text{C}_5\text{H}_{10} \)
   C. \( \text{C}_4\text{H}_8 \)
   D. \( \text{C}_4\text{H}_{11} \)
3. 12 molecules of hydrogen gas, $\text{H}_2(\text{g})$, and 5 molecules of oxygen gas, $\text{O}_2(\text{g})$, were mixed together under conditions which allowed the reaction to go to completion, according to the following equation.

$$2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{g})$$

The following diagram represents the mixture of reactants.

![Diagram of reactants]

Key:
- **Oxygen atom**
- **Hydrogen atom**

Which diagram represents the reaction mixture when the reaction was complete?

A. 

![Diagram A]

B. 

![Diagram B]

C. 

![Diagram C]

D. 

![Diagram D]
1. Which coefficients would balance this equation?

\[ \text{___ MnO}_2 + \text{___ HCl} \rightarrow \text{___ MnCl}_2 + \text{___ Cl}_2 + \text{___ H}_2\text{O} \]

<table>
<thead>
<tr>
<th></th>
<th>MnO(_2)</th>
<th>HCl</th>
<th>MnCl(_2)</th>
<th>Cl(_2)</th>
<th>H(_2)O</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B.</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C.</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>D.</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

2. What volume of carbon dioxide, in dm\(^3\) under standard conditions, is formed when 7.00 g of ethene (C\(_2\)H\(_4\), \(M_r = 28.1\)) undergoes complete combustion?

A. \(\frac{22.4 \times 28.1}{7.00}\)

B. \(\frac{22.4 \times 7.00}{28.1}\)

C. \(\frac{2 \times 22.4 \times 28.1}{7.00}\)

D. \(\frac{2 \times 22.4 \times 7.00}{28.1}\)

3. What will be the concentration of sulfate ions in mol dm\(^{-3}\) when 0.20 mol of KAl(SO\(_4\))\(_2\) is dissolved in water to give 100 cm\(^3\) of aqueous solution?

A. 0.2

B. 1.0

C. 2.0

D. 4.0
4. The volume of an ideal gas at 27.0°C is increased from 3.00 dm³ to 6.00 dm³. At what temperature, in °C, will the gas have the original pressure?

A. 13.5
B. 54.0
C. 327
D. 600

Topic: Chem 1 Q# 24/ IB/Paper 1/2009/s/Time Zone 2/Higher Level/

1. What is the number of oxygen atoms in one mole of CuSO₄·5H₂O?

A. 5
B. 9
C. 6.0 × 10²³
D. 5.4 × 10²⁴

2. Which sample has the greatest mass?

A. 6.0 × 10²⁵ molecules of hydrogen
B. 5.0 mol of neon atoms
C. 1.2 × 10²⁴ atoms of silver
D. 1.7 × 10³ g of iron

3. What volume of sulfur trioxide, in cm³, can be prepared using 40 cm³ sulfur dioxide and 20 cm³ oxygen gas by the following reaction? Assume all volumes are measured at the same temperature and pressure.

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightarrow 2\text{SO}_3(g) \]

A. 20
B. 40
C. 60
D. 80
4. Which sample of nitrogen gas, \( \text{N}_2 \), contains the greatest number of nitrogen molecules?
   
   A. 1.4 g \( \text{N}_2 \)
   
   B. 1.4 dm\(^3\) of \( \text{N}_2 \) at \( 1.01 \times 10^5 \) Pa and 273 K
   
   C. \( 1.4 \times 10^{23} \) \( \text{N}_2 \) molecules
   
   D. 1.4 mol \( \text{N}_2 \)

Topic: Chem 1 Q# 25/ IB/Paper 1/2009/s/Time Zone 1/Higher Level/

1. Which compound has the empirical formula with the largest mass?
   
   A. \( \text{C}_3\text{H}_6 \)
   
   B. \( \text{C}_3\text{H}_4 \)
   
   C. \( \text{C}_3\text{H}_2 \)
   
   D. \( \text{C}_3\text{H}_6 \)

2. 5 dm\(^3\) of carbon monoxide, \( \text{CO} \) (g), and 2 dm\(^3\) of oxygen, \( \text{O}_2 \) (g), at the same temperature and pressure are mixed together. Assuming complete reaction according to the equation given, what is the maximum volume of carbon dioxide, \( \text{CO}_2 \) (g), in dm\(^3\), that can be formed?

   \[
   2\text{CO} (g) + \text{O}_2 (g) \rightarrow 2\text{CO}_2 (g)
   \]

   A. 3
   
   B. 4
   
   C. 5
   
   D. 7

3. Which statement about solutions is correct?
   
   A. When vitamin D dissolves in fat, vitamin D is the solvent and fat is the solute.
   
   B. In a solution of NaCl in water, NaCl is the solute and water is the solvent.
   
   C. An aqueous solution consists of water dissolved in a solute.
   
   D. The concentration of a solution is the amount of solvent dissolved in 1 dm\(^3\) of solution.
1. Analytical chemists can detect amounts of amino acids as small as $2.0 \times 10^{-21}$ mol of molecules. How many molecules does this represent?

A. $2.0 \times 10^{-21}$
B. $1.2 \times 10^3$
C. $6.0 \times 10^{23}$
D. $3.0 \times 10^{44}$

2. What amount of solute ions, in moles, is present in 50 cm$^3$ of 0.10 mol dm$^{-3}$ sodium hydroxide solution?

A. $2.5 \times 10^{-3}$
B. $5.0 \times 10^{-2}$
C. $1.0 \times 10^{-2}$
D. $5.0 \times 10^{-2}$

3. A blast furnace contains 1600 kg of iron(III) oxide ($M_r=160$) and 144 kg of carbon ($M_r=12$). Assuming that they react according to the following equation:

$$\text{Fe}_2\text{O}_3(s) + 3\text{C}(s) \rightarrow 2\text{Fe}(s) + 3\text{CO}(g)$$

what is the limiting reagent and the maximum theoretical yield of iron?

<table>
<thead>
<tr>
<th>Limiting reagent</th>
<th>Maximum theoretical yield of iron / kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. iron(III) oxide</td>
<td>560</td>
</tr>
<tr>
<td>B. iron(III) oxide</td>
<td>1120</td>
</tr>
<tr>
<td>C. carbon</td>
<td>224</td>
</tr>
<tr>
<td>D. carbon</td>
<td>448</td>
</tr>
</tbody>
</table>
1. What is the amount of atoms, in moles, in 88 g of carbon dioxide?

A. $6.02 \times 10^{23}$
B. $1.204 \times 10^{24}$
C. 6
D. 1

2. The isotopic abundances for an element, X, are $\frac{21}{28}X = 20\%$ and $\frac{29}{28}X = 80\%$. What is the relative atomic mass of element X?

A. 14
B. 28.2
C. 28.5
D. 28.8

3. What is the volume (in cm$^3$) of a 0.800 mol dm$^{-3}$ solution of KOH needed for neutralization in a titration with 30.0 cm$^3$ of 0.200 mol dm$^{-3}$ H$_2$SO$_4$?

A. 7.50
B. 60.0
C. 15.0
D. 30.0

15. The temperature of 1 dm$^3$ of a gas is increased from 32°C to 64°C at constant pressure. What is the new volume in dm$^3$?

A. 1.1
B. 1.3
C. 1.6
D. 2.0
1. How many molecules are present in a 9.0 g sample of water?
   A. \(0.5\)
   B. \(1.0\)
   C. \(6.0 \times 10^{23}\)
   D. \(3.0 \times 10^{23}\)

2. What is the coefficient for oxygen when this equation is balanced using the lowest whole number?
   \[C_4H_{10} + O_2 \rightarrow CO + H_2O\]
   A. \(4\)
   B. \(5\)
   C. \(9\)
   D. \(13\)

3. What is the maximum mass of iron that can be produced from the reduction of 80 tonnes of iron(III) oxide (\(M = 160\)), based on this equation?
   \[Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2\]
   A. 28 tonnes
   B. 56 tonnes
   C. 84 tonnes
   D. 112 tonnes
<table>
<thead>
<tr>
<th>Question</th>
<th>Mark Scheme</th>
<th>Question</th>
<th>Mark Scheme</th>
</tr>
</thead>
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<td>Q# 17/IB/P1/2011/w/TZ 0/HL/</td>
<td>1. D 2. D 3. A</td>
</tr>
</tbody>
</table>
Topic 2

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4. Which is correct for the line emission spectrum for hydrogen?

![Line emission spectrum diagram]

A. Line M has a higher energy than line N.
B. Line N has a lower frequency than line M.
C. Line M has a longer wavelength than line N.
D. Lines converge at lower energy.

5. Which representation would be correct for a species, Z, which has 31 protons, 40 neutrons and 28 electrons?

A. \( \frac{31}{29}Z^{+} \)
B. \( \frac{31}{23}Z^{2+} \)
C. \( \frac{31}{40}Z^{2+} \)
D. \( \frac{31}{28}Z^{3+} \)

6. A period 3 element, M, forms an oxide of the type \( M_2O \). Which represents the first four successive ionization energies of M?

| Ionization energy / kJmol\(^{-1} \) |
|-----------------|-----------------|----------------|----------------|
| First | Second | Third | Fourth |
| A. | 496 | 4563 | 6913 | 9544 |
| B. | 738 | 1451 | 7733 | 10541 |
| C. | 578 | 1817 | 2745 | 11578 |
| D. | 787 | 1577 | 3232 | 4356 |
4. Which is correct for the chromium isotope $^{53}_{24}\text{Cr}$?
   A. 24 neutrons and 53 nucleons
   B. 24 protons and 29 neutrons
   C. 24 protons and 25 neutrons
   D. 24 electrons and 53 neutrons

5. Which electron configuration is correct for the selenide ion, $\text{Se}^{2-}$?
   A. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 4d^0\ 4p^6$
   B. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 4d^0\ 4p^6$
   C. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^0\ 4p^6$
   D. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^0\ 4p^6$

4. Ultraviolet radiation has a shorter wavelength than infrared radiation. How does the frequency and energy of ultraviolet radiation compare with infrared radiation?

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>higher</td>
</tr>
<tr>
<td>B.</td>
<td>higher</td>
</tr>
<tr>
<td>C.</td>
<td>lower</td>
</tr>
<tr>
<td>D.</td>
<td>lower</td>
</tr>
</tbody>
</table>

5. The first ionization energies (in kJ mol$^{-1}$) of five subsequent elements in the periodic table are:
   1314, 1681, 2081, 496 and 738
   What could these elements be?
   A. d-block elements
   B. The last two elements of one period and the first three elements of the next period
   C. The last three elements of one period and the first two elements of the next period
   D. The last five elements of a period

6. What is the total number of valence electrons in $\text{CH}_2\text{COO}^-$?
   A. 16
   B. 22
   C. 23
   D. 24
7. What is the definition of the term first ionization energy?

A. The energy released when one mole of electrons is removed from one mole of gaseous atoms.
B. The energy required to remove one mole of electrons from one mole of gaseous atoms.
C. The energy released when one mole of gaseous atoms gains one mole of electrons.
D. The energy required to add one mole of electrons to one mole of gaseous atoms.

8. Which statements are correct about the complex \([\text{Cu}(\text{NH}_3)_2\text{Cl}_2]\)?

I. Oxidation state of copper is +2.
II. Ammonia is a ligand.
III. Chloride ions act as Lewis acids.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

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4. Some possible electron transitions in a hydrogen atom are shown below. Which letter represents the electron transition with the highest energy in the emission spectrum of a hydrogen atom?
4. What is the abbreviated electron configuration of the cobalt(II) ion, Co$^{2+}$?

A. [Ar] 3d$^7$
B. [Ar] 4s$^2$ 3d$^5$
C. [Ar] 4s$^2$ 3d$^7$
D. [Ar] 4s$^1$ 3d$^6$

5. Which statement correctly describes the atomic emission spectrum of hydrogen?

A. It is a continuous spectrum converging at high frequency.
B. It is a line spectrum converging at high frequency.
C. It is a continuous spectrum converging at low frequency.
D. It is a line spectrum converging at low frequency.

4. The diagram represents the emission spectrum of hydrogen. Groups of arrows are labelled W, X and Y.

Which statement is correct?

A. The arrows represent the transition of electrons to different energy levels when heat is supplied.
B. The arrows of W represent emission in the UV region.
C. The smallest arrow of X represents a violet line in the emission spectrum.
D. The arrows of Y represent emission of electromagnetic waves with higher energy than those represented by X and W.
5. Which electron configurations do not follow the Hund’s rule?

<table>
<thead>
<tr>
<th></th>
<th>1s</th>
<th>2s</th>
<th>2p</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>↑↓</td>
<td>↑↓</td>
<td>↑</td>
</tr>
<tr>
<td>II.</td>
<td>↑↓</td>
<td>↑↓</td>
<td>↑</td>
</tr>
<tr>
<td>III.</td>
<td>↑↓</td>
<td>↑↓</td>
<td>↑</td>
</tr>
</tbody>
</table>

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III

4. What are the numbers of neutrons and electrons in the iodine ion, $^{125}\text{I}^-$?

<table>
<thead>
<tr>
<th>Neutrons</th>
<th>Electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 53</td>
<td>53</td>
</tr>
<tr>
<td>B. 72</td>
<td>52</td>
</tr>
<tr>
<td>C. 72</td>
<td>53</td>
</tr>
<tr>
<td>D. 125</td>
<td>52</td>
</tr>
</tbody>
</table>

5. What is the abbreviated electron configuration of the telluride ion, $\text{Te}^{2-}$?

A. $[\text{Kr}]5s^25d^{10}5p^6$  
B. $[\text{Kr}]5s^24d^{10}5p^3$  
C. $[\text{Kr}]5s^24d^{10}5p^4$  
D. $[\text{Kr}]5s^24d^{10}5p^6$
5. Which species has the electron configuration of 1s$^2$2s$^2$2p$^6$3s$^2$3p$^6$3d$^9$?

A. Ni
B. Ni$^{2+}$
C. Fe
D. Cu$^{2+}$

6. Element X is in group 5 and period 4 of the periodic table. Which statement is correct?

A. X has 5 occupied energy levels.
B. X can form ions with 3$^-$ charge.
C. X is a transition element.
D. X has 4 valence electrons.

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4. Which diagram shows a pattern similar to the emission spectrum of hydrogen?

Increasing wavelength

A. 

B. 

C. 

D. 

5. What is the correct electron configuration of the Cu$^{+}$ ion?

A. [Ar] 3d$^9$ 4s$^1$
B. [Ar] 3d$^7$ 4s$^2$
C. [Ar] 3d$^{10}$
D. [Ar] 3d$^8$ 4s$^1$
5. Which of the graphs below shows the successive logarithmic ionization energies of phosphorus?

A.  

B.  

C.  

D.  

5. In the electromagnetic spectrum, which will have the shortest wavelength and the greatest energy?

<table>
<thead>
<tr>
<th>Shortest wavelength</th>
<th>Greatest energy</th>
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</thead>
<tbody>
<tr>
<td>A. ultraviolet</td>
<td>ultraviolet</td>
</tr>
<tr>
<td>B. infrared</td>
<td>infrared</td>
</tr>
<tr>
<td>C. ultraviolet</td>
<td>infrared</td>
</tr>
<tr>
<td>D. infrared</td>
<td>ultraviolet</td>
</tr>
</tbody>
</table>
6. What is the electron configuration of Sn^{2+}?

A. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^2
B. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10}
C. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 4d^{10} 5p^2
D. 1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^8 5p^2

4. Which isotope has an atomic number of 9 and a mass number of 19?

A. ^9 F
B. ^19 K
C. ^19 F
D. ^28 Si

5. What is the order in which the energy sub-levels are occupied according to the Aufbau principle?

A. 5s, 5p, 4d
B. 4d, 5s, 5p
C. 5s, 4d, 5p
D. 5s, 5d, 5p

8. What are the electron configurations of Cu, Cu^+ and Cu^{2+}?

<table>
<thead>
<tr>
<th></th>
<th>Cu</th>
<th>Cu^+</th>
<th>Cu^{2+}</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>[Ar] 4s^2 3d^9</td>
<td>[Ar] 4s^2 3d^8</td>
<td>[Ar] 4s^2 3d^7</td>
</tr>
<tr>
<td>B.</td>
<td>[Ar] 4s^2 3d^9</td>
<td>[Ar] 4s^1 3d^9</td>
<td>[Ar] 3d^8</td>
</tr>
<tr>
<td>C.</td>
<td>[Ar] 4s^2 3d^9</td>
<td>[Ar] 3d^{10}</td>
<td>[Ar] 3d^8</td>
</tr>
<tr>
<td>D.</td>
<td>[Ar] 4s^1 3d^{10}</td>
<td>[Ar] 3d^{10}</td>
<td>[Ar] 3d^9</td>
</tr>
</tbody>
</table>
6. Which shows the sub-levels in order of increasing energy in the fourth energy level of an atom?

A. \( f < d < p < s \)

B. \( p < d < f < s \)

C. \( d < f < p < s \)

D. \( s < p < d < f \)

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4. Consider the relative abundance of the isotopes of element X.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Relative abundance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^{24}\text{X})</td>
<td>80</td>
</tr>
<tr>
<td>(^{25}\text{X})</td>
<td>10</td>
</tr>
<tr>
<td>(^{26}\text{X})</td>
<td>10</td>
</tr>
</tbody>
</table>

What is the relative atomic mass of X?

A. 24

B. 25

C. Between 24 and 25

D. Between 25 and 26

5. In the emission spectrum of hydrogen, which electronic transition would produce a line in the visible region of the electromagnetic spectrum?

A. \( n = 2 \rightarrow n = 1 \)

B. \( n = 3 \rightarrow n = 2 \)

C. \( n = 2 \rightarrow n = 3 \)

D. \( n = \infty \rightarrow n = 1 \)
5. What is the electron configuration of vanadium?

A. $1s^22s^22p^63s^23p^63d^44s^1$

B. $1s^22s^22p^63s^23p^63d^44s^2$

C. $1s^22s^22p^63s^23p^63d^44s^1$

D. $1s^22s^22p^63s^23p^63d^5$

6. Which quantities are the same for all atoms of chlorine?

I. Number of protons

II. Number of neutrons

III. Number of electrons

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

4. Which statement about the species $^{62}\text{Cu}^{2+}$ and $^{65}\text{Cu}^+$ is correct?

A. Both species have the same number of protons.

B. Both species have the same number of electrons.

C. Both species have the same number of neutrons.

D. Both species have the same electron arrangement.

5. What is the electron configuration of Fe$^{2+}$?

A. [Ar]$4s^23d^6$

B. [Ar]$3d^5$

C. [Ar]$4s^23d^5$

D. [Ar]$4s^23d^3$
4. Which describes the visible emission spectrum of hydrogen?

A. A series of lines converging at longer wavelength
B. A series of regularly spaced lines
C. A series of lines converging at lower energy
D. A series of lines converging at higher frequency

5. The graph represents the energy needed to remove nine electrons, one at a time, from an atom of an element. Not all of the electrons have been removed.

Which element could this be?

A. C
B. Si
C. P
D. S

6. An ion has the electron configuration $1s^2 \ 2s^2 \ 2p^6 \ 3s^2 \ 3p^6 \ 3d^{10}$. Which ion could it be?

A. $\text{Ni}^{2+}$
B. $\text{Cu}^+$
C. $\text{Cu}^{2+}$
D. $\text{Co}^{3+}$
5. The table below shows the number of protons, neutrons and electrons present in five species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of protons</th>
<th>Number of neutrons</th>
<th>Number of electrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>6</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>Y</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Z</td>
<td>7</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>W</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Q</td>
<td>8</td>
<td>10</td>
<td>8</td>
</tr>
</tbody>
</table>

Which two species are isotopes of the same element?

A. X and W  
B. Y and Z  
C. Z and W  
D. W and Q  

6. What is the order of increasing energy of the orbitals within a single energy level?

A. d < s < f < p  
B. s < p < d < f  
C. p < s < f < d  
D. f < d < p < s  

7. What is the electron configuration of the Cr⁺² ion?

A. [Ar] 3d⁵ 4s¹  
B. [Ar] 3d³ 4s¹  
C. [Ar] 3d⁶ 4s¹  
D. [Ar] 3d⁴ 4s⁰
4. Which is correct for the following regions of the electromagnetic spectrum?

<table>
<thead>
<tr>
<th></th>
<th>UV</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>high energy</td>
<td>short wavelength</td>
</tr>
<tr>
<td>B.</td>
<td>high energy</td>
<td>low frequency</td>
</tr>
<tr>
<td>C.</td>
<td>high frequency</td>
<td>short wavelength</td>
</tr>
<tr>
<td>D.</td>
<td>high frequency</td>
<td>long wavelength</td>
</tr>
</tbody>
</table>

5. Which species possesses only two unpaired electrons?
   
   A. Zn
   B. Mg
   C. Ti$^{2+}$
   D. Fe$^{2+}$

6. The mass spectrum of a sample of an element is shown below.

Which value is closest to the relative atomic mass of the element?

A. 64.5
B. 65.0
C. 65.5
D. 66.0
4. Which of the following describes the visible emission spectrum of hydrogen?
   A. A set of lines which are randomly spaced.
   B. A set of lines which converge towards a low energy value.
   C. A set of lines which converge towards a long wavelength value.
   D. A set of lines which converge towards a high frequency value.

12. Which species has the same electron configuration as a Ca\(^{2+}\) ion?
   A. Al\(^{3+}\) ion
   B. Br\(^{-}\) ion
   C. Ar atom
   D. K atom

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4. Which species represent a pair of isotopes?

<table>
<thead>
<tr>
<th>Species</th>
<th>Number of protons</th>
<th>Number of electrons</th>
<th>Number of neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>M</td>
<td>13</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>P</td>
<td>13</td>
<td>10</td>
<td>13</td>
</tr>
<tr>
<td>Q</td>
<td>12</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

A. L and M
B. L and P
C. P and Q
D. L and Q

5. How many unpaired electrons are there in the Co\(^{2+}\) ion?
   A. 7
   B. 5
   C. 3
   D. 2
### Topic 2 Mark Scheme

<table>
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<tr>
<th>Question</th>
<th>No.</th>
<th>Specification</th>
<th>Mark Scheme</th>
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<td>5.</td>
<td>A</td>
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<td>6.</td>
<td>D</td>
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<td></td>
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<tr>
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<td>8.</td>
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<tr>
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<td>B</td>
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<tr>
<td>Q# 48/1</td>
<td>IB/P1/2009/s/TZ 2/HL/</td>
<td>5.</td>
<td>D</td>
</tr>
<tr>
<td>6.</td>
<td>B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q# 49/1</td>
<td>IB/P1/2009/s/TZ 1/HL/</td>
<td>4.</td>
<td>A</td>
</tr>
<tr>
<td>5.</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q# 50/1</td>
<td>IB/P1/2008/w/TZ 0/HL/</td>
<td>6.</td>
<td>C</td>
</tr>
<tr>
<td>Q# 51/1</td>
<td>IB/P1/2008/s/TZ 2/HL/</td>
<td>4.</td>
<td>D</td>
</tr>
<tr>
<td>12.</td>
<td>C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q# 52/1</td>
<td>IB/P1/2008/s/TZ 1/HL/</td>
<td>4.</td>
<td>D</td>
</tr>
<tr>
<td>5.</td>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7. Which property increases down group 17, the halogens?
   A. Electron affinity
   B. Boiling point
   C. First ionization energy
   D. Reactivity

8. Which correctly describes the reaction between potassium and excess water?
   A. The reaction is endothermic.
   B. The final products of the reaction are potassium oxide and hydrogen.
   C. The final products of the reaction are potassium hydroxide and hydrogen.
   D. The final pH of the solution is 7.

9. The oxidation state of cobalt in the complex ion \([\text{Co(NH}_3\text{)}_5\text{Br}]^{3+}\) is +3. Which of the following statements are correct?
   I. The overall charge, \(x\), of the complex ion is 2+.
   II. The complex ion is octahedral.
   III. The cobalt(III) ion has a half-filled d-subshell.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

10. What is the correct explanation for the colour of \([\text{Cu(H}_2\text{O})_6]^{2+}\)?
    A. Light is absorbed when an electron moves to a d orbital of higher energy.
    B. Light is released when an electron moves to a d orbital of higher energy.
    C. Light is absorbed when electrons move from the ligands to the central metal ion.
    D. Light is absorbed when electrons move between d and s orbitals.
6. The diagram shows the first ionization energies of four consecutive elements in the periodic table. Which element is in Group 14?

![Diagram showing first ionization energy vs. increasing atomic number]

7. Which element is a metalloid?
   A. Co
   B. As
   C. Cs
   D. Es

8. Which periodic trend is described correctly?

<table>
<thead>
<tr>
<th>Trend in</th>
<th>Down the group (top to bottom)</th>
<th>Across the period (left to right)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. atomic radius</td>
<td>increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. ionic radius</td>
<td>decreases</td>
<td>increases</td>
</tr>
<tr>
<td>C. first ionization energy</td>
<td>decreases</td>
<td>decreases</td>
</tr>
<tr>
<td>D. electronegativity</td>
<td>decreases</td>
<td>increases</td>
</tr>
</tbody>
</table>

9. Which does not affect the colour of the complex ion formed by a particular transition metal?
   A. Oxidation state of the metal
   B. Number of ligands in the complex
   C. Identity of ligands in the complex
   D. Isotope of the metal
10. Which best explains why transition metal complexes are coloured?
   A. As electrons return to lower energy levels, light of a certain colour is emitted, and the complementary colour is observed.
   B. As electrons return to lower energy levels, light of a certain colour is emitted, so the complex appears to have the same colour.
   C. As electrons are promoted to higher energy levels, light of a certain colour is absorbed, and the complementary colour is observed.
   D. As electrons are promoted to higher energy levels, light of a certain colour is absorbed, so the complex appears to have the same colour.

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4. Which electronic transition would absorb the radiation of the shortest wavelength?

```
 n = 5
 n = 4
 n = 3
 n = 2
 n = 1
```

5. Which is the electron configuration of the ion Fe\(^{2-}\)?
   A. 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 3d\(^6\)
   B. 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 3d\(^6\) 4s\(^2\)
   C. 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 3d\(^4\) 4s\(^2\)
   D. 1s\(^2\) 2s\(^2\) 2p\(^6\) 3s\(^2\) 3p\(^6\) 3d\(^6\) 4s\(^1\)

6. Which element is in group 2?

<table>
<thead>
<tr>
<th></th>
<th>1(^{st}) ionization energy / kJ mol(^{-1})</th>
<th>2(^{nd}) ionization energy / kJ mol(^{-1})</th>
<th>3(^{rd}) ionization energy / kJ mol(^{-1})</th>
<th>4(^{th}) ionization energy / kJ mol(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>1402</td>
<td>2856</td>
<td>4578</td>
<td>7475</td>
</tr>
<tr>
<td>B.</td>
<td>590</td>
<td>1145</td>
<td>4912</td>
<td>6474</td>
</tr>
<tr>
<td>C.</td>
<td>403</td>
<td>2632</td>
<td>3900</td>
<td>5080</td>
</tr>
<tr>
<td>D.</td>
<td>578</td>
<td>1817</td>
<td>2745</td>
<td>11578</td>
</tr>
</tbody>
</table>
7. Which element is in the f-block of the periodic table?
   A. Be
   B. Ce
   C. Ge
   D. Re

8. Which property increases down group 1 of the periodic table?
   A. Melting point
   B. First ionization energy
   C. Atomic radius
   D. Electronegativity

9. What is the overall charge on the complex ion formed by iron(II) and six cyanide ions, \( \text{CN}^- \)?
   A. 4+
   B. 4–
   C. 8–
   D. 8+

10. Which statement about transition metal complex ions is correct?
    A. The difference in energy of the d orbitals is independent of the oxidation state of the metal.
    B. The colour of the complex is caused by light emitted when an electron falls back from a higher to a lower energy level.
    C. The colour of the complex is the colour of the light absorbed when an electron moves from a lower to a higher energy level.
    D. The difference in energy of the d orbitals depends on the nature of the ligand.
5. Which statement is correct about the first ionization energies of consecutive elements shown in the graph?

![Graph showing first ionization energies vs atomic number]

A. The graph falls between Be and B because there is an electron in the third energy level.
B. The graph increases from B to N because the atomic radius is increasing.
C. The graph increases from Li to Ne because the number of electrons is increasing.
D. The graph falls between Be and B because the outer electron in B is in a p sub-level.

6. Which element has the greatest first ionization energy?

A. Al
B. Ar
C. Cl
D. Cs

7. Which elements are in the same group of the periodic table?

A. Ca, Na, Rb, Sr
B. Al, Ar, Cl, S
C. Au, Hg, Pb, Pt
D. As, Bi, P, Sb
8. Which property of transition metals enables them to behave as catalysts?

A. High melting point
B. Variable oxidation number
C. High density
D. Split d sub-levels

5. What is the electron configuration of the copper(II) ion, Cu^2+?

A. 1s^22s^22p^63s^23p^64s^23d^8
B. 1s^22s^22p^63s^23p^64s^23d^6
C. 1s^22s^22p^63s^23p^64s^13d^10
D. 1s^22s^22p^63s^23p^63d^10

6. Which combination of properties best describes sodium oxide, Na_2O?

<table>
<thead>
<tr>
<th>Nature of bonding</th>
<th>Acidic or basic behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. covalent</td>
<td>acidic</td>
</tr>
<tr>
<td>B. ionic</td>
<td>basic</td>
</tr>
<tr>
<td>C. covalent</td>
<td>basic</td>
</tr>
<tr>
<td>D. ionic</td>
<td>acidic</td>
</tr>
</tbody>
</table>

7. What is the definition of electronegativity?

A. The relative measure of the tendency of an atom when bonded in a molecule to attract a shared pair of electrons towards itself.
B. The minimum energy required to remove a mole of electrons from a mole of gaseous atoms.
C. The enthalpy change occurring in kJ mol\(^{-1}\) when a gaseous atom gains one electron to form a negative ion.
D. The strength of an atom measured in kJ mol\(^{-1}\) to attract an electron to itself when bonded in a molecule.

8. Which species cannot act as a ligand?

A. NH_4^+
B. H_2O
C. Cl^-
D. OH^–
5. Successive ionization energies for an element, $Z$, are shown in the table below.

<table>
<thead>
<tr>
<th>Electrons removed</th>
<th>1st</th>
<th>2nd</th>
<th>3rd</th>
<th>4th</th>
<th>5th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ionization energy / kJ mol$^{-1}$</td>
<td>736</td>
<td>1450</td>
<td>7740</td>
<td>10500</td>
<td>13600</td>
</tr>
</tbody>
</table>

What is the most likely formula for the ion of $Z$?

A. $Z^+$
B. $Z^{2+}$
C. $Z^{3+}$
D. $Z^{4+}$

6. Which statements are correct for the oxides of period 3 going from Na to Cl?

   I. The oxides become increasingly acidic.
   II. The bonding of the oxides changes from ionic to covalent.
   III. All the oxides dissolve readily in water.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

7. The elements argon, potassium, and calcium are consecutive in the periodic table. Which gives the correct order of increasing first ionization energies?

A. $\text{Ar} < \text{Ca} < \text{K}$
B. $\text{K} < \text{Ar} < \text{Ca}$
C. $\text{Ca} < \text{K} < \text{Ar}$
D. $\text{K} < \text{Ca} < \text{Ar}$
8. Cobalt forms the complex \([\text{Co(NH}_3\text{)}_5\text{Cl}]^{2-}\). Which statements are correct for this complex?

   I. The cobalt ion acts as a Lewis acid.
   II. The cobalt ion has an oxidation number of +II.
   III. There are 90° bond angles between the cobalt ion and the ligands.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

6. Which equation represents the second ionization energy of potassium?

   A. \(\text{K}(g) \rightarrow \text{K}^{2+}(g) + 2\text{e}^-\)
   B. \(\text{K}^+(g) \rightarrow \text{K}^{2+}(g) + \text{e}^-\)
   C. \(\text{K}(s) \rightarrow \text{K}^{2+}(g) + 2\text{e}^-\)
   D. \(\text{K}^+(s) \rightarrow \text{K}^{2+}(g) + \text{e}^-\)

7. Which pair of elements shows the greatest difference in electronegativity?

   A. Mg and O
   B. Li and F
   C. K and F
   D. Li and I
6. The horizontal axis of the bar chart represents the elements of period 3 from sodium to chlorine (excluding silicon). What could the vertical axis represent?

A. Melting point of the element
B. Electronegativity of the bonded atom
C. Ionic radius of the most common ion
D. First ionization energy in the gaseous state

7. Which statements about reactivity are correct?

I. Potassium reacts more vigorously than sodium with chlorine.
II. Lithium reacts more vigorously than potassium with water.
III. Fluorine reacts more vigorously than bromine with a potassium iodide solution.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
6. Which series is arranged in order of increasing radius?

A. F < Cl^- < Cl
B. Rb < K < Na
C. Al^{3+} < Mg^{2+} < Na^+
D. I^- < Br^- < Cl^-

7. Which oxides form acidic solutions when added to water?

A. P_4O_{10}(s) and SO_3(g)
B. Na_2O(s) and MgO(s)
C. Al_2O_3(s) and SiO_2(s)
D. MgO(s) and Al_2O_3(s)

8. Which compound is likely to be colourless?

A. [Zn(H_2O)_6]Cl_2
B. [NH_4]_2[Fe(H_2O)_6]SO_4
C. K_2[Co(CN)_6]
D. [Ni(NH_3)_6][BF_4]_2

9. What is the formula of calcium nitride?

A. Ca_3N_2
B. Ca_2N_2
C. Ca(NO_2)_2
D. Ca(NO_2)_2
7. Which statements are correct for the alkali metals Li to Cs?

   I. Melting point increases
   II. First ionization energy decreases
   III. Ionic radius increases

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

8. Which statements about \([\text{Ag(NH}_3\text{)}_2]^+\) are correct?

   I. \(\text{NH}_3\) forms a dative covalent (co-ordinate) bond with \(\text{Ag}^+\).
   II. The formation of the bond between \(\text{NH}_3\) and \(\text{Ag}^+\) is an example of a Lewis acid–base reaction.
   III. \(\text{Ag}^+\) is the ligand in this complex ion.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

6. Which statement concerning electronegativity is correct?

   A. Electronegativity increases from left to right across a period.
   B. Metals generally have higher electronegativity values than non-metals.
   C. Electronegativity increases on descending a group.
   D. Noble gases have the highest electronegativity values.
7. Which statements are correct?

   I. Fluorine will react with potassium chloride solution to produce chlorine.
   II. Iodine will react with sodium chloride solution to produce chlorine.
   III. Bromine will react with lithium iodide solution to produce iodine.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

8. Each of the following oxides is added to separate equal volumes of distilled water. Which of the following is the most acidic oxide?

   A. \( \text{P}_2\text{O}_{10} \)
   B. \( \text{SO}_3 \)
   C. \( \text{Cl}_2\text{O}_7 \)
   D. \( \text{SiO}_2 \)

9. What are the correct formulas of the following ions?

<table>
<thead>
<tr>
<th>Nitrate</th>
<th>Sulfate</th>
<th>Phosphate</th>
<th>Hydrogencarbonate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ( \text{NO}_3^- )</td>
<td>( \text{SO}_4^{2-} )</td>
<td>( \text{PO}_4^{3-} )</td>
<td>( \text{HCO}_3^- )</td>
</tr>
<tr>
<td>B. ( \text{NO}_5^- )</td>
<td>( \text{SO}_4^{2-} )</td>
<td>( \text{PO}_3^{3-} )</td>
<td>( \text{HCO}_3^{2-} )</td>
</tr>
<tr>
<td>C. ( \text{NO}_2^- )</td>
<td>( \text{SO}_4^- )</td>
<td>( \text{PO}_4^{3-} )</td>
<td>( \text{HCO}_3^- )</td>
</tr>
<tr>
<td>D. ( \text{NO}_2^- )</td>
<td>( \text{SO}_3^{2-} )</td>
<td>( \text{PO}_3^{3-} )</td>
<td>( \text{HCO}_3^{2-} )</td>
</tr>
</tbody>
</table>
6. Which combination is correct for the properties of the alkali metals from Li to Cs?

<table>
<thead>
<tr>
<th>Atomic radius</th>
<th>Melting point</th>
<th>First ionization energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. increases</td>
<td>increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. increases</td>
<td>decreases</td>
<td>decreases</td>
</tr>
<tr>
<td>C. increases</td>
<td>increases</td>
<td>decreases</td>
</tr>
<tr>
<td>D. decreases</td>
<td>decreases</td>
<td>increases</td>
</tr>
</tbody>
</table>

7. Which equation represents a reaction that occurs under normal conditions?

A. \(2\text{LiBr(aq)} + \text{I}_2(aq) \rightarrow 2\text{LiI(aq)} + \text{Br}_2(aq)\)

B. \(2\text{KF(aq)} + \text{Cl}_2(aq) \rightarrow 2\text{KCl(aq)} + \text{F}_2(aq)\)

C. \(2\text{LiCl(aq)} + \text{I}_2(aq) \rightarrow 2\text{LiI(aq)} + \text{Cl}_2(aq)\)

D. \(2\text{KBr(aq)} + \text{Cl}_2(aq) \rightarrow 2\text{KCl(aq)} + \text{Br}_2(aq)\)

8. Which combination of statements about the oxides of period 3 elements is correct?

<table>
<thead>
<tr>
<th>State at room temperature</th>
<th>Electrical conductivity in molten state</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\text{Na}_2\text{O})</td>
</tr>
<tr>
<td>A. solid</td>
<td>solid</td>
</tr>
<tr>
<td>B. solid</td>
<td>solid</td>
</tr>
<tr>
<td>C. solid</td>
<td>liquid</td>
</tr>
<tr>
<td>D. solid</td>
<td>solid</td>
</tr>
</tbody>
</table>
7. Which series is correctly arranged in order of decreasing radius?
   A. $\text{Al}^{3+} > \text{Mg}^{2+} > \text{Na}^+ > \text{F}^-$
   B. $\text{F}^- > \text{Na}^+ > \text{Mg}^{2+} > \text{Al}^{3+}$
   C. $\text{F}^- > \text{Al}^{3+} > \text{Mg}^{2+} > \text{Na}^+$
   D. $\text{Na}^+ > \text{Mg}^{2+} > \text{Al}^{3+} > \text{F}^-$

8. Which complex is colourless in solution?
   A. $[\text{Fe(H}_2\text{O)}_6]\text{Cl}_2$
   B. $[\text{Ni(NH}_3)_6]\text{Cl}_2$
   C. $[\text{Zn(H}_2\text{O)}_6](\text{NO}_3)_2$
   D. $\text{K}_3[\text{Co(CN)}_6]$

6. Which species are in the order of increasing ionic radius?
   A. $\text{Cl}^- < \text{K}^+ < \text{S}^{2-}$
   B. $\text{K}^- < \text{Cl}^- < \text{S}^{2-}$
   C. $\text{Cl}^- < \text{S}^{2-} < \text{K}^+$
   D. $\text{S}^{2-} < \text{Cl}^- < \text{K}^+$

7. Which combination of descriptions is correct for the oxides of period 3 elements?

<table>
<thead>
<tr>
<th>Chlorine</th>
<th>Magnesium</th>
<th>Silicon</th>
<th>Sodium</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. basic</td>
<td>acidic</td>
<td>basic</td>
<td>acidic</td>
</tr>
<tr>
<td>B. acidic</td>
<td>basic</td>
<td>basic</td>
<td>basic</td>
</tr>
<tr>
<td>C. basic</td>
<td>acidic</td>
<td>acidic</td>
<td>acidic</td>
</tr>
<tr>
<td>D. acidic</td>
<td>basic</td>
<td>acidic</td>
<td>basic</td>
</tr>
</tbody>
</table>
7. Which physical property of elements is represented by \( y \) on the graph below?

A. First ionization energy  
B. Ionic radius  
C. Atomic radius  
D. Electronegativity

8. Which of the following redox reactions take place?

I. \( \text{Cl}_2(aq) + 2\text{NaI}(aq) \rightarrow \text{I}_2(aq) + 2\text{NaCl}(aq) \)
II. \( \text{Br}_2(aq) + 2\text{NaI}(aq) \rightarrow \text{I}_2(aq) + 2\text{NaBr}(aq) \)
III. \( \text{I}_2(aq) + 2\text{NaBr}(aq) \rightarrow \text{Br}_2(aq) + 2\text{NaI}(aq) \)

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III
9. Which metals are considered to be transition elements?

I. Ti
II. Zn
III. Fe

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

6. Values for the successive ionization energies for an unknown element are given in the table below.

<table>
<thead>
<tr>
<th>First ionization energy / kJ mol(^{-1})</th>
<th>Second ionization energy / kJ mol(^{-1})</th>
<th>Third ionization energy / kJ mol(^{-1})</th>
<th>Fourth ionization energy / kJ mol(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>420</td>
<td>3600</td>
<td>4400</td>
<td>5900</td>
</tr>
</tbody>
</table>

In which group of the periodic table would the unknown element be found?

A. 1
B. 2
C. 3
D. 4

7. Which pair of elements has the greatest difference in electronegativity?

A. Cs and F
B. Cs and Cl
C. Cs and Br
D. Cs and I
8. Ligands can form dative covalent bonds with metal ions to form complex ions. Which of the following can act as a ligand?

   I. Cl⁻  
   II. NH₃  
   III. H₂O

   A. I and II only  
   B. I and III only  
   C. II and III only  
   D. I, II and III

9. Which metal nitrate solution is coloured?

   A. Zn(NO₃)₂ (aq)  
   B. Ni(NO₃)₂ (aq)  
   C. Mg(NO₃)₂ (aq)  
   D. Sc(NO₃)₂ (aq)

7. Which property generally decreases across period 3?

   A. Atomic number  
   B. Electronegativity  
   C. Atomic radius  
   D. First ionization energy

8. Which statement about the elements in group 7 is correct?

   A. Br₂ will oxidize Cl⁻.  
   B. F₂ has the least tendency to be reduced.  
   C. Cl₂ will oxidize I⁻.  
   D. I₂ is a stronger oxidizing agent than F₂.
9. Which electron transitions are responsible for the colours of transition metal compounds?

A. Between d orbitals and s orbitals
B. Among the attached ligands
C. From the metal ion to the attached ligands
D. Between d orbitals

7. Which property generally decreases across period 3?

A. Atomic number
B. Electronegativity
C. Atomic radius
D. First ionization energy

8. Which statement about the elements in group 7 is correct?

A. Br₂ will oxidize Cl⁻.
B. F₂ has the least tendency to be reduced.
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D. I₂ is a stronger oxidizing agent than F₂.

9. Which electron transitions are responsible for the colours of transition metal compounds?

A. Between d orbitals and s orbitals
B. Among the attached ligands
C. From the metal ion to the attached ligands
D. Between d orbitals
5. The graph below shows the first four ionization energies of four elements A, B, C and D (the letters are not their chemical symbols). Which element is magnesium?

6. Which statements about the periodic table are correct?

I. The elements Mg, Ca and Sr have similar chemical properties.

II. Elements in the same period have the same number of main energy levels.

III. The oxides of Na, Mg and P are basic.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III
7. The x-axis of the graph below represents the atomic number of the elements in period 3.

Which variable could represent the y-axis?

A. Melting point  
B. Electronegativity  
C. Ionic radius  
D. Atomic radius

8. In which complexes does iron have an oxidation number of +3?

I. \([\text{Fe(H}_2\text{O)}_6]\)\(^{3+}\)  
II. \([\text{Fe(H}_2\text{O)}_3\text{(CN)}]\)\(^{2+}\)  
III. \([\text{Fe(CN)}_6]\)\(^{3-}\)

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III
6. Which ion has the largest radius?

A. Cl⁻
B. K⁺
C. Br⁻
D. F⁻

7. Which oxides produce an acidic solution when added to water?

I. P₄O₁₀
II. MgO
III. SO₃

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

8. What is the ligand in the complex K₂[Fe(CN)₆]? 

A. CN⁻
B. Fe³⁺
C. K⁺
D. [Fe(CN)₆]³⁻
7. Which statements about the periodic table are correct?
   
   I. Elements in period 3 have similar chemical properties.
   II. Elements in group 7 show a gradual change in physical properties.
   III. The position of an element in period 3 is related to the number of electrons in the highest occupied energy level.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

8. Which statements about period 3 are correct?
   
   I. The oxides of the elements change from ionic to covalent across period 3.
   II. The oxides of the elements change from basic to acidic across period 3.
   III. First ionization energy of the elements increases linearly across period 3.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

9. Which statements are correct for the complex ion $[\text{CuCl}_4]^{2-}$?
   
   I. The oxidation number of Cu in the complex ion is $+2$.
   II. The coordination number of the copper ion is 4.
   III. Chloride ions are behaving as ligands.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
6. Between which ionization energies of boron will there be the greatest difference?
   
   A. Between 1st and 2nd ionization energies
   
   B. Between 2nd and 3rd ionization energies
   
   C. Between 3rd and 4th ionization energies
   
   D. Between 4th and 5th ionization energies

7. What happens when sodium is added to water?
   
   I. A gas is evolved
   II. The temperature of the water increases
   III. A clear, colourless solution is formed

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

8. Which species has the largest radius?
   
   A. \( \text{Cl}^- \)
   B. \( \text{K} \)
   C. \( \text{Na}^+ \)
   D. \( \text{K}^- \)

9. Which process is responsible for the colour of a transition metal complex?
   
   A. The absorption of light when electrons move between s orbitals and d orbitals
   B. The emission of light when electrons move between s orbitals and d orbitals
   C. The absorption of light when electrons move between different d orbitals
   D. The emission of light when electrons move between different d orbitals
8. Which statement describes the trends of electronegativity values in the periodic table?
   A. Values increase from left to right across a period and increase down a group.
   B. Values increase from left to right across a period and decrease down a group.
   C. Values decrease from left to right across a period and increase down a group.
   D. Values decrease from left to right across a period and decrease down a group.

9. Which equation best represents the first ionization energy of magnesium?
   A. \( \text{Mg}(s) \rightarrow \text{Mg}^{+}(s) + e^- \)
   B. \( \text{Mg}(g) \rightarrow \text{Mg}^{2+}(g) + 2e^- \)
   C. \( \text{Mg}(g) \rightarrow \text{Mg}^+(g) + e^- \)
   D. \( \text{Mg}(s) \rightarrow \text{Mg}^+(g) + e^- \)

10. What are the products of the reaction between chlorine and water?
    A. \( \text{O}_2, \text{H}_2 \) and \( \text{HCl} \)
    B. \( \text{H}_2 \) and \( \text{OCl}_2 \)
    C. \( \text{HCl} \) and \( \text{HOCl} \)
    D. \( \text{HOCl}, \text{H}_2 \) and \( \text{Cl}_2 \)

6. Which is the best definition of electronegativity?
   A. Electronegativity is the energy required for a gaseous atom to gain an electron.
   B. Electronegativity is the attraction of an atom for a bonding pair of electrons.
   C. Electronegativity is the attraction between the nucleus and the valence electrons of an atom.
   D. Electronegativity is the ability of an atom to attract electrons from another atom.
7. Which statements are correct for the reactions of \( \text{Cl}_2 \), \( \text{MgCl}_2 \), and \( \text{SiCl}_4 \) with water?

<table>
<thead>
<tr>
<th></th>
<th>( \text{Cl}_2 )</th>
<th>( \text{MgCl}_2 )</th>
<th>( \text{SiCl}_4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>forms a neutral solution</td>
<td>forms a neutral solution</td>
<td>no reaction</td>
</tr>
<tr>
<td>B.</td>
<td>forms an acidic solution</td>
<td>forms an acidic solution</td>
<td>forms an acidic solution</td>
</tr>
<tr>
<td>C.</td>
<td>forms an acidic solution</td>
<td>forms an acidic solution</td>
<td>no reaction</td>
</tr>
<tr>
<td>D.</td>
<td>forms a neutral solution</td>
<td>forms a neutral solution</td>
<td>forms an acidic solution</td>
</tr>
</tbody>
</table>

8. Which transition element, or compound of a transition element, is used as a catalyst in the Contact process?

A. \( \text{Fe} \)
B. \( \text{MnO}_2 \)
C. \( \text{V}_2\text{O}_5 \)
D. \( \text{Ni} \)

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4. The first ionization energies of successive elements in the periodic table are shown below.

Which statements are correct?

I. Elements E and M are in Group 0 of the periodic table.
II. Atoms of elements G and O have the outer electron configuration ns\(^2\).
III. Atoms of elements B and J contain half-filled p orbitals.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
6. The mass spectrum of a sample of an element is shown below.

Which value is closest to the relative atomic mass of the element?

A. 64.5  
B. 65.0  
C. 65.5  
D. 66.0

7. In what order are the elements listed in the periodic table?

A. In order of relative atomic mass  
B. In order of reactivity  
C. In order of nuclear charge  
D. In order of electronegativity
8. The graph shows the trend in a physical property down group 7 in the periodic table.

![Graph showing trend in physical property down group 7]

What is the physical property?
A. Atomic radius
B. Electronegativity
C. Density
D. Melting point

9. Which species can act as ligands with transition metal ions?

I. NH₃
II. Cl⁻
III. CH₄

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
11. The table shows the boiling points of the hydrogen halides.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Boiling point / °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF</td>
<td>20</td>
</tr>
<tr>
<td>HCl</td>
<td>−85</td>
</tr>
<tr>
<td>HBr</td>
<td>−67</td>
</tr>
<tr>
<td>HI</td>
<td>−35</td>
</tr>
</tbody>
</table>

Which statement explains the higher boiling point of hydrogen fluoride?

A. The covalent bond in hydrogen fluoride is stronger than those in the other hydrogen halides.
B. There is strong hydrogen bonding between the hydrogen fluoride molecules.
C. Fluorine is the most reactive element in group 7.
D. Fluorine has the highest first ionization energy in group 7.

12. Which substance has the lowest electrical conductivity?

A. Al(s)
B. Al₂O₃(l)
C. KCl(aq)
D. HCl(g)

13. Which bond has the lowest polarity?

A. C−H in methane, CH₄
B. C=O in carbon dioxide, CO₂
C. C−C in ethane, C₂H₆
D. C−C in ethanol, C₂H₅OH

14. What is the correct description of hybridization present in buta-1,3-diene, H₂C=CH−CH=CH₂?

A. sp
B. sp³
C. sp and sp³
D. sp³, sp³ and sp
15. Which molecules contain a bond angle of 90°?
   I. PF₅
   II. SiCl₄
   III. SF₅
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

5. Which statement about ionization energy is correct?
   A. First ionization energies decrease across period 3.
   B. Second ionization energies refer to the removal of two electrons from an atom.
   C. Third ionization energies always involve the removal of an electron from a p-orbital.
   D. The fourth ionization energy of an element is always greater than its third ionization energy.

7. Which properties vary in the same way down groups 1 and 7 of the periodic table?
   I. Boiling points
   II. Ionic radii
   III. Atomic radii
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

8. Which statements support the description of aluminium oxide as amphoteric?
   I. It can show acidic behaviour in the presence of strong alkalis.
   II. It can show alkaline behaviour in the presence of strong acids.
   III. It dissolves in water to form a neutral solution.
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
9. Which of these species involves the transition metal in one of its common oxidation states?
   
   I. \( \text{Cr}_2\text{O}_7^{2-} \)
   II. \( \text{MnO}_4^{2-} \)
   III. \( \text{FeCl}_3 \)
   
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

11. What are the correct formulas of magnesium nitride and aluminium sulfide?
   
   A. \( \text{Mg}_2\text{N}_3 \) and \( \text{Al}_2\text{S}_3 \)
   B. \( \text{Mg}_2\text{N}_2 \) and \( \text{Al}_2\text{S}_3 \)
   C. \( \text{Mg}_2\text{N}_3 \) and \( \text{Al}_2\text{S}_3 \)
   D. \( \text{Mg}_2\text{N}_2 \) and \( \text{Al}_2\text{S}_3 \)

7. Which properties decrease in value when descending group 1?
   
   I. Atomic radius
   II. Ionization energy
   III. Electronegativity
   
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

8. The ionization energies of three consecutive elements in the periodic table are 1680, 2080 and 494 kJ mol\(^{-1}\) respectively. Which of the following shows the elements with these values?
   
   A. O  F  Ne
   B. F  Ne  Na
   C. Ne  Na  Mg
   D. Na  Mg  Al
9. Which comparison of radii of atoms and ions is correct?
   A. $\text{Cl}^- > \text{Cl}$
   B. $\text{H}^+ > \text{H}^-$
   C. $\text{Na}^+ > \text{Na}$
   D. $\text{Mg}^{2+} > \text{Mg}^+$

10. Which trend is correct when the elements are considered from left to right across period 3?
   A. The acidic character of the oxides decreases.
   B. The electrical conductivity of the elements increases.
   C. The bonding of the chlorides changes from ionic to covalent.
   D. Electronegativity decreases.

**Topic 3 Mark Scheme**

Q# 53/ IB/P1/2016/w/TZ 2/HL/
7. B
8. C
9. A

Q# 54/ IB/P1/2016/s/TZ 0/HL/
6. B
7. B
8. D

Q# 57/ IB/P1/2015/s/TZ 2/HL/
5. D

Q# 56/ IB/P1/2015/w/TZ 2/HL/
5. D
6. B
7. D
8. B

Q# 58/ IB/P1/2014/w/TZ 0/HL/
5. B

Q# 59/ IB/P1/2014/w/TZ 2/HL/
4. B
5. B

Q# 60/ IB/P1/2014/s/TZ 1/HL/
7. C

Q# 61/ IB/P1/2013/w/TZ 0/HL/
6. C
7. A
8. A

Q# 62/ IB/P1/2013/s/TZ 2/HL/
7. C
8. A

Q# 63/ IB/P1/2013/s/TZ 1/HL/
6 A

Q# 64/ IB/P1/2013/w/TZ 0/HL/
6. B
7. D
8. B

Q# 65/ IB/P1/2012/w/TZ 2/HL/
7. B
8. C

Q# 66/ IB/P1/2012/w/TZ 2/HL/
6. B
Q# 67/ IB/P1/2012/s/TZ 1/HL/
  7. D

Q# 68/ IB/P1/2011/w/TZ 0/HL/
  7. C
  8. A
  9. B

Q# 69/ IB/P1/2011/s/TZ 2/HL/
  6. A
  7. A
  8. D
  9. B

Q# 70/ IB/P1/2011/s/TZ 1/HL/
  7. C
  8. C
  9. D

Q# 71/ IB/P1/2010/w/TZ 0/HL/
  5. B
  6. A
  7. A
  8. D
  9. D

Q# 72/ IB/P1/2010/s/TZ 2/HL/
  6. C
  7. B
  8. A

Q# 73/ IB/P1/2010/s/TZ 1/HL/
  7. C
  8. A

Q# 74/ IB/P1/2009/w/TZ 0/HL/
  7. D
  8. B

Q# 75/ IB/P1/2009/s/TZ 2/HL/
  8. B
  9. C

Q# 76/ IB/P1/2009/s/TZ 1/HL/
  6. B
  7. B
  8. C

Q# 77/ IB/P1/2008/w/TZ 0/HL/
  4. D

Q# 78/ IB/P1/2008/w/TZ 0/HL/
  9. A

Q# 79/ IB/P1/2008/w/TZ 0/HL/
  10. C

Q# 80/ IB/P1/2008/s/TZ 2/HL/
  5. D
  7. C

Q# 81/ IB/P1/2008/s/TZ 1/HL/
  8. A
  9. B

Q# 82/ IB/P1/2008/s/TZ 0/HL/
  11. B

Q# 83/ IB/P1/2008/s/TZ 1/HL/
  8. B
  9. A
Topic 4

11. How many electrons form the carbon–oxygen bond in methanal, HCHO?
   A. 2
   B. 4
   C. 8
   D. 12

12. Between which pair of molecules can hydrogen bonding occur?
   A. CH₄ and H₂O
   B. CH₃OCH₃ and CF₄
   C. CH₄ and HF
   D. CH₃OH and H₂O

13. Which substance has a giant covalent structure?

<table>
<thead>
<tr>
<th>Melting point / °C</th>
<th>Solubility in water</th>
<th>Electrical conductivity in the molten state</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 186</td>
<td>high</td>
<td>none</td>
</tr>
<tr>
<td>B. 801</td>
<td>high</td>
<td>good</td>
</tr>
<tr>
<td>C. 1083</td>
<td>low</td>
<td>good</td>
</tr>
<tr>
<td>D. 1710</td>
<td>low</td>
<td>none</td>
</tr>
</tbody>
</table>

14. Which species has bond angles of 90°?
   A. AlCl₄⁻
   B. ICl⁻
   C. NH₄⁺
   D. SiCl₄
15. What is the hybridization of the numbered atoms in ethanoic acid?

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{O} \\
\text{H}
\end{array}
\]

<table>
<thead>
<tr>
<th>Atom 1</th>
<th>Atom 2</th>
<th>Atom 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. sp(^3)</td>
<td>sp</td>
<td>sp(^2)</td>
</tr>
<tr>
<td>B. sp(^3)</td>
<td>sp(^2)</td>
<td>sp</td>
</tr>
<tr>
<td>C. sp(^2)</td>
<td>sp(^3)</td>
<td>sp(^2)</td>
</tr>
<tr>
<td>D. sp(^3)</td>
<td>sp(^2)</td>
<td>sp(^3)</td>
</tr>
</tbody>
</table>

11. Which species breaks the octet rule?

A. \(\text{PCl}_3\)
B. \(\text{BF}_4^-\)
C. \(\text{SCl}_4\)
D. \(\text{NH}_4^+\)
12. Which compound contains both ionic and covalent bonds?
   A. SiH₄
   B. NaNO₃
   C. H₂CO
   D. Na₂S

13. Which of the following are van der Waals’ forces?
   I. Dipole-dipole forces
   II. Hydrogen bonds
   III. London (dispersion) forces
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

14. In which group do both compounds contain delocalized electrons?
   A. C₆H₁₆, C₆H₁₀
   B. Na₂CO₃, NaOH
   C. NaHCO₃, C₆H₆
   D. NaHCO₃, C₆H₁₂

15. Which of the following is correct?

<table>
<thead>
<tr>
<th>Atom</th>
<th>Number of electron domains</th>
<th>Molecular geometry</th>
<th>Hybridization</th>
</tr>
</thead>
<tbody>
<tr>
<td>C in C₂H₂</td>
<td>2</td>
<td>linear</td>
<td>sp</td>
</tr>
<tr>
<td>C in C₂H₆</td>
<td>4</td>
<td>square planar</td>
<td>sp³</td>
</tr>
<tr>
<td>N in NH₃</td>
<td>3</td>
<td>trigonal pyramidal</td>
<td>sp³</td>
</tr>
<tr>
<td>O in H₂O</td>
<td>4</td>
<td>bent</td>
<td>sp²</td>
</tr>
</tbody>
</table>
11. Which is the best description of ionic bonding?

A. Electrostatic attraction between oppositely charged ions
B. Electrostatic attraction between positive ions and electrons
C. Electrostatic attraction of nuclei towards shared electrons in the bond between the nuclei
D. Electrostatic attraction between nuclei

12. Which intermolecular forces are covered by the term van der Waals'?

I. London dispersion forces
II. Dipole-induced dipole forces
III. Dipole-dipole forces

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

13. Which bond is the least polar?

A. C=O in CO₂
B. C–H in CH₄
C. C–Cl in CCl₄
D. N–H in CH₃NH₂

14. Which pair of compounds contains 9 sigma, σ, and 2 pi, π, bonds in each molecule?

A. CH₃CO₂H and CH₃CH(OH)CH₃
B. CH₃COCH₃ and CH₃COOCH₂CH₂
C. CHCCH₂CH₂ and CH₂CHCHCH₂
D. CH₃COH and CH₃CH₂OH
15. Which molecule contains an atom with sp\(^3\) hybridization?
   A. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_3\)
   B. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CN}\)
   C. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}\)
   D. \(\text{CH}_3\text{CH}_2\text{CHCHCH}_3\)

9. Which statement best describes the lattice structure of solid sodium chloride?
   A. Each sodium ion is surrounded by one chloride ion.
   B. Each chloride ion is surrounded by two sodium ions.
   C. Each chloride ion is surrounded by four sodium ions.
   D. Each sodium ion is surrounded by six chloride ions.

10. Which compound is most likely to contain ionic bonding?
    A. ClO\(_2\)
    B. CsCl
    C. SCl\(_2\)
    D. SiCl\(_4\)

11. Which molecule is polar?
    A. \(\text{C}_2\text{H}_5\)
    B. \(\text{CH}_2\text{Cl}_2\)
    C. \(\text{CO}_2\)
    D. \(\text{CCl}_4\)

12. What is the shape of the hexacyanoferrate(III) ion, \([\text{Fe(CN)}_6]^{3-}\)?
    A. Square planar
    B. Hexagonal
    C. Octahedral
    D. Trigonal bipyramidal
13. Which set contains two or more species with delocalized $\pi$ electrons?
   A. CH$_3$CH$_3$, H$_2$C=CH$_2$, H$_2$C=O
   B. NaCl, C$_2$H$_6$, H$_2$C=O
   C. CO$_3^{2-}$, C$_6$H$_5$, C$_6$H$_4$
   D. O$_2$, CH$_3$COCH$_3$, CH$_3$COOCH$_3$

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9. The formula of gallium phosphite is GaPO$_4$. What is the correct formula of gallium sulfate?
   A. GaSO$_4$
   B. GaS
   C. Ga$_2$(SO$_4$)$_3$
   D. Ga$_2$S$_3$

10. Which diagrams can be used to represent the Lewis (electron dot) structure of boron trifluoride?

   
   \[ \text{I.} \quad \text{II.} \quad \text{III.} \]

   \[ \begin{array}{c}
   \text{I.} \\
   F \quad B \quad F \\
   F \quad B \quad F \\
   \end{array} \quad \begin{array}{c}
   \text{II.} \\
   F :: B :: F \\
   \end{array} \quad \begin{array}{c}
   \text{III.} \\
   \text{B} \\
   F X F \\
   \end{array} \]

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

11. Which correctly lists butane (M$_r$ = 58), propanone (M$_r$ = 58), propan-1-ol (M$_r$ = 60) and propan-2-ol (M$_r$ = 60) in order of increasing boiling point?

   A. C$_4$H$_{10}$ < CH$_3$COCH$_3$ < CH$_3$CH(OH)CH$_3$ < CH$_3$CH$_2$CH$_2$OH
   B. CH$_3$CH$_2$CH$_2$OH < CH$_3$CH(OH)CH$_3$ < CH$_3$COCH$_3$ < C$_4$H$_{10}$
   C. C$_4$H$_{10}$ < CH$_3$CH(OH)CH$_3$ < CH$_3$CH$_2$CH$_2$OH < CH$_3$COCH$_3$
   D. C$_4$H$_{10}$ < CH$_3$COCH$_3$ < CH$_3$CH$_2$CH$_2$OH < CH$_3$CH(OH)CH$_3$
12. Which combination of shape and bond angle is correct for a molecule of xenon tetrafluoride, XeF₄?

<table>
<thead>
<tr>
<th>Shape</th>
<th>Bond angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. square pyramid</td>
<td>90°</td>
</tr>
<tr>
<td>B. square planar</td>
<td>90°</td>
</tr>
<tr>
<td>C. tetrahedral</td>
<td>109.5°</td>
</tr>
<tr>
<td>D. octahedral</td>
<td>90°</td>
</tr>
</tbody>
</table>

13. Which combination correctly describes the types of hybridization shown by the two carbon atoms labelled α and β and the oxygen atom labelled γ in the molecule of paracetamol shown below?

![Paracetamol](image)

<table>
<thead>
<tr>
<th></th>
<th>α</th>
<th>β</th>
<th>γ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>sp²</td>
<td>sp²</td>
<td>sp³</td>
</tr>
<tr>
<td>B.</td>
<td>sp³</td>
<td>sp²</td>
<td>sp²</td>
</tr>
<tr>
<td>C.</td>
<td>sp²</td>
<td>sp²</td>
<td>sp²</td>
</tr>
<tr>
<td>D.</td>
<td>sp²</td>
<td>sp³</td>
<td>sp³</td>
</tr>
</tbody>
</table>
9. Which molecules react to form a dative covalent (coordinate) bond?
   A. CH₄ and NH₃
   B. C₂H₂ and Cl₂
   C. NH₃ and HF
   D. Cl₂ and HF

10. The following compounds have similar molar masses:
    \[ \text{CH₃CH₂COOH, CH₃CH₂CH₂CH₂OH and CH₃CH₂CH₂CH₂CH₃} \]
    What is the order of increasing boiling points?
    A. CH₃CH₂CH₂CH₂OH < CH₃CH₂COOH < CH₃CH₂CH₂CH₂CH₃
    B. CH₃CH₂COOH < CH₃CH₂CH₂CH₂OH < CH₃CH₂CH₂CH₂CH₃
    C. CH₃CH₂COOH < CH₃CH₂CH₂CH₂OH < CH₃CH₂CH₂CH₂CH₃
    D. CH₃CH₂CH₂CH₂CH₃ < CH₃CH₂CH₂CH₂OH < CH₃CH₂COOH

11. Which substance has the following properties?
    • Low melting point
    • Very soluble in water
    • Does not conduct electricity when molten
    A. Glucose, C₆H₁₂O₆
    B. Silicon dioxide, SiO₂
    C. Sodium chloride, NaCl
    D. Tetrachloromethane, CCl₄

12. What is correct for PCl₅?

<table>
<thead>
<tr>
<th>Shape</th>
<th>Bond angle(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Octahedral</td>
<td>90° and 180°</td>
</tr>
<tr>
<td>B. Trigonal pyramidal</td>
<td>107°</td>
</tr>
<tr>
<td>C. Square pyramidal</td>
<td>90° and 180°</td>
</tr>
<tr>
<td>D. Trigonal bipyramidal</td>
<td>90°, 120° and 180°</td>
</tr>
</tbody>
</table>
13. Which molecules have sp² hybridization?
   I. \( \text{C}_2\text{H}_4 \)
   II. \( \text{C}_4\text{H}_{10} \)
   III. \( \text{C}_6\text{H}_6 \)
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

9. Which species contains a dative covalent (coordinate) bond?
   A. HCN
   B. \( \text{C}_2\text{H}_2 \)
   C. \( \text{CO}_2 \)
   D. CO

10. Which sequence has the molecules in order of increasing nitrogen-nitrogen bond length?
    A. \( \text{N}_2 \text{ < N}_2\text{H}_4 \text{ < N}_2\text{H}_2 \)
    B. \( \text{N}_2 \text{ < N}_2\text{H}_2 \text{ < N}_2\text{H}_4 \)
    C. \( \text{N}_2\text{H}_4 \text{ < N}_2\text{H}_2 \text{ < N}_2 \)
    D. \( \text{N}_2\text{H}_2 \text{ < N}_2\text{H}_4 \text{ < N}_2 \)

11. Which process involves the breaking of hydrogen bonds?
    A. \( 2\text{HI}(g) \rightarrow \text{H}_2(g) + \text{I}_2(g) \)
    B. \( \text{CH}_4(g) \rightarrow \text{C}(g) + 4\text{H}(g) \)
    C. \( \text{H}_2(l) \rightarrow \text{H}_2(g) \)
    D. \( \text{NH}_3(l) \rightarrow \text{NH}_3(g) \)
12. What is the correct number of sigma (σ) and pi (π) bonds in prop-2-enitrile, CH₂CHCN?

<table>
<thead>
<tr>
<th></th>
<th>σ bonds</th>
<th>π bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>B.</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>C.</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>D.</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

13. Which group of ions and molecules has delocalized electrons in all the species?

A. CH₃COCH₃, C₂H₅COO⁻ and O₃
B. NO₃⁻, NO₂⁻ and CO₂
C. C₆H₆, CO₃²⁻ and graphite
D. C₆H₆, CO₃²⁻ and C₂H₂

9. Which properties do typical ionic compounds have?

<table>
<thead>
<tr>
<th>Melting point</th>
<th>Conductivity of solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>high</td>
</tr>
<tr>
<td>B.</td>
<td>low</td>
</tr>
<tr>
<td>C.</td>
<td>high</td>
</tr>
<tr>
<td>D.</td>
<td>low</td>
</tr>
</tbody>
</table>

10. What is the difference between the strength and the length of the carbon-oxygen bond in butanal and in butan-1-ol?

A. The bond in butanal is stronger and longer than in butan-1-ol.
B. The bond in butanal is weaker and shorter than in butan-1-ol.
C. The bond in butanal is weaker and longer than in butan-1-ol.
D. The bond in butanal is stronger and shorter than in butan-1-ol.
11. Which allotropes of carbon show sp\(^2\) hybridization?
   
   I. Diamond
   II. Graphite
   III. C\(_{60}\) fullerene
   
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

9. Which properties do typical ionic compounds have?

<table>
<thead>
<tr>
<th>Melting point</th>
<th>Conductivity of solid</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. high</td>
<td>good</td>
</tr>
<tr>
<td>B. low</td>
<td>good</td>
</tr>
<tr>
<td>C. high</td>
<td>poor</td>
</tr>
<tr>
<td>D. low</td>
<td>poor</td>
</tr>
</tbody>
</table>

10. What is the difference between the strength and the length of the carbon-oxygen bond in butanal and in butan-1-ol?

   A. The bond in butanal is stronger and longer than in butan-1-ol.
   B. The bond in butanal is weaker and shorter than in butan-1-ol.
   C. The bond in butanal is weaker and longer than in butan-1-ol.
   D. The bond in butanal is stronger and shorter than in butan-1-ol.
11. Which allotropes of carbon show $sp^2$ hybridization?
   
   I. Diamond  
   II. Graphite  
   III. $C_{60}$ fullerene

   A. I and II only  
   B. I and III only  
   C. II and III only  
   D. I, II and III

12. Which molecule is trigonal bipyramidal in shape?

   A. $\text{PCl}_3$  
   B. $\text{SiCl}_4$  
   C. $\text{PCl}_5$  
   D. $\text{SF}_6$

13. Which diagram represents the bonding in $\text{SiO}_2$?

   A. 
   B. 
   C. 
   D.
8. Which ion is colourless?
   A. \([\text{Sc} (\text{H}_2\text{O})_6]^{3+}\)
   B. \([\text{Cr} (\text{H}_2\text{O})_6]^{3+}\)
   C. \([\text{Fe} (\text{H}_2\text{O})_6]^{3+}\)
   D. \([\text{Fe} (\text{CN})_6]^{3-}\)

9. The electronegativities of four elements are given in the table.

<table>
<thead>
<tr>
<th>Element</th>
<th>W</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronegativity</td>
<td>0.9</td>
<td>1.1</td>
<td>3.4</td>
<td>4.0</td>
</tr>
</tbody>
</table>

   Which statement is correct?
   A. W and X form an ionic compound.
   B. W and X form a covalent compound.
   C. Y and Z form an ionic compound.
   D. Y and Z form a covalent compound.

10. Which combination of length and strength of the carbon-to-carbon bonds in \(\text{C}_2\text{H}_2\) and \(\text{C}_2\text{H}_4\) is correct?

<table>
<thead>
<tr>
<th>Bond length</th>
<th>Bond strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\text{C}_2\text{H}_2 &gt; \text{C}_2\text{H}_4)</td>
<td>(\text{C}_2\text{H}_2 &lt; \text{C}_2\text{H}_4)</td>
</tr>
<tr>
<td>(\text{C}_2\text{H}_2 &gt; \text{C}_2\text{H}_4)</td>
<td>(\text{C}_2\text{H}_2 &gt; \text{C}_2\text{H}_4)</td>
</tr>
<tr>
<td>(\text{C}_2\text{H}_2 &lt; \text{C}_2\text{H}_4)</td>
<td>(\text{C}_2\text{H}_2 &lt; \text{C}_2\text{H}_4)</td>
</tr>
<tr>
<td>(\text{C}_2\text{H}_2 &lt; \text{C}_2\text{H}_4)</td>
<td>(\text{C}_2\text{H}_2 &gt; \text{C}_2\text{H}_4)</td>
</tr>
</tbody>
</table>
11. A solid has a melting point of 1582 °C and does not dissolve in water. It does not conduct electricity in the molten state. What type of structure does the solid have?

A. Ionic
B. Metallic
C. Giant molecular
D. Simple molecular

12. The diagrams below show $s$ and $p$ orbitals in different positions. Which combinations can form a $\sigma$-bond?

I. 

II. 

III. 

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

13. Which species contain delocalized electrons?

I. 

II. 

III. 

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
10. Which compounds have an ionic lattice structure in the solid state?

I. Silicon dioxide
II. Sodium fluoride
III. Ammonium nitrate

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

11. Which intermolecular forces exist between the following molecules?

<table>
<thead>
<tr>
<th></th>
<th>H₂Se</th>
<th>CO</th>
<th>H₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ only</td>
</tr>
<tr>
<td>B.</td>
<td>van der Waals’, dipole-dipole and hydrogen bonding</td>
<td>van der Waals’ only</td>
<td>van der Waals’ and hydrogen bonding</td>
</tr>
<tr>
<td>C.</td>
<td>van der Waals’, dipole-dipole and hydrogen bonding</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ only</td>
</tr>
<tr>
<td>D.</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ and hydrogen bonding</td>
</tr>
</tbody>
</table>

12. Which species have dative covalent bonding?

I. [Fe(H₂O)₆]Cl₃
II. NH₄⁺
III. H₂O

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
13. How many sigma (σ) and pi (π) bonds are there in CH₃CH₂CCCH₂COOH?
   
   A. 13σ and 5π
   B. 15σ and 2π
   C. 15σ and 3π
   D. 15σ only

14. What is the hybridization of atoms X, Y and Z in epinephrine?

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>sp²</td>
<td>sp³</td>
<td>sp³</td>
</tr>
<tr>
<td>B.</td>
<td>sp³</td>
<td>sp</td>
<td>sp³</td>
</tr>
<tr>
<td>C.</td>
<td>sp³</td>
<td>sp²</td>
<td>sp²</td>
</tr>
<tr>
<td>D.</td>
<td>sp³</td>
<td>sp³</td>
<td>sp³</td>
</tr>
</tbody>
</table>
25. Which compound has the highest enthalpy of vaporization?

A. CO₂
B. NH₃
C. H₂S
D. H₂O

9. Which is the best description of a metallic bond?

A. Electrostatic attraction between oppositely charged ions
B. Electrostatic attraction between a pair of electrons and positively charged nuclei
C. Electrostatic attraction between a lattice of positive ions and delocalized electrons
D. Electrostatic attraction for a bonding pair of electrons which have been supplied by one of the atoms

10. Which statements about the structure and bonding of silicon dioxide are correct?

<table>
<thead>
<tr>
<th>Structure</th>
<th>Bonding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon dioxide forms a giant covalent network.</td>
<td>Each oxygen atom is covalently bonded to two silicon atoms.</td>
</tr>
<tr>
<td>Silicon dioxide molecules are V-shaped or bent.</td>
<td>Each silicon atom is covalently bonded to two oxygen atoms.</td>
</tr>
<tr>
<td>Silicon dioxide molecules are linear.</td>
<td>A double covalent bond exists between silicon and oxygen atoms.</td>
</tr>
<tr>
<td>Silicon dioxide forms a giant covalent network.</td>
<td>Each oxygen atom is covalently bonded to four silicon atoms.</td>
</tr>
</tbody>
</table>

11. Which series shows increasing boiling points?

A. CH₃CH₂CH₃ < CH₃CH₂OH < CH₃CHO
B. CH₃CHO < CH₃CH₂CH₃ < CH₃CH₂OH
C. CH₃CH₂OH < CH₃CHO < CH₃CH₂CH₃
D. CH₃CH₂CH₃ < CH₃CHO < CH₃CH₂OH
12. How many sigma (σ) and pi (π) bonds are there in the following molecule?

\[
\begin{array}{c}
\text{H} \\
\text{C} \\
\text{C} \\
\text{C} \\
\text{O} \\
\text{H}
\end{array}
\]

<table>
<thead>
<tr>
<th>σ bonds</th>
<th>π bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>9</td>
</tr>
<tr>
<td>B.</td>
<td>9</td>
</tr>
<tr>
<td>C.</td>
<td>11</td>
</tr>
<tr>
<td>D.</td>
<td>11</td>
</tr>
</tbody>
</table>

13. Which species have delocalized π electrons?

I. \( \text{CH}_3\text{COCH}_3 \)
II. \( \text{NO}_2^- \)
III. \( \text{CO}_3^{2-} \)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

Topic Chem 4 Q# 95/ IB/Paper 1/2013/s/Time Zone 1/Higher Level/

10. Which compound is predominantly covalent?

A. \( \text{LiCl} \)
B. \( \text{Al}_2\text{O}_3 \)
C. \( \text{ClF} \)
D. \( \text{ZnCl}_2 \)
11. Which combination best describes the type of bonding present and the melting point of silicon and silicon dioxide?

<table>
<thead>
<tr>
<th></th>
<th>Silicon</th>
<th>Silicon dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>covalent bonding</td>
<td>high melting point</td>
</tr>
<tr>
<td></td>
<td>covalent bonding</td>
<td>high melting point</td>
</tr>
<tr>
<td>B.</td>
<td>metallic bonding</td>
<td>high melting point</td>
</tr>
<tr>
<td></td>
<td>covalent bonding</td>
<td>low melting point</td>
</tr>
<tr>
<td>C.</td>
<td>ionic bonding</td>
<td>high melting point</td>
</tr>
<tr>
<td></td>
<td>ionic bonding</td>
<td>low melting point</td>
</tr>
<tr>
<td>D.</td>
<td>covalent bonding</td>
<td>low melting point</td>
</tr>
<tr>
<td></td>
<td>ionic bonding</td>
<td>high melting point</td>
</tr>
</tbody>
</table>

12. Which species has a square planar shape?

A.  
```
: F : ..
: F : : C : F :
: F : ..
: F :
```

B.  
```
: F : ..
: F : : S : F :
: F : ..
: F :
```

C.  
```
: F : ..
: F : : B : F :
: F : ..
: F :
```

D.  
```
: F : ..
: F : : Cl : F :
: F : ..
: F :
```
13. What are the hybridizations of the atoms labelled 1, 2 and 3 in the molecule below?

[Diagram of a molecule with hybridizations]

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>sp²</td>
<td>sp²</td>
<td>sp</td>
</tr>
<tr>
<td>B</td>
<td>sp³</td>
<td>sp²</td>
<td>sp³</td>
</tr>
<tr>
<td>C</td>
<td>sp²</td>
<td>sp</td>
<td>sp³</td>
</tr>
<tr>
<td>D</td>
<td>sp³</td>
<td>sp²</td>
<td>sp</td>
</tr>
</tbody>
</table>

9. Which is an ionic compound?

A. Mg₃N₂
B. Al₂Cl₆
C. SrO₂
D. SF₆

10. Which molecule is polar?

<table>
<thead>
<tr>
<th>Molecule</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. CO₂</td>
<td>linear</td>
</tr>
<tr>
<td>B. SO₃</td>
<td>trigonal planar</td>
</tr>
<tr>
<td>C. CCl₄</td>
<td>tetrahedral</td>
</tr>
<tr>
<td>D. SO₂</td>
<td>bent (V-shaped)</td>
</tr>
</tbody>
</table>
11. Which intermolecular forces are present in HI(I)?
   I. Hydrogen bonding
   II. Dipole-dipole forces
   III. Van der Waals' (London dispersion) forces
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

12. In the molecule SF₄, which are the correct bond angles?

![Diagram](Image)

<table>
<thead>
<tr>
<th></th>
<th>α / °</th>
<th>β / °</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>180</td>
<td>120</td>
</tr>
<tr>
<td>B</td>
<td>187</td>
<td>103</td>
</tr>
<tr>
<td>C</td>
<td>187</td>
<td>120</td>
</tr>
<tr>
<td>D</td>
<td>180</td>
<td>90</td>
</tr>
</tbody>
</table>

13. Which substances have delocalized electrons in their structure?
   I. Ethanal
   II. Ozone
   III. Benzene
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
9. Which species contain dative covalent bonds?

   I. CO
   II. NH$_3$
   III. H$_2$O$^+$

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

10. Which single covalent bond is the most polar, given the following electronegativity values?

<table>
<thead>
<tr>
<th>Element</th>
<th>H</th>
<th>C</th>
<th>S</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronegativity</td>
<td>2.2</td>
<td>2.6</td>
<td>2.6</td>
<td>3.4</td>
</tr>
</tbody>
</table>

   A. C–O
   B. S–H
   C. C–H
   D. O–H
11. The Lewis (electron dot) structure of paracetamol (acetaminophen) is:

![Lewis Structure]

What are the approximate values of the bond angles?

<table>
<thead>
<tr>
<th></th>
<th>α</th>
<th>β</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>104.5°</td>
<td>120°</td>
<td>109.5°</td>
</tr>
<tr>
<td>B</td>
<td>109.5°</td>
<td>109.5°</td>
<td>109.5°</td>
</tr>
<tr>
<td>C</td>
<td>120°</td>
<td>120°</td>
<td>90°</td>
</tr>
<tr>
<td>D</td>
<td>104.5°</td>
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<td>90°</td>
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<th>O</th>
</tr>
</thead>
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<td>2.6</td>
<td>2.6</td>
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<th>β</th>
<th>θ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>104.5°</td>
<td>120°</td>
<td>109.5°</td>
</tr>
<tr>
<td>B</td>
<td>109.5°</td>
<td>109.5°</td>
<td>109.5°</td>
</tr>
<tr>
<td>C</td>
<td>120°</td>
<td>120°</td>
<td>90°</td>
</tr>
<tr>
<td>D</td>
<td>104.5°</td>
<td>120°</td>
<td>90°</td>
</tr>
</tbody>
</table>

12. Which types of intermolecular forces exist in HBr, Cl₂ and CH₃F?

<table>
<thead>
<tr>
<th></th>
<th>HBr</th>
<th>Cl₂</th>
<th>CH₃F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ only</td>
<td>van der Waals’ and dipole-dipole</td>
</tr>
<tr>
<td>B</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ only</td>
<td>van der Waals’, dipole-dipole and hydrogen bonding</td>
</tr>
<tr>
<td>C</td>
<td>van der Waals’ only</td>
<td>van der Waals’ only</td>
<td>van der Waals’, dipole-dipole and hydrogen bonding</td>
</tr>
<tr>
<td>D</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’ and dipole-dipole</td>
<td>van der Waals’, dipole-dipole and hydrogen bonding</td>
</tr>
</tbody>
</table>
13. Retinol (vitamin A) contains a total of 5 double bonds and 46 single bonds.

Which statements are correct?

I. There are 51 \( \sigma \) and 5 \( \pi \) bonds.

II. The oxygen atom is \( \text{sp}^3 \) hybridized.

III. Retinol is a primary alcohol.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

14. Zinc metal contains metallic bonding. Which is the best description of a metallic bond?

A. The electrostatic attraction between a pair of electrons and positively charged nuclei.

B. The electrostatic attraction between oppositely charged ions.

C. The electrostatic attraction between a lattice of positive ions and delocalized electrons.

D. The bond formed when one atom provides both electrons in a shared pair.
9. What is the correct number of centres of negative charge for carbon and the shape of $\text{H}_2\text{CO}$?

![H_2CO structure](image)

<table>
<thead>
<tr>
<th>Centres of negative charge on C-atom</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 3</td>
<td>trigonal pyramidal</td>
</tr>
<tr>
<td>B. 3</td>
<td>trigonal planar</td>
</tr>
<tr>
<td>C. 4</td>
<td>trigonal pyramidal</td>
</tr>
<tr>
<td>D. 4</td>
<td>trigonal planar</td>
</tr>
</tbody>
</table>

10. Which statement about intermolecular forces is correct?

A. The intermolecular force between $\text{H}_2$ molecules is hydrogen bonding, because $\text{H}_2$ has temporary dipoles.

B. The intermolecular forces between $\text{PH}_3$ molecules are greater than the intermolecular forces between $\text{NH}_3$ molecules, because they have a greater mass.

C. The intermolecular force between $\text{H}_2$ molecules is hydrogen bonding, because $\text{H}_2$ has permanent dipoles.

D. The intermolecular forces between $\text{Br}_2$ molecules are van der Waals', because $\text{Br}_2$ has temporary dipoles.

11. Which substances are soluble in hexane, $\text{C}_6\text{H}_{14}$?

I. $\text{C}_6\text{H}_{13}$
II. $\text{CH}_4$
III. $\text{H}_2\text{O}$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
12. Diagrams I and II show two p orbitals on adjacent atoms in different relative orientations.

Which types of bonds are formed when the orbitals overlap?

<table>
<thead>
<tr>
<th>Orientation I</th>
<th>Orientation II</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ( \sigma )</td>
<td>( \sigma )</td>
</tr>
<tr>
<td>B. ( \pi )</td>
<td>( \pi )</td>
</tr>
<tr>
<td>C. ( \pi )</td>
<td>( \sigma )</td>
</tr>
<tr>
<td>D. ( \sigma )</td>
<td>( \pi )</td>
</tr>
</tbody>
</table>

13. Which molecules have delocalized \( \pi \) electrons?

I. \( \text{C}_6\text{H}_6 \)
II. \( \text{CH}_3\text{COOH} \)
III. \( \text{O}_3 \)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

10. When \( \text{C}_2\text{H}_2 \), \( \text{C}_2\text{H}_4 \) and \( \text{C}_2\text{H}_6 \) are arranged in order of increasing carbon-carbon bond strength (weakest bond first), what is the correct order?

A. \( \text{C}_2\text{H}_4, \text{C}_2\text{H}_2, \text{C}_2\text{H}_6 \)
B. \( \text{C}_2\text{H}_2, \text{C}_2\text{H}_4, \text{C}_2\text{H}_6 \)
C. \( \text{C}_2\text{H}_6, \text{C}_2\text{H}_4, \text{C}_2\text{H}_2 \)
D. \( \text{C}_2\text{H}_6, \text{C}_2\text{H}_3, \text{C}_2\text{H}_4 \)
11. Which molecule has a non-bonding (lone) pair of electrons around the central atom?
   
   A. BF₃
   B. SO₂
   C. PCl₃
   D. SiF₄

12. Which particles are responsible for the conduction of electricity in molten aluminium?
   
   A. Cations
   B. Anions
   C. Electrons
   D. Protons

13. How many sigma and pi bonds are there in propyne, CH₃CCH?
   
   A. 2 sigma and 2 pi
   B. 7 sigma and 1 pi
   C. 6 sigma and 2 pi
   D. 5 sigma and 3 pi

14. Which species does not have delocalized electrons?
   
   A. NO₃⁻
   B. NO₂⁻
   C. O₃
   D. C₂H₆
15. In which compound are all the carbon atoms sp² hybridized?

A. \[
\begin{array}{c}
\text{COOH} \\
\end{array}
\]

B. \[
\begin{array}{c}
\text{CH}_3 \\
\end{array}
\]

C. CH₂CH₃

D. CH₂CH₂CHCHCH₂CH₃

Topic Chem 4 Q# 101/ IB/Paper 1/2011/s/Time Zone 1/Higher Level/

10. How many \(\sigma\) and \(\pi\) bonds are present in a molecule of propyne, CH₃CCH?

<table>
<thead>
<tr>
<th></th>
<th>(\sigma)</th>
<th>(\pi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>8</td>
<td>0</td>
</tr>
</tbody>
</table>

11. Which species does not contain delocalized electrons?

A. CH₃CH₂O⁻

B. CH₃CO₅⁻

C. O₃

D. NO₃⁻

12. Which compound forms hydrogen bonds in the liquid state?

A. C₂H₅OH

B. CHCl₃

C. CH₃CHO

D. (CH₃CH₂)₃N
13. Which particles are responsible for electrical conductivity in metals?

A. Anions  
B. Cations  
C. Electrons  
D. Protons  

14. The Lewis structure of SO₂ is given below.

\[ 
\begin{array}{c}
\cdot \cdot \\
\cdot \cdot \\
\cdot \cdot \\
\end{array}
\begin{array}{c}
S \\
O \\
O \\
\end{array}
\]

What is the shape of the SO₂ molecule?

A. Bent (V-shaped)  
B. Linear  
C. T-shaped  
D. Triangular planar  

9. The electronegativities of four different elements are given below (the letters are not their chemical symbols).

<table>
<thead>
<tr>
<th>Element</th>
<th>W</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronegativity</td>
<td>0.9</td>
<td>1.2</td>
<td>3.4</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Based on this information which statement is correct?

A. W is a non-metal.  
B. W and X form an ionic compound.  
C. Y is a metal.  
D. Y and Z form a covalent compound.
10. Which species contain a dative covalent bond?

   I. HCHO
   II. CO
   III. H₂O

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

11. Which substance is made up of a lattice of positive ions and free moving electrons?

   A. Graphite
   B. Sodium chloride
   C. Sulfur
   D. Sodium

12. Which molecule has an octahedral shape?

   A. SF₆
   B. PCl₅
   C. XeF₄
   D. BF₃

13. Which species have delocalized electrons?

   ![Chemical structures]

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
9. Which species have a dative covalent bond?
   
   I. CO
   II. NH₃
   III. H₂O⁺

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

10. Which substance can form intermolecular hydrogen bonds in the liquid state?

   A. CH₃OCH₃
   B. CH₂CH₂OH
   C. CH₂CHO
   D. CH₃CH₂CH₃

11. Which molecule is polar?

   A. CH₂Cl₂
   B. BCl₃
   C. Cl₂
   D. CCl₄

12. The Lewis structure of XeF₂ contains two bonding pairs of electrons and three non-bonding pairs of electrons (lone pairs) around the central xenon atom. What is the shape of XeF₂ molecule?

   A. Bent
   B. Trigonal bipyramidal
   C. Square planar
   D. Linear
13. How many sigma (σ) bonds are present in (CH₃)₂C=CClCH₃CH₃?
   A. 1
   B. 4
   C. 16
   D. 17

10. Which molecule has the shortest carbon-oxygen bond length?
   A. CH₃COOH
   B. CH₃CH₂OH
   C. CO₂
   D. CO

11. Which pair of compounds is arranged in correct order of relative boiling points?

<table>
<thead>
<tr>
<th>Lower Boiling Point</th>
<th>Higher Boiling Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. CH₃OCH₃</td>
<td>CH₃CH₂OH</td>
</tr>
<tr>
<td>B. CH₃CHO</td>
<td>CH₃CH₂CH₃</td>
</tr>
<tr>
<td>C. CH₃CH₂OH</td>
<td>CH₃CHO</td>
</tr>
<tr>
<td>D. CH₃COOH</td>
<td>CH₃CH₂OH</td>
</tr>
</tbody>
</table>

12. Which intermolecular forces exist between molecules of carbon monoxide, CO?
   A. Hydrogen bonds and van der Waals’ forces
   B. Dipole-dipole attractions and van der Waals’ forces
   C. Van der Waals’ forces only
   D. Dipole-dipole attractions only
13. Which statements about $\sigma$ and $\pi$ bonds are correct?

I. $\sigma$ bonds result from the axial overlap of orbitals.
II. $\sigma$ bonds only form from s orbitals.
III. $\pi$ bonds result from the sideways overlap of parallel p orbitals.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

14. In which substance does a carbon atom have $sp^3$ hybridization?

A. 2-methylbutan-1-ol
B. Propyne, CH$_3$CCH
C. C$_{60}$ fullerene
D. Diamond

10. What is the correct order if the compounds are arranged in order of increasing boiling point?

A. CH$_4$ < CH$_3$Cl < SiH$_4$ < CH$_3$OH
B. CH$_3$OH < CH$_4$ < CH$_3$Cl < SiH$_4$
C. CH$_3$OH < CH$_3$Cl < SiH$_4$ < CH$_4$
D. CH$_4$ < SiH$_4$ < CH$_3$Cl < CH$_3$OH

11. What is the bond angle in the H$_2$O$^+$ ion?

A. 104°
B. 107°
C. 109°
D. 120°
12. Which compound does not form hydrogen bonds between its molecules?

A. CH₃NH₃  
B. CH₃COCH₂  
C. CH₂COOH  
D. CH₃CH₂OH

13. How many atoms is each carbon directly bonded to in its allotropes?

<table>
<thead>
<tr>
<th></th>
<th>Diamond</th>
<th>Graphite</th>
<th>C₆₀ fullerene</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>B.</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C.</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>D.</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

14. What is the type of hybridization of the silicon and oxygen atoms in silicon dioxide?

<table>
<thead>
<tr>
<th></th>
<th>Silicon</th>
<th>Oxygen</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>sp³</td>
<td>sp³</td>
</tr>
<tr>
<td>B.</td>
<td>sp³</td>
<td>sp²</td>
</tr>
<tr>
<td>C.</td>
<td>sp²</td>
<td>sp³</td>
</tr>
<tr>
<td>D.</td>
<td>sp³</td>
<td>sp³</td>
</tr>
</tbody>
</table>

11. Which statement best describes the intramolecular bonding in HCN(l)?

A. Electrostatic attractions between H⁺ and CN⁻ ions  
B. Only van der Waals' forces  
C. Van der Waals' forces and hydrogen bonding  
D. Electrostatic attractions between pairs of electrons and positively charged nuclei
12. How many bonding pairs and lone pairs of electrons surround the sulfur atom in the SF₄ molecule?

<table>
<thead>
<tr>
<th>Bonding pairs</th>
<th>Lone pairs</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>4</td>
</tr>
<tr>
<td>B.</td>
<td>4</td>
</tr>
<tr>
<td>C.</td>
<td>6</td>
</tr>
<tr>
<td>D.</td>
<td>8</td>
</tr>
</tbody>
</table>

13. Metal M has only one oxidation number and forms a compound with the formula MCO₃. Which formula is correct?

A. MNO₃
B. MNH₄
C. MSO₄
D. MPO₄

14. Which of the following best describes the formation of π bonds?

A. They are formed by the sideways overlap of parallel orbitals.
B. They are formed by the axial overlap of orbitals.
C. They are formed by the sideways overlap of an s and p orbital.
D. They are formed by the axial overlap of either s or p orbitals.

15. What is the hybridization of the carbon atom, and the number of σ and π bonds in the methanal molecule?

\[
\text{H} = \overset{\text{C}}{=} \overset{\text{O}}{\text{H}}
\]

<table>
<thead>
<tr>
<th>Hybridization</th>
<th>σ bonds</th>
<th>π bonds</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>sp³</td>
<td>3</td>
</tr>
<tr>
<td>B.</td>
<td>sp³</td>
<td>3</td>
</tr>
<tr>
<td>C.</td>
<td>sp³</td>
<td>4</td>
</tr>
<tr>
<td>D.</td>
<td>sp³</td>
<td>4</td>
</tr>
</tbody>
</table>
9. Which is the best description of ionic bonding?

A. The electrostatic attraction between positively charged nuclei and an electron pair
B. The electrostatic attraction between positive ions and delocalized negative ions
C. The electrostatic attraction between positive ions and delocalized electrons
D. The electrostatic attraction between oppositely charged ions

10. Which statements best describe the structure of sodium chloride, NaCl?

I. Each sodium ion is surrounded by six chloride ions.
II. The chloride ions are arranged octahedrally around each sodium ion.
III. The lattice forms a cubic structure.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

11. Which molecule contains a dative covalent (coordinate) bond?

A. HCN
B. H₂O₂
C. CO₂
D. CO
12. Identify the hybridization of carbon atoms in this molecule

\[
\begin{array}{c}
\text{H} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \\
\text{H} \quad \text{H} \quad \text{H} \quad \text{OH}
\end{array}
\]

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>$sp^3$</td>
<td>$sp^2$</td>
<td>$sp^2$</td>
<td>$sp^2$</td>
</tr>
<tr>
<td>B</td>
<td>$sp^2$</td>
<td>$sp^2$</td>
<td>$sp^2$</td>
<td>$sp$</td>
</tr>
<tr>
<td>C</td>
<td>$sp^3$</td>
<td>$sp$</td>
<td>$sp^2$</td>
<td>$sp$</td>
</tr>
<tr>
<td>D</td>
<td>$sp$</td>
<td>$sp^2$</td>
<td>$sp$</td>
<td>$sp^2$</td>
</tr>
</tbody>
</table>

13. Which structure has delocalized $\pi$ electrons?

A. $O_3$
B. CO
C. HCN
D. $CO_2$

13. When are ionic bonds most likely to form?

A. When two elements with high electronegativity values react with each other.
B. When two metals of different groups react with each other.
C. When two non-metallic elements react with each other.
D. When a metal and a non-metal react with each other.

14. What is the shape of PF$_5$?

A. Tetrahedral
B. Trigonal pyramidal
C. Square planar
D. Trigonal bipyramidal
15. The formula of tetrachloromethane is CCl₄. Which combination correctly shows the number of lone pairs of electrons in the Lewis structure, the shape of the molecule and the type of hybridization of the carbon atom?

<table>
<thead>
<tr>
<th>Lone pairs of electrons in Lewis Structure</th>
<th>Shape of molecule</th>
<th>Type of hybridization</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>4</td>
<td>pyramidal</td>
</tr>
<tr>
<td>B.</td>
<td>8</td>
<td>square planar</td>
</tr>
<tr>
<td>C.</td>
<td>12</td>
<td>tetrahedral</td>
</tr>
<tr>
<td>D.</td>
<td>16</td>
<td>tetrahedral</td>
</tr>
</tbody>
</table>

11. Which substance will **not** conduct an electric current?

A. C(s) (graphite)

B. NaF (l)

C. CaO (s)

D. KI (aq)

12. Which of the following liquids is non-polar?

A. Water

B. Hexane

C. Propanone

D. Ethanol

13. The following substances all contain a nitrogen to nitrogen bond: N₂, N₂H₄, N₂H₂. Which shows them in **increasing** order of nitrogen to nitrogen bond length (smallest first)?

A. N₂H₄, N₂H₂, N₂

B. N₂, N₂H₂, N₂H₄

C. N₂H₂, N₂H₄, N₂

D. N₂H₄, N₂, N₂H₂
14. What is the bond angle in $\text{NO}_3^-$?

A. 107°
B. 109.5°
C. 120°
D. 180°

**Topic 4 Mark Scheme**

<table>
<thead>
<tr>
<th>Question</th>
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<th>IB/P1/2015/s/TZ 2/HL</th>
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<td>C</td>
<td>D</td>
</tr>
<tr>
<td>Q# 83/12</td>
<td>D</td>
<td>C</td>
<td>C</td>
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<td>D</td>
<td>C</td>
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<td>A</td>
<td>D</td>
<td>A</td>
</tr>
<tr>
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<td>B</td>
<td>G</td>
<td>A</td>
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<tr>
<td>Q# 85/14</td>
<td>A</td>
<td>D</td>
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<th>IB/P1/2015/w/TZ 2/HL</th>
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<td>C</td>
<td>A</td>
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<tr>
<td>Q# 83/12</td>
<td>C</td>
<td>D</td>
<td>A</td>
</tr>
<tr>
<td>Q# 84/13</td>
<td>C</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>Q# 85/14</td>
<td>A</td>
<td>C</td>
<td>C</td>
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<tr>
<td>Q# 82/11</td>
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<tr>
<td>Q# 83/12</td>
<td>C</td>
</tr>
<tr>
<td>Q# 84/13</td>
<td>A</td>
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<tr>
<td>Q# 85/14</td>
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<tr>
<td>Q# 82/11</td>
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<tr>
<td>Q# 83/12</td>
<td>D</td>
</tr>
<tr>
<td>Q# 84/13</td>
<td>A</td>
</tr>
<tr>
<td>Q# 85/14</td>
<td>C</td>
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<th>IB/P1/2013/w/TZ 0/HL</th>
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<tbody>
<tr>
<td>Q# 82/11</td>
<td>C</td>
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<tr>
<td>Q# 83/12</td>
<td>A</td>
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<td>D</td>
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<tr>
<td>Q# 85/14</td>
<td>C</td>
</tr>
</tbody>
</table>
16. Hydrazine reacts with oxygen.

\[ \text{N}_2\text{H}_4(\text{l}) + \text{O}_2(\text{g}) \rightarrow \text{N}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \quad \Delta H^\circ = -623 \text{kJ} \]

What is the standard enthalpy of formation of \( \text{N}_2\text{H}_4(\text{l}) \) in kJ? The standard enthalpy of formation of \( \text{H}_2\text{O}(\text{l}) \) is \(-286 \text{kJ}\).

A. \(-623 - 286\)
B. \(-623 + 572\)
C. \(-572 + 623\)
D. \(-286 + 623\)

17. 5.35 g of solid ammonium chloride, \( \text{NH}_4\text{Cl(s)} \), was added to water to form 25.0 g of solution. The maximum decrease in temperature was 14 K. What is the enthalpy change, in kJmol\(^{-1}\), for this reaction? (Molar mass of \( \text{NH}_4\text{Cl} = 53.5 \text{g mol}^{-1}\); the specific heat capacity of the solution is 4.18 Jg\(^{-1}\)K\(^{-1}\))

A. \( \Delta H = \frac{25.0 \times 4.18 \times (14 + 273)}{0.1 \times 1000} \)
B. \( \Delta H = \frac{25.0 \times 4.18 \times 14}{0.1 \times 1000} \)
C. \( \Delta H = \frac{25.0 \times 4.18 \times 14}{0.1 \times 1000} \)
D. \( \Delta H = \frac{25.0 \times 4.18 \times 14}{1000} \)

18. Which represents the enthalpy change of hydration of the chloride ion?

A. \( \text{Cl}^-(\text{g}) \rightarrow \text{Cl}^-(\text{aq}) \)
B. \( \text{Cl}^- \rightarrow \text{Cl}^-(\text{aq}) \)
C. \( \frac{1}{2}\text{Cl}_2(\text{g}) \rightarrow \text{Cl}^-(\text{aq}) \)
D. \( \frac{1}{2}\text{Cl}_2(\text{aq}) \rightarrow \text{Cl}^-(\text{aq}) \)

19. Which ionic compound has the largest value of lattice enthalpy?

A. \( \text{MgS} \)
B. \( \text{MgO} \)
C. \( \text{CaBr}_2 \)
D. \( \text{NaF} \)
16. The equation for the formation of ethyne is:

\[ 2C(s) + H_2(g) \rightarrow C_2H_2(g) \]

What is the enthalpy change, in kJ, for this reaction using the enthalpy of combustion data below?

<table>
<thead>
<tr>
<th>Reaction</th>
<th>( \Delta H^{\circ} ) / kJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C(s) + O_2(g) \rightarrow CO_2(g) )</td>
<td>-394</td>
</tr>
<tr>
<td>( 2H_2(g) + O_2(g) \rightarrow 2H_2O(l) )</td>
<td>-572</td>
</tr>
<tr>
<td>( 2C_2H_2(g) + 5O_2(g) \rightarrow 4CO_2(g) + 2H_2O(l) )</td>
<td>-2602</td>
</tr>
</tbody>
</table>

A. \( 2 \times (-394) + \frac{1}{2}(-572) - \frac{1}{2}(-2602) \)
B. \( 2 \times (-394) + (-572) - (-2602) \)
C. \( 2 \times (-394) + \frac{1}{2}(-572) + \frac{1}{2}(-2602) \)
D. \( 2 \times (-394) + (-572) + (-2602) \)

17. Which equation represents the average bond enthalpy of the Si–H bond in SiH₄?

A. \( \text{SiH}_4(g) \rightarrow \text{SiH}_3(g) + \text{H}(g) \)
B. \( \frac{1}{4} \text{SiH}_4(g) \rightarrow \frac{1}{4} \text{Si}(g) + \text{H}(g) \)
C. \( \text{SiH}_4(g) \rightarrow \text{SiH}_3(g) + \frac{1}{2} \text{H}_2(g) \)
D. \( \text{SiH}_4(g) \rightarrow \text{Si}(g) + 4\text{H}(g) \)

18. Which transition represents an enthalpy of hydration?

A. \( 2\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}^+(aq) + \text{OH}^-(aq) \)
B. \( \text{NaCl}(s) \rightarrow \text{Na}^+(aq) + \text{Cl}^-(aq) \)
C. \( \text{K}^+(s) \rightarrow \text{K}^+(aq) \)
D. \( \text{K}^+(g) \rightarrow \text{K}^+(aq) \)
19. What are the signs for the entropy changes associated with this reaction?

\[ \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{O}(l) \]

<table>
<thead>
<tr>
<th></th>
<th>( \Delta S_{\text{surroundings}} )</th>
<th>( \Delta S_{\text{system}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>+</td>
<td>−</td>
</tr>
<tr>
<td>B.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>C.</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>D.</td>
<td>−</td>
<td>+</td>
</tr>
</tbody>
</table>

Topic Chem 5 Q# 112/ IB/Paper 1/2016/s/Specimen Paper/Higher Level/

1. Which changes of state are endothermic processes?

   I. Condensing
   II. Melting
   III. Subliming

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
16. When 0.46 g of ethanol is burned under a water-filled calorimeter, the temperature of 500 g of water is raised by 3.0 K. (Molar mass of ethanol = 46 g mol\(^{-1}\); specific heat capacity of water = 4.18 J g\(^{-1}\) K\(^{-1}\); \(q = mc\Delta T\))

What is the expression for the enthalpy of combustion, \(\Delta H_c\), in kJ mol\(^{-1}\)?

A. \[-\frac{500 \times 4.18 \times 3.0 \times 46}{0.46}\]

B. \[-\frac{500 \times 4.18 \times (273 + 3.0) \times 46}{0.46 \times 1000}\]

C. \[-\frac{500 \times 4.18 \times 3.0 \times 46}{0.46 \times 1000}\]

D. \[-\frac{0.46 \times 1000}{500 \times 4.18 \times 3.0 \times 46}\]

17. Given the following information, what is the standard enthalpy of formation, \(\Delta H_f^\circ\), of methane?

\[
\begin{align*}
\text{C(s)} + \text{O}_2(g) &\rightarrow \text{CO}_2(g) & \Delta H &= E \text{ kJ} \\
\text{H}_2(g) + \frac{1}{2} \text{O}_2(g) &\rightarrow \text{H}_2\text{O}(l) & \Delta H &= F \text{ kJ} \\
\text{CH}_4(g) + 2\text{O}_2(g) &\rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l) & \Delta H &= G \text{ kJ}
\end{align*}
\]

A. E + F + G

B. E + F - G

C. E + 2F + G

D. E + 2F - G
18. Which combination has the most endothermic lattice enthalpy?

<table>
<thead>
<tr>
<th></th>
<th>Radius of positive ion / nm</th>
<th>Radius of negative ion / nm</th>
<th>Charge on positive ion</th>
<th>Charge on negative ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>0.100</td>
<td>0.185</td>
<td>2+</td>
<td>2–</td>
</tr>
<tr>
<td>B.</td>
<td>0.102</td>
<td>0.180</td>
<td>1+</td>
<td>1–</td>
</tr>
<tr>
<td>C.</td>
<td>0.149</td>
<td>0.180</td>
<td>1+</td>
<td>1–</td>
</tr>
<tr>
<td>D.</td>
<td>0.100</td>
<td>0.140</td>
<td>2+</td>
<td>2–</td>
</tr>
</tbody>
</table>

19. In which reaction is the value of ΔS positive?

A. \(CaCO_3(s) \rightarrow CaO(s) + CO_2(g)\)

B. \(H_2O(g) \rightarrow H_2O(s)\)

C. \(2KI(aq) + Pb(NO_3)_2(aq) \rightarrow PbI_2(s) + 2 KNO_3(aq)\)

D. \(2ZnS(s) + 3O_2(g) \rightarrow 2ZnO(s) + 2SO_2(g)\)

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14. Which of the following changes are exothermic?

I. \(H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + 2H_2O(l)\)

II. \(2C_6H_{12}(g) + 17O_2(g) \rightarrow 16CO(g) + 18H_2O(g)\)

III. \(C_6H_{16}(g) \rightarrow C_6H_{14}(l)\)

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

15. Which change represents the standard enthalpy change of formation?

A. The formation of 1 mol of a compound in its standard state from its gaseous atoms

B. The formation of 1 mol of a compound in its standard state from its elements

C. The formation of 1 mol of a compound in its standard state from its gaseous atoms in their standard states

D. The formation of 1 mol of a compound in its standard state from its elements in their standard states
16. Which equation represents electron affinity?

A. \[ \text{C}(g) + \text{e}^{-} \rightarrow \text{C}^{-}(g) \]
B. \[ \text{Na}^{+}(\text{aq}) + \text{e}^{-} \rightarrow \text{Na}(\text{s}) \]
C. \[ \frac{1}{2} \text{Cl}_{2}(g) + \text{e}^{-} \rightarrow \text{Cl}^{-}(g) \]
D. \[ \text{B}(g) + \text{e}^{-} \rightarrow \text{B}^{-}(g) + 2\text{e}^{-} \]

17. Which combination results in an ionic compound having the greatest magnitude of lattice enthalpy?

<table>
<thead>
<tr>
<th>Sum of ionic radii</th>
<th>Ionic charges</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. small</td>
<td>large</td>
</tr>
<tr>
<td>B. large</td>
<td>large</td>
</tr>
<tr>
<td>C. large</td>
<td>small</td>
</tr>
<tr>
<td>D. small</td>
<td>small</td>
</tr>
</tbody>
</table>

18. Under which conditions does a sample of the same mass of carbon dioxide have the lowest entropy value?

A. Solid at high temperature
B. Solid at low temperature
C. Gas at high temperature
D. Gas at low temperature

19. Curves I and II represent samples of the same gas at a constant pressure but at different temperatures. The areas under curves I and II are equal. What does curve II represent?

A. Curve II is at the lower temperature and there are less molecules in the sample.
B. Curve II is at the lower temperature and there are the same number of molecules in the samples.
C. Curve II is at the higher temperature and there are more molecules in the sample.
D. Curve II is at the higher temperature and there are the same number of molecules in the samples.
14. When four moles of aluminium and four moles of iron combine with oxygen to form their oxides, the enthalpy changes are $-3338 \text{kJ}$ and $-1644 \text{kJ}$ respectively.

$$4\text{Al}(s) + 3\text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s) \quad \Delta H = -3338 \text{kJ}$$
$$4\text{Fe}(s) + 3\text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(s) \quad \Delta H = -1644 \text{kJ}$$

What is the enthalpy change, in $\text{kJ}$, for the reduction of one mole of iron(III) oxide by aluminium?

$$\text{Fe}_2\text{O}_3(s) + 2\text{Al}(s) \rightarrow 2\text{Fe}(s) + \text{Al}_2\text{O}_3(s)$$

A. $+1694$
B. $+847$
C. $-847$
D. $-1694$

14. When four moles of aluminium and four moles of iron combine with oxygen to form their oxides, the enthalpy changes are $-3338 \text{kJ}$ and $-1644 \text{kJ}$ respectively.

$$4\text{Al}(s) + 3\text{O}_2(g) \rightarrow 2\text{Al}_2\text{O}_3(s) \quad \Delta H = -3338 \text{kJ}$$
$$4\text{Fe}(s) + 3\text{O}_2(g) \rightarrow 2\text{Fe}_2\text{O}_3(s) \quad \Delta H = -1644 \text{kJ}$$

What is the enthalpy change, in $\text{kJ}$, for the reduction of one mole of iron(III) oxide by aluminium?

$$\text{Fe}_2\text{O}_3(s) + 2\text{Al}(s) \rightarrow 2\text{Fe}(s) + \text{Al}_2\text{O}_3(s)$$

A. $+1694$
B. $+847$
C. $-847$
D. $-1694$

15. Which enthalpy changes can be calculated using only bond enthalpy data?

I. $\text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g)$
II. $\text{C}_2\text{H}_5\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 3\text{H}_2\text{O}(g)$
III. $\text{CH}_4(g) + \text{Cl}_2(g) \rightarrow \text{CH}_3\text{Cl}(g) + \text{HCl}(g)$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
16. Which equation represents the standard enthalpy change of formation, $\Delta H^\circ_r$, of tetrachloromethane?

A. $\text{C}(g) + 4\text{Cl}(g) \rightarrow \text{CCl}_4(g)$
B. $\text{C}(s) + 4\text{Cl}(g) \rightarrow \text{CCl}_4(l)$
C. $\text{C}(g) + 2\text{Cl}_2(g) \rightarrow \text{CCl}_4(g)$
D. $\text{C}(s) + 2\text{Cl}_2(g) \rightarrow \text{CCl}_4(l)$

17. What is the correct order for increasing lattice enthalpy?

A. $\text{MgO} < \text{MgCl}_2 < \text{NaCl} < \text{CsCl}$
B. $\text{CsCl} < \text{NaCl} < \text{MgCl}_2 < \text{MgO}$
C. $\text{NaCl} < \text{CsCl} < \text{MgO} < \text{MgCl}_2$
D. $\text{NaCl} < \text{CsCl} < \text{MgCl}_2 < \text{MgO}$

18. Which combinations of values will result in a spontaneous reaction?

<table>
<thead>
<tr>
<th>$\Delta H / \text{kJ mol}^{-1}$</th>
<th>$\Delta S / \text{JK}^{-1} \text{mol}^{-1}$</th>
<th>$T / \text{K}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. $-100$</td>
<td>$-100$</td>
<td>$300$</td>
</tr>
<tr>
<td>II. $+100$</td>
<td>$-100$</td>
<td>$300$</td>
</tr>
<tr>
<td>III. $+100$</td>
<td>$+100$</td>
<td>$3000$</td>
</tr>
</tbody>
</table>

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

Topic Chem 5 Q# 117/ IB/Paper 1/2015/s/Time Zone 1/Higher Level/

14. The same amount of heat energy is added to 1.00g of each substance.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Specific heat capacity / Jg$^{-1}$K$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>0.39</td>
</tr>
<tr>
<td>Aluminium</td>
<td>0.90</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.90</td>
</tr>
<tr>
<td>Water</td>
<td>4.18</td>
</tr>
</tbody>
</table>

Which statement is correct if all the substances are at the same temperature before the heat energy is added?

A. Copper will reach the highest temperature.
B. Water will reach the highest temperature.
C. All four substances will reach the same temperature.
D. Aluminium will reach a higher temperature than sodium chloride.
15. The heat change in a neutralization reaction can be determined by mixing equal volumes of HCl(aq) and NaOH(aq) of the same concentration in a glass beaker. The maximum temperature change is recorded using an alcohol thermometer.

What is the biggest source of error in this experiment?

A. Heat absorbed by the glass thermometer
B. Random error in the thermometer reading
C. Heat loss to the surroundings
D. Systematic error in measuring the volumes of HCl(aq) and NaOH(aq) using burettes

16. Which equation represents the standard enthalpy of formation of liquid methanol?

A. C(g) + 2H2(g) + 1/2O2(g) → CH3OH(l)
B. C(g) + 4H(g) + O(g) → CH3OH(l)
C. C(s) + 4H(g) + O(g) → CH3OH(l)
D. C(s) + 2H2(g) + 1/2O2(g) → CH3OH(l)

17. Which species are arranged in order of increasing entropy?

A. C2H4(g) < CH3OH(l) < Hg(l) < Na(s)
B. CH3OH(l) < C2H4(g) < Hg(l) < Na(s)
C. Na(s) < Hg(l) < CH3OH(l) < C2H4(g)
D. Na(s) < Hg(l) < C2H4(g) < CH3OH(l)

18. Which combination of $\Delta H$ and $\Delta S$ values corresponds to a non-spontaneous reaction at all temperatures?

<table>
<thead>
<tr>
<th></th>
<th>$\Delta H$</th>
<th>$\Delta S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>D</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
14. Consider the following equations.

\[
2\text{Fe}(s) + 1\frac{1}{2}\text{O}_2(g) \rightarrow \text{Fe}_2\text{O}_3(s) \quad \Delta H^\circ = x \\
\text{CO}(g) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) \quad \Delta H^\circ = y
\]

What is the enthalpy change of the reaction below?

\[
\text{Fe}_2\text{O}_3(s) + 3\text{CO}(g) \rightarrow 3\text{CO}_2(g) + 2\text{Fe}(s)
\]

A. \(3y - x\)  
B. \(3y + x\)  
C. \(-3y - x\)  
D. \(-3y + x\)

15. Consider the following bond enthalpy data.

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond enthalpy / kJ mol(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>H–H</td>
<td>436</td>
</tr>
<tr>
<td>Cl–Cl</td>
<td>243</td>
</tr>
<tr>
<td>H–Cl</td>
<td>432</td>
</tr>
</tbody>
</table>

What is the enthalpy change, in kJ mol\(^{-1}\), of this reaction?

\[
\text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g)
\]

A. +247  
B. −247  
C. −185  
D. +185
16. Which processes have a negative value for $\Delta S^\circ$?

I. $\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(s)$
II. $2\text{H}_2\text{O}_2(l) \rightarrow 2\text{H}_2\text{O}(l) + \text{O}_2(g)$
III. $2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(g)$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

17. The Born–Haber cycle for the formation of magnesium oxide is shown below.

What is a correct description of the steps X, Y and Z in this cycle?

<table>
<thead>
<tr>
<th></th>
<th>Step X</th>
<th>Step Y</th>
<th>Step Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2nd ionization energy of Mg</td>
<td>enthalpy of formation of MgO</td>
<td>lattice enthalpy of MgO</td>
</tr>
<tr>
<td>B</td>
<td>2nd ionization energy of Mg</td>
<td>lattice enthalpy of MgO</td>
<td>enthalpy of formation of MgO</td>
</tr>
<tr>
<td>C</td>
<td>sum of the 1st and 2nd ionization energies of Mg</td>
<td>lattice enthalpy of MgO</td>
<td>enthalpy of formation of MgO</td>
</tr>
<tr>
<td>D</td>
<td>sum of 1st and 2nd ionization energies of Mg</td>
<td>enthalpy of formation of MgO</td>
<td>lattice enthalpy of MgO</td>
</tr>
</tbody>
</table>
18. Consider the values of $\Delta H^\circ$ and $\Delta S^\circ$ for the reaction of nitrogen with oxygen at 298 K.

$$\text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g}) \quad \Delta H^\circ = +181 \text{kJ mol}^{-1}$$

$$\Delta S^\circ = +25 \text{JK}^{-1}\text{mol}^{-1}$$

Which statement is correct for this reaction?

A. $\Delta G^\circ$ is positive at all temperatures.

B. $\Delta G^\circ$ is negative at all temperatures.

C. $\Delta G^\circ$ is positive at high temperatures.

D. $\Delta G^\circ$ is positive at low temperatures.

14. What is the value of $\Delta H$ for the exothermic reaction represented by the diagram below?

```
| A.   | +   |
| B.   | +   |
| C.   | -   |
| D.   | -   |
```

15. Which combination of enthalpy change and entropy change produces a non-spontaneous reaction at all temperatures?
16. Which equation represents the lattice enthalpy of calcium chloride?
   A. \( \text{CaCl}_2(s) \rightarrow \text{Ca}^+(g) + \text{Cl}^-(g) \)
   B. \( \text{CaCl}_2(s) \rightarrow \text{Ca}^{2+}(g) + 2\text{Cl}^-(g) \)
   C. \( \text{CaCl}_2(g) \rightarrow \text{Ca}^{2+}(g) + 2\text{Cl}^-(g) \)
   D. \( \text{CaCl}_2(s) \rightarrow \text{Ca}^{2+}(aq) + 2\text{Cl}^-(aq) \)

17. In which reaction will the entropy of the system increase significantly?
   A. \( \text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g) \)
   B. \( \text{H}_2\text{O}(g) \rightarrow \text{H}_2\text{O}(l) \)
   C. \( \text{HCl}(g) + \text{NH}_3(g) \rightarrow \text{NH}_4\text{Cl}(s) \)
   D. \( \text{NaOH}(aq) + \text{HCl}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l) \)

18. Which equation represents the second electron affinity of oxygen?
   A. \( \frac{1}{2} \text{O}_2(g) + 2\text{e}^- \rightarrow \text{O}^{2-}(g) \)
   B. \( \text{O}(g) + 2\text{e}^- \rightarrow \text{O}^{2-}(g) \)
   C. \( \text{O}_2(g) + 4\text{e}^- \rightarrow 2\text{O}^{2-}(g) \)
   D. \( \text{O}^-(g) + \text{e}^- \rightarrow \text{O}^{2-}(g) \)

19. What is the temperature rise when 2100J of energy is supplied to 100g of water? (Specific heat capacity of water = 4.2 J g\(^{-1}\) K\(^{-1}\).)
   A. 5 \( ^\circ \text{C} \)
   B. 278 K
   C. 0.2 \( ^\circ \text{C} \)
   D. 20 \( ^\circ \text{C} \)
14. Which statement is correct for the reaction with this enthalpy level diagram?

A. Heat energy is released during the reaction and the reactants are more stable than the products.
B. Heat energy is absorbed during the reaction and the reactants are more stable than the products.
C. Heat energy is released during the reaction and the products are more stable than the reactants.
D. Heat energy is absorbed during the reaction and the products are more stable than the reactants.

15. The enthalpy changes of three reactions are given below.

\[ \text{2HCOOH(l) + O}_2\text{(g) \rightarrow 2CO}_2\text{(g) + 2H}_2\text{O(l)}} \quad \Delta H = a \\
\text{C}_2\text{H}_5\text{OH(l) + 3O}_2\text{(g) \rightarrow 2CO}_2\text{(g) + 3H}_2\text{O(l)}} \quad \Delta H = b \\
\text{2HCOOC}_2\text{H}_5\text{(l) + 7O}_2\text{(g) \rightarrow 6CO}_3\text{(g) + 6H}_2\text{O(l)}} \quad \Delta H = c \\

What is the enthalpy change for the following reaction?

\[ \text{HCOOH(l) + C}_2\text{H}_5\text{OH(l) \rightarrow HCOOC}_2\text{H}_5\text{(l) + H}_2\text{O(l)}} \]

A. \( a + b + c \)
B. \( a + 2b - c \)
C. \( \frac{1}{2a} + b + \frac{1}{b}c \)
D. \( \frac{1}{2a} + b - \frac{1}{2}c \)
16. What is the correct definition of lattice enthalpy?

A. Enthalpy change when one mole of a solid ionic compound is separated into gaseous ions.
B. Enthalpy change when one mole of a solid ionic compound is separated into its ions in their standard state.
C. Enthalpy change when one mole of a solid ionic compound is formed from gaseous elements.
D. Enthalpy change when one mole of a compound is formed from the elements in their standard states.

17. Which reaction has the greatest increase in entropy?

A. \(2\text{CH}_3\text{OH}(l) + 3\text{O}_2(g) \rightarrow 2\text{CO}_2(g) + 4\text{H}_2\text{O}(l)\)
B. \(\text{N}_2(g) + 3\text{H}_2(g) \rightarrow 2\text{NH}_3(g)\)
C. \(2\text{HCl(aq)} + \text{MgCO}_3(s) \rightarrow \text{MgCl}_2(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)\)
D. \(\text{NH}_3(g) + \text{HCl}(g) \rightarrow \text{NH}_4\text{Cl}(s)\)

18. Which change must be negative when a reaction occurs spontaneously?

A. \(\Delta H\)
B. \(\Delta G\)
C. \(\Delta S\)
D. \(\Delta T\)

Topic Chem 5 Q# 121/ IB/Paper 1/2013/w/Time Zone 0/Higher Level/

15. Which processes are exothermic?

I. \(\text{CH}_3\text{CH}_2\text{CH}_3(g) + 5\text{O}_2(g) \rightarrow 3\text{CO}_2(g) + 4\text{H}_2\text{O}(g)\)
II. \(\text{Cl}_2(g) \rightarrow 2\text{Cl}(g)\)
III. \(\text{CH}_3\text{CH}_2\text{COOH(aq)} + \text{NaOH(aq)} \rightarrow \text{CH}_3\text{CH}_2\text{COONa(aq)} + \text{H}_2\text{O}(l)\)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
16. Consider the following two equations.

\[2\text{Ca (s)} + \text{O}_2 (g) \rightarrow 2\text{CaO (s)} \quad \Delta H^\circ = +x \text{ kJ}\]
\[\text{Ca (s)} + 0.5\text{O}_2 (g) + \text{CO}_2 (g) \rightarrow \text{CaCO}_3 (s) \quad \Delta H^\circ = +y \text{ kJ}\]

What is \(\Delta H^\circ\), in kJ, for the following reaction?

\[\text{CaO (s)} + \text{CO}_2 (g) \rightarrow \text{CaCO}_3 (s)\]

A. \(y - 0.5x\)
B. \(y - x\)
C. \(0.5 - y\)
D. \(x - y\)

17. Which ionic compound has the most endothermic lattice enthalpy?

A. Sodium chloride
B. Sodium oxide
C. Magnesium chloride
D. Magnesium oxide

18. Which processes are predicted to have a positive entropy change, \(\Delta S\)?

I. \(\text{I}_2 (g) \rightarrow \text{I}_2 (s)\)
II. \(4\text{NH}_3 (g) + 5\text{O}_2 (g) \rightarrow 4\text{NO} (g) + 6\text{H}_2\text{O} (g)\)
III. \(\text{CH}_3\text{OH} (l) \rightarrow \text{CH}_3\text{OH} (g)\)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
19. Which combination of $\Delta H$ and $\Delta S$ signs will always result in a spontaneous reaction at all temperatures?

<table>
<thead>
<tr>
<th></th>
<th>$\Delta H$</th>
<th>$\Delta S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>B</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>

14. The specific heat capacity of aluminium is $0.900 \text{ J g}^{-1} \text{ K}^{-1}$. What is the heat energy change, in $\text{ J}$, when 10.0 g of aluminium is heated and its temperature increases from 15.0 °C to 35.0 °C?

A. +180
B. +315
C. +1800
D. +2637

15. Enthalpy changes of reaction are provided for the following reactions.

\[
\begin{align*}
2\text{C(s)} + 2\text{H}_2(\text{g}) &\rightarrow \text{C}_2\text{H}_4(\text{g}) & \Delta H^\circ &= +52 \text{ kJ mol}^{-1} \\
2\text{C(s)} + 3\text{H}_2(\text{g}) &\rightarrow \text{C}_2\text{H}_6(\text{g}) & \Delta H^\circ &= -85 \text{ kJ mol}^{-1}
\end{align*}
\]

What is the enthalpy change, in $\text{ kJ mol}^{-1}$, for the reaction between ethene and hydrogen?

\[
\text{C}_2\text{H}_4(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{C}_2\text{H}_6(\text{g})
\]

A. -137
B. -33
C. +33
D. +137

16. Which reaction has an enthalpy change equal to the standard enthalpy change of combustion?

A. $\text{C}_2\text{H}_6(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{g})$
B. $\text{C}_2\text{H}_4(\text{g}) + 5\text{O}_2(\text{g}) \rightarrow 3\text{CO}_2(\text{g}) + 4\text{H}_2\text{O}(\text{l})$
C. $2\text{C}_2\text{H}_4(\text{g}) + 13\text{O}_2(\text{g}) \rightarrow 8\text{CO}_2(\text{g}) + 10\text{H}_2\text{O}(\text{l})$
D. $\text{C}_2\text{H}_6(\text{g}) + 8\text{O}_2(\text{g}) \rightarrow 5\text{CO}_2(\text{g}) + 6\text{H}_2\text{O}(\text{g})$
17. Which reactions/processes have a positive entropy change, $\Delta S^\circ$?

I. $\text{NaCl}(s) \rightarrow \text{NaCl}(aq)$
II. $\text{Na}_2\text{CO}_3(s) + 2\text{HCl}(aq) \rightarrow \text{CO}_2(g) + 2\text{NaCl}(aq) + \text{H}_2\text{O}(l)$
III. $\text{AgNO}_3(aq) + \text{NaCl}(aq) \rightarrow \text{AgCl}(s) + \text{NaNO}_3(aq)$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

18. Which compound has the most positive lattice enthalpy of dissociation?

A. $\text{NaCl}$
B. $\text{NaBr}$
C. $\text{MgCl}_2$
D. $\text{MgBr}_2$

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14. Which statement is correct for the enthalpy level diagram shown?

[Diagram showing an enthalpy level with a peak and a trough]

A. The reaction is exothermic and the products are more stable than the reactants.
B. The reaction is exothermic and the sign of the enthalpy change is positive.
C. The reaction is endothermic and the sign of the enthalpy change is negative.
D. The reaction is endothermic and the products are more stable than the reactants.
15. Which process is endothermic?
   A. \(2C_2H_4(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)\)
   B. \(\text{Na}(g) \rightarrow \text{Na}^+(g) + e^-\)
   C. \(\text{H}_2\text{SO}_4(aq) + 2\text{KOH}(aq) \rightarrow \text{K}_2\text{SO}_4(aq) + 2\text{H}_2\text{O}(l)\)
   D. \(\text{NH}_3(g) \rightarrow \text{NH}_3(l)\)

16. Which combination of ions will give the greatest absolute lattice enthalpy?
   A. A small positive ion with a high charge and a small negative ion with a high charge
   B. A small positive ion with a low charge and a small negative ion with a low charge
   C. A large positive ion with a high charge and a large negative ion with a high charge
   D. A large positive ion with a low charge and a small negative ion with a low charge

17. Which process would be expected to have a \(\Delta S^0\) value which is negative?
   A. \(2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(g)\)
   B. \(\text{NaCl}(s) \rightarrow \text{Na}^+(g) + \text{Cl}^-(g)\)
   C. \(\text{H}_2(g) + \text{I}_2(g) \rightarrow 2\text{HI}(g)\)
   D. \(\text{OF}_2(g) + \text{H}_2\text{O}(g) \rightarrow \text{O}_2(g) + 2\text{HF}(g)\)

18. When solid potassium chlorate, \(\text{KClO}_3\), dissolves in distilled water the temperature of the solution decreases. What are the signs of \(\Delta H^0\), \(\Delta S^0\) and \(\Delta G^0\) for this spontaneous process?

<table>
<thead>
<tr>
<th></th>
<th>(\Delta H^0)</th>
<th>(\Delta S^0)</th>
<th>(\Delta G^0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>B.</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>C.</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>D.</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
</tbody>
</table>
14. A 5.00 g sample of a substance was heated from 25.0 °C to 35.0 °C using $2.00 \times 10^3$ J of energy. What is the specific heat capacity of the substance in J g$^{-1}$ K$^{-1}$?

A. $4.00 \times 10^{-3}$

B. $2.50 \times 10^{-1}$

C. 2.00

D. 4.00

15. Using the equations below:

$$\text{C (s)} + \text{O}_2 (g) \rightarrow \text{CO}_2 (g) \quad \Delta H^\circ = -390 \text{ kJ}$$
$$\text{H}_2 (g) + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{H}_2\text{O} (l) \quad \Delta H^\circ = -286 \text{ kJ}$$
$$\text{CH}_4 (g) + 2\text{O}_2 (g) \rightarrow \text{CO}_2 (g) + 2\text{H}_2\text{O} (l) \quad \Delta H^\circ = -890 \text{ kJ}$$

What is $\Delta H^\circ$, in kJ, for the following reaction?

$$\text{C (s)} + 2\text{H}_2 (g) \rightarrow \text{CH}_4 (g)$$

A. −214

B. −72

C. +72

D. +214

16. Which is the best definition of electron affinity?

A. The ability of an atom to attract the electrons in a covalent bond.

B. The attraction of an atom for an electron.

C. The enthalpy change when an atom gains an electron.

D. The enthalpy change when a gaseous atom gains an electron.
17. Which is the best definition of the standard state?

A. The standard state of a solid is the most pure form of the solid.
B. The standard state of a solid is the most pure form of the solid at 298 °C.
C. The standard state of a gas is the most pure form of the gas at 298 °C.
D. The standard state of a gas is the most pure form of the gas at a pressure of 100 kPa.

18. Consider the following information:

\[ \text{CaCO}_3(s) \rightarrow \text{CaO}(s) + \text{CO}_2(g) \]
\[ \Delta H = +179 \text{ kJ mol}^{-1} \]
\[ \Delta S = +161.0 \text{ J K}^{-1} \text{mol}^{-1} \]

What happens to the spontaneity of this reaction as the temperature is increased?

A. The reaction becomes more spontaneous as the temperature is increased.
B. The reaction becomes less spontaneous as the temperature is increased.
C. The reaction remains spontaneous at all temperatures.
D. The reaction remains non-spontaneous at all temperatures.

15. Which reactions are exothermic?

I. \( \text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(l) \)
II. Reaction of aspirin with sodium hydroxide

III. \( 2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(g) \)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

Aspirin
16. Which equation represents the electron affinity of chlorine?
   A. Cl(g) + e\(^-\) → Cl\(^-\) (g)
   B. Cl(g) + e\(^-\) → Cl\(^+\) (g)
   C. Cl\(_2\) (g) + 2e\(^-\) → 2Cl\(^-\) (g)
   D. Cl(g) → Cl\(^+\) (g) + e\(^-\)

17. During which process is there a decrease in the entropy of the system?
   A. Ag(s) + 2H\(^+\)(aq) + NO\(_3\)\(^-\)(aq) → Ag\(^+\)(aq) + H\(_2\)O(l) + NO\(_2\) (g)
   B. Ba(OH)\(_2\) (s) → BaO(s) + H\(_2\)O(g)
   C. PCl\(_3\) (g) + Cl\(_2\) (g) → PCl\(_5\) (g)
   D. H\(_2\)O(s) → H\(_2\)O (l)

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14. What are the units for specific heat capacity?
   A. kJ kg K
   B. kJ kg K\(^-1\)
   C. kJ kg\(^-1\) K
   D. kJ kg\(^-1\) K\(^-1\)
15. In each of two different experiments, A and B, a solution of sodium hydroxide is added to a solution of hydrochloric acid. The initial temperature of each solution is 25°C.

Experiment A

50 cm³ 1.0 mol dm⁻³ NaOH(aq)

50 cm³ 1.0 mol dm⁻³ HCl(aq)

Experiment B

50 cm³ 1.0 mol dm⁻³ NaOH(aq)

100 cm³ 1.0 mol dm⁻³ HCl(aq)

Which statement is correct?

A. The highest recorded temperature of experiment A is lower than the highest recorded temperature of experiment B.

B. The highest recorded temperature of both experiments is equal.

C. The heat produced in experiment A is lower than the heat produced in experiment B.

D. The heat produced in both experiments is equal.
16. The diagram represents the Born–Haber cycle for the lattice enthalpy of sodium chloride.

What is the name of the enthalpy changes I, II and III?

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>ionization energy of Na</td>
<td>electron affinity of Cl</td>
<td>lattice enthalpy of NaCl</td>
</tr>
<tr>
<td>B.</td>
<td>lattice enthalpy of NaCl</td>
<td>ionization energy of Na</td>
<td>electron affinity of Cl</td>
</tr>
<tr>
<td>C.</td>
<td>electron affinity of Cl</td>
<td>ionization energy of Na</td>
<td>lattice enthalpy of NaCl</td>
</tr>
<tr>
<td>D.</td>
<td>ionization energy of Na</td>
<td>lattice enthalpy of NaCl</td>
<td>electron affinity of Cl</td>
</tr>
</tbody>
</table>

17. Which statements about entropy for the following reaction at 298 K are correct?

\[ 2\text{NO}(g) + \text{O}_2(g) \rightarrow 2\text{NO}_2(g) \]

I. \[ S^\circ (\text{O}_2) = 0 \]
II. \[ \Delta S^\circ = 2S^\circ (\text{NO}_2) - 2S^\circ (\text{NO}) - S^\circ (\text{O}_2) \]
III. \[ \Delta S^\circ < 0 \]

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
18. Which reaction is spontaneous at high temperatures, but not at low temperatures?

A. \[ \text{CH}_4(\text{g}) + 2\text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{g}) \quad \Delta H < 0 \]

B. \[ \text{CaCO}_3(\text{s}) \rightarrow \text{CO}_2(\text{g}) + \text{CaO}(\text{s}) \quad \Delta H > 0 \]

C. \[ \text{Fe}(\text{s}) + \text{Cl}_2(\text{g}) \rightarrow \text{FeCl}_2(\text{s}) \quad \Delta H < 0 \]

D. \[ 2\text{C}(\text{s}) + 2\text{H}_2\text{O}(\text{g}) \rightarrow \text{CH}_3\text{COOH}(\text{l}) \quad \Delta H > 0 \]

10. Which bonds are arranged in order of increasing polarity?

A. \[ \text{H–F} < \text{H–Cl} < \text{H–Br} < \text{H–I} \]

B. \[ \text{H–I} < \text{H–Br} < \text{H–F} < \text{H–Cl} \]

C. \[ \text{H–I} < \text{H–Br} < \text{H–Cl} < \text{H–F} \]

D. \[ \text{H–Br} < \text{H–I} < \text{H–Cl} < \text{H–F} \]

11. Which row correctly describes the bonding type and melting point of carbon and carbon dioxide?

<table>
<thead>
<tr>
<th></th>
<th>Carbon</th>
<th>Carbon dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>covalent bonding</td>
<td>high melting point</td>
</tr>
<tr>
<td>B.</td>
<td>ionic bonding</td>
<td>low melting point</td>
</tr>
<tr>
<td>C.</td>
<td>ionic bonding</td>
<td>high melting point</td>
</tr>
<tr>
<td>D.</td>
<td>covalent bonding</td>
<td>low melting point</td>
</tr>
</tbody>
</table>
12. What is the correct order of increasing boiling points?

A. \( \text{CH}_3\text{CH}_3 < \text{CH}_3\text{CH}_2\text{Cl} < \text{CH}_3\text{CH}_2\text{Br} < \text{CH}_3\text{CH}_2\text{I} \)
B. \( \text{CH}_3\text{CH}_2\text{Cl} < \text{CH}_3\text{CH}_2\text{Br} < \text{CH}_3\text{CH}_3 < \text{CH}_3\text{CH}_2\text{I} \)
C. \( \text{CH}_3\text{CH}_2\text{I} < \text{CH}_3\text{CH}_2\text{Br} < \text{CH}_3\text{CH}_2\text{Cl} < \text{CH}_3\text{CH}_3 \)
D. \( \text{CH}_3\text{CH}_2\text{Br} < \text{CH}_3\text{CH}_2\text{Cl} < \text{CH}_3\text{CH}_2\text{I} < \text{CH}_3\text{CH}_3 \)

13. What are the correct formulas of the following ions?

<table>
<thead>
<tr>
<th>Nitrate</th>
<th>Phosphate</th>
<th>Carbonate</th>
<th>Ammonium</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ( \text{NO}_3^- )</td>
<td>( \text{PO}_4^{3-} )</td>
<td>( \text{CO}_3^- )</td>
<td>( \text{NH}_4^+ )</td>
</tr>
<tr>
<td>B. ( \text{NO}_3^{2-} )</td>
<td>( \text{PO}_3^{2-} )</td>
<td>( \text{CO}_3^{2-} )</td>
<td>( \text{NH}_3^+ )</td>
</tr>
<tr>
<td>C. ( \text{NO}_3^- )</td>
<td>( \text{PO}_4^{3-} )</td>
<td>( \text{CO}_3^{2-} )</td>
<td>( \text{NH}_4^+ )</td>
</tr>
<tr>
<td>D. ( \text{NO}_3^{2-} )</td>
<td>( \text{PO}_3^{2-} )</td>
<td>( \text{CO}_3^{2-} )</td>
<td>( \text{NH}_4^+ )</td>
</tr>
</tbody>
</table>

14. Which statements about hybridization are correct?

I. The hybridization of carbon in diamond is \( \text{sp}^3 \).
II. The hybridization of carbon in graphite is \( \text{sp}^2 \).
III. The hybridization of carbon in \( \text{C}_{60} \) fullerene is \( \text{sp}^3 \).

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
15. A student measured the temperature of a reaction mixture over time using a temperature probe. By considering the graph, which of the following deductions can be made?

I. The reaction is exothermic.
II. The products are more stable than the reactants.
III. The reactant bonds are stronger than the product bonds.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

16. Consider the following enthalpy of combustion data.

\[
\begin{align*}
C(s) + O_2(g) &\rightarrow CO_2(g) & \Delta H^\circ &= -x \text{ kJ mol}^{-1} \\
H_2(g) + \frac{1}{2} O_2(g) &\rightarrow H_2O(l) & \Delta H^\circ &= -y \text{ kJ mol}^{-1} \\
C_2H_6(g) + 3\frac{1}{2} O_2(g) &\rightarrow 2CO_2(g) + 3H_2O(l) & \Delta H^\circ &= -z \text{ kJ mol}^{-1}
\end{align*}
\]

What is the enthalpy of formation of ethane in kJ mol\(^{-1}\)?

\[
2C(s) + 3H_2(g) \rightarrow C_2H_6(g)
\]

A. \([(-x) + (-y)] - (-z)\)
B. \((-z) - [(-x) + (-y)]\)
C. \([(-2x) + (-3y)] - (-z)\)
D. \((-z) - [(-2x) + (-3y)]\)
17. Which row of the table correctly represents the equations for the lattice enthalpy of substance XY and the electron affinity of atom Y?

<table>
<thead>
<tr>
<th>Lattice enthalpy</th>
<th>Electron affinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. $X^+(g) + Y^-(g) \rightarrow XY(g)$</td>
<td>$Y^-(g) + e^- \rightarrow Y^{2-}(g)$</td>
</tr>
<tr>
<td>B. $X^+(g) + Y^-(g) \rightarrow XY(s)$</td>
<td>$Y(g) + e^- \rightarrow Y^-(g)$</td>
</tr>
<tr>
<td>C. $X^-(g) + Y^-(g) \rightarrow XY(s)$</td>
<td>$Y(s) + e^- \rightarrow Y^-(s)$</td>
</tr>
<tr>
<td>D. $X^+(g) + Y^-(g) \rightarrow XY(g)$</td>
<td>$Y(g) + e^- \rightarrow Y^-(g)$</td>
</tr>
</tbody>
</table>

18. Which factors will increase the entropy of this system?

$$\text{CaCO}_3(s) \rightleftharpoons \text{CaO}(s) + \text{CO}_2(g)$$

I. Increasing the temperature without changing the volume of the container.
II. Decreasing the concentration of the gas without changing the volume of the container.
III. Increasing the pressure without changing the volume of the container.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
16. Which ionic compound has the greatest lattice enthalpy?
   A. MgO
   B. CaO
   C. NaF
   D. KF

17. Which equation represents the bond enthalpy for the H–Br bond in hydrogen bromide?
   A. HBr (g) → H (g) + Br (g)
   B. HBr (g) → H (g) + Br (l)
   C. HBr (g) → H(g) + ½ Br₂ (l)
   D. HBr (g) → H (g) + ½ Br₂ (g)

18. Which change will not increase the entropy of a system?
   A. Increasing the temperature
   B. Changing the state from liquid to gas
   C. Mixing different types of particles
   D. A reaction where four moles of gaseous reactants changes to two moles of gaseous products

19. $\Delta G^\circ$ calculations predict that a reaction is always spontaneous for which of the following combinations of $\Delta H^\circ$ and $\Delta S^\circ$?
   A. $+\Delta H^\circ$ and $+\Delta S^\circ$
   B. $+\Delta H^\circ$ and $-\Delta S^\circ$
   C. $-\Delta H^\circ$ and $-\Delta S^\circ$
   D. $-\Delta H^\circ$ and $+\Delta S^\circ$
15. When hydrogen peroxide decomposes, the temperature of the reaction mixture increases.

\[ 2\text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{O}_3(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

What are the signs of \( \Delta H \), \( \Delta S \) and \( \Delta G \) for this reaction?

<table>
<thead>
<tr>
<th></th>
<th>( \Delta H )</th>
<th>( \Delta S )</th>
<th>( \Delta G )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

16. Which reaction has the greatest increase in entropy?

A. \( \text{SO}_2(\text{g}) + 2\text{H}_2\text{S}(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) + 3\text{S}(\text{s}) \)

B. \( \text{CaO}(\text{s}) + \text{CO}_2(\text{g}) \rightarrow \text{CaCO}_3(\text{s}) \)

C. \( \text{CaC}_2(\text{s}) + 2\text{H}_2\text{O}(\text{l}) \rightarrow \text{Ca(OH)}_2(\text{s}) + \text{C}_2\text{H}_2(\text{g}) \)

D. \( \text{N}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}(\text{g}) \)

17. Consider the two reactions involving iron and oxygen.

\[ 2\text{Fe}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{FeO}(\text{s}) \quad \Delta H^\circ = -544 \text{ kJ} \]

\[ 4\text{Fe}(\text{s}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{Fe}_2\text{O}_3(\text{s}) \quad \Delta H^\circ = -1648 \text{ kJ} \]

What is the enthalpy change, in kJ, for the reaction below?

\[ 4\text{FeO}(\text{s}) + \text{O}_2(\text{g}) \rightarrow 2\text{Fe}_2\text{O}_3(\text{s}) \]

A. \(-1648 - 2(-544)\)

B. \(-544 - (-1648)\)

C. \(-1648 - 544\)

D. \(-1648 - 2(544)\)
18. Which statement about bonding is correct?
   
   A. Bond breaking is endothermic and requires energy.
   
   B. Bond breaking is endothermic and releases energy.
   
   C. Bond making is exothermic and requires energy.
   
   D. Bond making is endothermic and releases energy.

19. Which equation corresponds to the lattice enthalpy for silver iodide, AgI?
   
   A. \( \text{AgI}(s) \rightarrow \text{Ag}(s) + \text{I}(g) \)
   
   B. \( \text{AgI}(s) \rightarrow \text{Ag}(s) + \frac{1}{2} \text{I}_2(g) \)
   
   C. \( \text{AgI}(s) \rightarrow \text{Ag}^+(aq) + \text{I}^-(aq) \)
   
   D. \( \text{AgI}(s) \rightarrow \text{Ag}^+(g) + \text{I}^-(g) \)

14. Identical pieces of magnesium are added to two beakers, A and B, containing hydrochloric acid. Both acids have the same initial temperature but their volumes and concentrations differ.

   Which statement is correct?
   
   A. The maximum temperature in A will be higher than in B.
   
   B. The maximum temperature in A and B will be equal.
   
   C. It is not possible to predict whether A or B will have the higher maximum temperature.
   
   D. The temperature in A and B will increase at the same rate.
15. Consider the equations below.

\[ \text{CH}_2(g) + \text{O}_2(g) \rightarrow \text{HCHO} (l) + \text{H}_2\text{O} (l) \quad \Delta H^\circ = x \]

\[ \text{HCHO} (l) + \frac{1}{2} \text{O}_2 (g) \rightarrow \text{HCOOH} (l) \quad \Delta H^\circ = y \]

\[ 2\text{HCOOH} (l) + \frac{1}{2} \text{O}_2 (g) \rightarrow (\text{COOH})_2 (s) + \text{H}_2\text{O} (l) \quad \Delta H^\circ = z \]

What is the enthalpy change of the reaction below?

\[ 2\text{CH}_4(g) + 3 \frac{1}{2} \text{O}_2(g) \rightarrow (\text{COOH})_2 (s) + 3\text{H}_2\text{O} (l) \]

A. \( x + y + z \)
B. \( 2x + y + z \)
C. \( 2x + 2y + z \)
D. \( 2x + 2y + 2z \)

16. Given the enthalpy change for the reaction below:

\[ 2\text{H}_2(g) + \text{O}_3(g) \rightarrow 2\text{H}_2\text{O} (l) \quad \Delta H^\circ = -572 \text{ kJ} \]

which statement is correct?

A. The standard enthalpy change of combustion of \( \text{H}_2(g) \) is \(-286 \text{ kJ mol}^{-1}\).
B. The standard enthalpy change of combustion of \( \text{H}_2(g) \) is \(+286 \text{ kJ mol}^{-1}\).
C. The standard enthalpy change of formation of \( \text{H}_2\text{O}(l) \) is \(-572 \text{ kJ mol}^{-1}\).
D. The standard enthalpy change of formation of \( \text{H}_2\text{O}(l) \) is \(+572 \text{ kJ mol}^{-1}\).

17. Which is a correct definition of lattice enthalpy?

A. It is the enthalpy change that occurs when an electron is removed from 1 mol of gaseous atoms.
B. It is the enthalpy change that occurs when 1 mol of a compound is formed from its elements.
C. It is the enthalpy change that occurs when 1 mol of solid crystal changes into a liquid.
D. It is the enthalpy change that occurs when 1 mol of solid crystal is formed from its gaseous ions.
18. Which reaction has the largest increase in entropy?
   A. $\text{H}_2(g) + \text{Cl}_2(g) \rightarrow 2\text{HCl}(g)$
   B. $\text{Al(OH)}_3(s) + \text{NaOH}(aq) \rightarrow \text{Al(OH)}_4^-(aq) + \text{Na}^+(aq)$
   C. $\text{Na}_2\text{CO}_3(s) + 2\text{HCl}(aq) \rightarrow 2\text{NaCl}(aq) + \text{CO}_2(g) + \text{H}_2\text{O}(l)$
   D. $\text{BaCl}_2(aq) + \text{Na}_2\text{SO}_4(aq) \rightarrow \text{BaSO}_4(s) + 2\text{NaCl}(aq)$

14. Which processes are exothermic?
   I. Ice melting
   II. Neutralization
   III. Combustion
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

15. The standard enthalpy changes for the combustion of carbon and carbon monoxide are shown below.

   $\text{C(s)} + \frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) \quad \Delta H_{\text{c}}^{\circ} = -394 \text{ kJ mol}^{-1}$

   $\text{CO}_2(g) + \frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}_2(g) \quad \Delta H_{\text{c}}^{\circ} = -283 \text{ kJ mol}^{-1}$

   What is the standard enthalpy change, in kJ, for the following reaction?

   $\text{C(s)} + \frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}(g)$

   A. $-677$
   B. $-111$
   C. $+111$
   D. $+677$
16. Which reaction has the most negative change in entropy?

A. \( 2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{SO}_3(\text{g}) \)

B. \( \text{NH}_4\text{Cl}(s) \rightarrow \text{NH}_3(\text{g}) + \text{HCl}(\text{g}) \)

C. \( \text{PbCl}_2(s) \rightarrow \text{Pb}^{2+}(\text{aq}) + 2\text{Cl}^-(\text{aq}) \)

D. \( \text{C}(s) + \text{O}_2(\text{g}) \rightarrow \text{CO}_2(\text{g}) \)

17. What is the standard free energy change, \( \Delta G^\circ \), in kJ, for the following reaction?

\[
\text{C}_2\text{H}_5\text{OH}(l) + 3\text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) + 3\text{H}_2\text{O}(\text{g})
\]

<table>
<thead>
<tr>
<th>Compound</th>
<th>( \Delta G^\circ ) / kJ mol(^{-1} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{C}_2\text{H}_5\text{OH}(l) )</td>
<td>-175</td>
</tr>
<tr>
<td>( \text{CO}_2(\text{g}) )</td>
<td>-394</td>
</tr>
<tr>
<td>( \text{H}_2\text{O}(\text{g}) )</td>
<td>-229</td>
</tr>
<tr>
<td>( \text{O}_2(\text{g}) )</td>
<td>0</td>
</tr>
</tbody>
</table>

A. -1650

B. -1300

C. -448

D. +1300

19. Consider the endothermic reaction below.

\[
5\text{CO}(\text{g}) + \text{I}_2\text{O}_3(\text{g}) \rightleftharpoons 5\text{CO}_2(\text{g}) + \text{I}_2(\text{g})
\]

According to Le Chatelier's principle, which change would result in an increase in the amount of \( \text{CO}_2 \)?

A. Increasing the temperature

B. Decreasing the temperature

C. Increasing the pressure

D. Decreasing the pressure
20. Which combination of ionic radius and ionic charge would result in the highest lattice enthalpy for an ionic compound?

<table>
<thead>
<tr>
<th>Ionic radius</th>
<th>Ionic charge</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. small</td>
<td>high</td>
</tr>
<tr>
<td>B. large</td>
<td>high</td>
</tr>
<tr>
<td>C. small</td>
<td>low</td>
</tr>
<tr>
<td>D. large</td>
<td>low</td>
</tr>
</tbody>
</table>

15. Which types of reaction are always exothermic?

I. Neutralization
II. Decomposition
III. Combustion

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

16. Which reaction has an enthalpy change equal to a standard enthalpy change of formation, $\Delta H_f^{\circ}$? All reactions occur at 298 K and 1.01×10^5 Pa.

A. $\text{C}_4\text{H}_4(g) + \text{H}_2\text{O}(g) \rightarrow \text{C}_4\text{H}_9\text{OH}(l)$
B. $4\text{CO}_2(g) + 5\text{H}_2\text{O}(g) \rightarrow 4\text{C}_4\text{H}_9\text{OH}(l) + \frac{11}{2}\text{O}_2(g)$
C. $4\text{C}(s) + 5\text{H}_2(g) + \frac{1}{2}\text{O}_2(g) \rightarrow 4\text{C}_4\text{H}_9\text{OH}(l)$
D. $8\text{C}(s) + 10\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{C}_4\text{H}_9\text{OH}(l)$

17. Which process has an enthalpy change that represents the lattice enthalpy of sodium chloride?

A. $\text{NaCl}(s) \rightarrow \text{Na}^+(g) + \text{Cl}^-(g)$
B. $\text{NaCl}(s) \rightarrow \text{Na}(s) + \frac{1}{2}\text{Cl}_2(g)$
C. $\text{NaCl}(g) \rightarrow \text{Na}^+(g) + \text{Cl}^-(g)$
D. $\text{NaCl}(s) \rightarrow \text{Na}(s) + \text{Cl}(g)$
18. Which is the correct order of increasing magnitude of lattice enthalpy (lowest first)?

A. NaCl < KCl < MgS < MgO
B. MgO < MgS < KCl < NaCl
C. KCl < NaCl < MgS < MgO
D. MgO < NaCl < KCl < MgS

15. In a reaction that occurs in 50 g of aqueous solution, the temperature of the reaction mixture increases by 20°C. If 0.10 mol of the limiting reagent is consumed, what is the enthalpy change (in kJ mol⁻¹) for the reaction? Assume the specific heat capacity of the solution = 4.2 kJ kg⁻¹ K⁻¹.

A. \(-0.10 \times 50 \times 4.2 \times 20\)
B. \(-0.10 \times 0.050 \times 4.2 \times 20\)
C. \(\frac{-50 \times 4.2 \times 20}{0.10}\)
D. \(\frac{-0.050 \times 4.2 \times 20}{0.10}\)

16. Use the average bond enthalpies below to calculate the enthalpy change, in kJ, for the following reaction.

\[ \text{H}_2(g) + \text{I}_2(g) \rightarrow 2\text{HI}(g) \]

<table>
<thead>
<tr>
<th>Bond</th>
<th>Bond energy / kJ mol⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>H–H</td>
<td>440</td>
</tr>
<tr>
<td>I–I</td>
<td>150</td>
</tr>
<tr>
<td>H–I</td>
<td>300</td>
</tr>
</tbody>
</table>

A. +290
B. +10
C. -10
D. -290
17. Which ionic compound has the most endothermic lattice enthalpy?
   A. NaCl
   B. KCl
   C. NaF
   D. KF

18. Which change leads to an increase in entropy?
   A. $\text{CO}_2(g) \rightarrow \text{CO}_2(s)$
   B. $\text{SF}_6(g) \rightarrow \text{SF}_6(l)$
   C. $\text{H}_2\text{O}(l) \rightarrow \text{H}_2\text{O}(s)$
   D. $\text{NaCl}(s) \rightarrow \text{NaCl}(aq)$

16. What is the energy, in kJ, released when 1.00 mol of carbon monoxide is burned according to the following equation?

$$2\text{CO}(g) + \text{O}_2(g) \rightarrow 2\text{CO}_2(g) \quad \Delta H^\circ = -564 \text{ kJ}$$

   A. 141
   B. 282
   C. 564
   D. 1128

17. The specific heat of iron is 0.450 J g$^{-1}$ K$^{-1}$. What is the energy, in J, needed to increase the temperature of 50.0 g of iron by 20.0 K?

   A. 9.00
   B. 22.5
   C. 45.0
   D. 450
18. What is the standard entropy change, \( \Delta S^\circ \), for the following reaction?

\[
2\text{CO}(g) + \text{O}_2(g) \rightarrow 2\text{CO}_2(g)
\]

<table>
<thead>
<tr>
<th>( \Delta S^\circ / \text{J K}^{-1} \text{ mol}^{-1} )</th>
<th>CO(g)</th>
<th>O(_2)(g)</th>
<th>CO(_2)(g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>198</td>
<td>205</td>
<td>214</td>
<td></td>
</tr>
</tbody>
</table>

A. \(-189\)
B. \(-173\)
C. \(+173\)
D. \(+189\)

19. Which step(s) is/are endothermic in the Born-Haber cycle for the formation of LiCl?

A. \( \frac{1}{2} \text{Cl}_2(g) \rightarrow \text{Cl}(g) \) and \( \text{Li}(s) \rightarrow \text{Li}(g) \)
B. \( \text{Cl}(g) + e^- \rightarrow \text{Cl}^- (g) \) and \( \text{Li}(g) \rightarrow \text{Li}^+(g) + e^- \)
C. \( \text{Li}^+(g) + \text{Cl}^-(g) \rightarrow \text{LiCl}(s) \)
D. \( \frac{1}{2} \text{Cl}_2(g) \rightarrow \text{Cl}(g) \) and \( \text{Cl}(g) + e^- \rightarrow \text{Cl}^- (g) \)

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14. 1.0 g of sodium hydroxide, NaOH, was added to 99.0 g of water. The temperature of the solution increased from 18.0°C to 20.5°C. The specific heat capacity of the solution is 4.18 J g\(^{-1}\) K\(^{-1}\). Which expression gives the heat evolved in kJ mol\(^{-1}\)?

A. \[
\frac{2.5 \times 100.0 \times 4.18 \times 1000}{40.0}
\]
B. \[
\frac{2.5 \times 100.0 \times 4.18}{1000 \times 40.0}
\]
C. \[
\frac{2.5 \times 100.0 \times 4.18 \times 40.0}{1000}
\]
D. \[
\frac{2.5 \times 1.0 \times 4.18 \times 40.0}{1000}
\]
15. Which process represents the C–Cl bond enthalpy in tetrachloromethane?

A. \( \text{CCl}_4(g) \rightarrow \text{C}(g) + 4\text{Cl}(g) \)

B. \( \text{CCl}_4(g) \rightarrow \text{CCl}_3(g) + \text{Cl}(g) \)

C. \( \text{CCl}_4(l) \rightarrow \text{C}(g) + 4\text{Cl}(g) \)

D. \( \text{CCl}_4(l) \rightarrow \text{C}(s) + 2\text{Cl}_2(g) \)

16. Which reaction has the greatest increase in entropy?

A. \( \text{C}_2\text{H}_4(g)+5\text{O}_2(g) \rightarrow 3\text{CO}_2(g)+4\text{H}_2\text{O}(g) \)

B. \( \text{H}_2(g)+\text{Cl}_2(g) \rightarrow 2\text{HCl}(g) \)

C. \( \text{N}_2(g)+3\text{H}_2(g) \rightarrow 2\text{NH}_3(g) \)

D. \( \text{C}_2\text{H}_4(g)+\text{H}_2(g) \rightarrow \text{C}_2\text{H}_6(g) \)

17. The reaction between but-1-ene and water vapour produces butan-1-ol.

\[ \text{C}_4\text{H}_8(g) + \text{H}_2\text{O}(g) \rightarrow \text{C}_4\text{H}_9\text{OH}(l) \]

The standard entropy values \( (\Delta S^\circ) \) for but-1-ene, water vapour and butan-1-ol are 310, 189 and 228 J K\(^{-1}\) mol\(^{-1}\) respectively. What is the standard entropy change for this reaction in J K\(^{-1}\) mol\(^{-1}\)?

A. +271

B. +271

C. −107

D. +107

18. A reaction has a standard enthalpy change, \( \Delta H^\circ \), of +10.00 kJ mol\(^{-1}\) at 298 K. The standard entropy change, \( \Delta S^\circ \), for the same reaction is +10.00 J K\(^{-1}\) mol\(^{-1}\). What is the value of \( \Delta G^\circ \) for the reaction in kJ mol\(^{-1}\)?

A. +9.75

B. +7.02

C. −240

D. −2970
16. 75 cm$^3$ of an unknown gas has a mass of 0.18 g at a temperature of 25°C and a pressure of 1 atm. Which is the correct expression for the molar mass, $M$, in g mol$^{-1}$ of the gas? ($R = 8.3\text{ J K}^{-1}\text{ mol}^{-1}$, 1 atm = $1.01\times10^5\text{ Pa}$)

A. $M = \frac{0.18 \times 8.3 \times 25}{1 \times 75}$

B. $M = \frac{75 \times 10^{-5} \times 8.3 \times 25}{1.01 \times 10^5 \times 298}$

C. $M = \frac{0.18 \times 8.3 \times 298}{1.01 \times 10^5 \times 75 \times 10^{-6}}$

D. $M = \frac{1.01 \times 10^5 \times 75 \times 10^{-6}}{0.18 \times 8.3 \times 298}$

17. The average bond enthalpy for the C–H bond is 412 kJ mol$^{-1}$. Which process has an enthalpy change closest to this value?

A. CH$_4$(g) $\rightarrow$ C(s) + 2H$_2$(g)

B. CH$_4$(g) $\rightarrow$ C(g) + 2H$_2$(g)

C. CH$_4$(g) $\rightarrow$ C(g) + 4H(g)

D. CH$_4$(g) $\rightarrow$ CH$_3$(g) + H(g)

18. A reaction has a positive $\Delta H^\circ$ and a negative $\Delta S^\circ$ value. Which statement about this reaction is correct?

A. It is not spontaneous at any temperature.

B. It is spontaneous at all temperatures.

C. It is spontaneous only at low temperatures.

D. It is spontaneous only at high temperatures.
19. When 50 cm$^3$ of 1.0 mol dm$^{-3}$ nitric acid solution, HNO$_3$(aq), is added to 50 cm$^3$ of 1.0 mol dm$^{-3}$ potassium hydroxide solution, KOH(aq), the temperature of the mixture increases by 6.4°C. What will be the temperature change when 25 cm$^3$ of each of these solutions are mixed together?

A. 1.6°C  
B. 3.2°C  
C. 6.4°C  
D. 12.8°C

20. Which features of a positive ion lead to a higher lattice enthalpy in its compounds?

I. A higher charge on the ion  
II. A smaller ionic radius  
III. A lower first ionization energy of the metal to form the ion

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III

21. This reaction was used in flash photography:

$$3\text{Mg}(s) + \text{KClO}_3(s) \rightarrow 3\text{MgO}(s) + \text{KCl}(s)$$

Relevant enthalpy changes of formation values are shown below.

<table>
<thead>
<tr>
<th>Compound</th>
<th>$\Delta H^\circ / \text{kJ mol}^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KClO$_3$(s)</td>
<td>$-391$</td>
</tr>
<tr>
<td>MgO(s)</td>
<td>$-602$</td>
</tr>
<tr>
<td>KCl(s)</td>
<td>$-437$</td>
</tr>
</tbody>
</table>

What is the enthalpy change, in kJ, of this reaction?

A. $-1852$  
B. $-648$  
C. $+740$  
D. $+1760$
16. A gas sample occupies a volume $V_1$ at a pressure $P_1$ and a Kelvin temperature $T_1$. What would be the temperature of the gas, $T_2$, if both its pressure and volume are doubled?

- A. $T_2 = \frac{1}{2}T_1$
- B. $T_2 = T_1$
- C. $T_2 = 2T_1$
- D. $T_2 = 4T_1$

17. A possible method of preparing hydrogen peroxide is:

$$\text{H}_2\text{(g)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{H}_2\text{O}\text{(l)} \quad \Delta H^\circ = x$$

$$\text{H}_2\text{O}\text{(l)} + \frac{1}{2}\text{O}_2\text{(g)} \rightarrow \text{H}_2\text{O}_2\text{(l)} \quad \Delta H^\circ = y$$

Which expression can be used to calculate the enthalpy change for the decomposition of hydrogen peroxide using this data?

$$\text{H}_2\text{O}_2\text{(l)} \rightarrow \text{H}_2\text{(g)} + \text{O}_2\text{(g)}$$

- A. $-x - y$
- B. $x + y$
- C. $-x + y$
- D. $x - y$

18. Which of the following is correct about the energy changes during bond breaking and bond formation?

<table>
<thead>
<tr>
<th>Bond breaking</th>
<th>Bond formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. exothermic</td>
<td>endothermic</td>
</tr>
<tr>
<td>B. exothermic</td>
<td>endothermic</td>
</tr>
<tr>
<td>C. endothermic</td>
<td>endothermic</td>
</tr>
<tr>
<td>D. endothermic</td>
<td>exothermic</td>
</tr>
</tbody>
</table>

19. What should be the signs of $\Delta G$, $\Delta H$ and $\Delta S$ for a chemical reaction to be spontaneous at any temperature?

<table>
<thead>
<tr>
<th></th>
<th>$\Delta G$</th>
<th>$\Delta H$</th>
<th>$\Delta S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>positive</td>
<td>negative</td>
<td>positive</td>
</tr>
<tr>
<td>B.</td>
<td>negative</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>C.</td>
<td>negative</td>
<td>negative</td>
<td>positive</td>
</tr>
<tr>
<td>D.</td>
<td>negative</td>
<td>positive</td>
<td>negative</td>
</tr>
</tbody>
</table>
20. Which compound has the highest lattice enthalpy?
   A. CaO
   B. CaS
   C. LiF
   D. LiF

21. The standard free energy changes of formation of some compounds are shown in the table:

<table>
<thead>
<tr>
<th>Compound</th>
<th>MgO(s)</th>
<th>H₂O(l)</th>
<th>Mg(OH)₂(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔG°_f / kJ mol⁻¹</td>
<td>-570</td>
<td>-237</td>
<td>-834</td>
</tr>
</tbody>
</table>

Which statement is correct about the following reaction?

MgO(s) + H₂O(l) → Mg(OH)₂(s)

A. The reaction is spontaneous and ΔG° = +27 kJ mol⁻¹.
B. The reaction is not spontaneous and ΔG° = +27 kJ mol⁻¹.
C. The reaction is spontaneous and ΔG° = -27 kJ mol⁻¹.
D. The reaction is not spontaneous and ΔG° = -27 kJ mol⁻¹.

16. Which change does not lead to an increase in entropy?

A. Mixing nitrogen and oxygen gases at room temperature
B. Cooling steam so that it condenses to water
C. Heating hexane to its boiling point
D. Dissolving sugar in water
17. The enthalpy changes for two reactions are shown below.

\[
S(s) + O_2(g) \rightarrow SO_2(g) \quad \Delta H^\circ = -300 \text{ kJ} \\
2S(s) + 3O_2(g) \rightarrow 2SO_3(g) \quad \Delta H^\circ = -800 \text{ kJ}
\]

What is the enthalpy change for this reaction in kJ?

\[
2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)
\]

A. −200 
B. −500 
C. −1100 
D. −1400 

18. Which process is exothermic?

A. \( \text{Na}(s) \rightarrow \text{Na}(g) \) 
B. \( \text{Ca} (g) \rightarrow \text{Ca}^+(g) + e^- \) 
C. \( \text{Br}(g) + e^- \rightarrow \text{Br}^-(g) \) 
D. \( \text{I}_2 (g) \rightarrow 2\text{I}(g) \) 

19. Which equation represents the standard enthalpy of formation of calcium fluoride?

A. \( \text{Ca} (g) + \text{F}_2 (g) \rightarrow \text{CaF}_2 (g) \) 
B. \( \text{Ca} (s) + \text{F}_2 (g) \rightarrow \text{CaF}_2 (s) \) 
C. \( \text{Ca}^{2+}(g) + 2\text{F}^-(g) \rightarrow \text{CaF}_2 (s) \) 
D. \( \text{Ca}^{2+}(s) + 2\text{F}^-(g) \rightarrow \text{CaF}_2 (s) \)
20. 25 cm$^3$ of 1.0 mol dm$^{-3}$ NaOH is added to 25 cm$^3$ of 1.0 mol dm$^{-3}$ HCl. The temperature rise is 6°C. Which reactants will also give a temperature rise of 6°C?

A. 25 cm$^3$ of 2.0 mol dm$^{-3}$ NaOH and 25 cm$^3$ of 2.0 mol dm$^{-3}$ HCl.
B. 50 cm$^3$ of 1.0 mol dm$^{-3}$ NaOH and 50 cm$^3$ of 1.0 mol dm$^{-3}$ HCl.
C. 50 cm$^3$ of 0.5 mol dm$^{-3}$ NaOH and 50 cm$^3$ of 0.5 mol dm$^{-3}$ HCl.
D. 100 cm$^3$ of 0.25 mol dm$^{-3}$ NaOH and 100 cm$^3$ of 0.25 mol dm$^{-3}$ HCl.

21. Which reaction is the most exothermic?

A. Li$^+$ (g) + F$^-$ (g) → LiF (s)
B. Na$^+$ (g) + Cl$^-$ (g) → NaCl(s)
C. Mg$^{2+}$ (g) + O$^2-$ (g) → MgO (s)
D. Ca$^{2+}$ (g) + S$^{2-}$ (g) → CaS (s)

**Topic 5 Mark Scheme**

<table>
<thead>
<tr>
<th>Question</th>
<th>2015/16 Marks</th>
<th>2015/14 Marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>14.</td>
<td>D</td>
<td>A</td>
</tr>
<tr>
<td>15.</td>
<td>D</td>
<td>C</td>
</tr>
<tr>
<td>16.</td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>17.</td>
<td>A</td>
<td>C</td>
</tr>
<tr>
<td>18.</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>19.</td>
<td>D</td>
<td>D</td>
</tr>
</tbody>
</table>

Q# 138/ IB/P1/2008/s/TZ 2/HL/

16. D
17. A
18. D
19. C
20. A
21. C

Q# 139/ IB/P1/2008/s/TZ 1/HL/

16. B
17. A
18. C
19. B
20. B
21. C

Topic 6

Topic Chem 6 Q# 140/ IB/Paper 1/2016/w/Time Zone 2/Higher Level/

20. Which experimental methods could be used to observe the progress of the following reaction?

\[ \text{Cr}_2\text{O}_7^{2-} (aq) + 6\text{I}^- (aq) + 14\text{H}^+ (aq) \rightarrow 2\text{Cr}^{3+} (aq) + 3\text{I}_2 (aq) + 7\text{H}_2\text{O} (l) \]

I. Change in colour
II. Change in mass
III. Change in electrical conductivity

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

21. Which statement describes the characteristics of a transition state relative to the potential energy of the reactants and products?

A. It is an unstable species with lower potential energy.
B. It is an unstable species with higher potential energy.
C. It is a stable species with lower potential energy.
D. It is a stable species with higher potential energy.
22. Decomposition of hydrogen peroxide in an aqueous solution proceeds as follows.

\[ 2\text{H}_2\text{O}_2 (aq) \rightarrow 2\text{H}_2\text{O} (l) + \text{O}_2 (g) \]

The rate expression for the reaction was found to be: \( \text{rate} = k [\text{H}_2\text{O}_2] \).

Which graph is consistent with the given rate expression?

A.

\[
\text{Rate} / \text{mol dm}^{-3} \text{s}^{-1}
\]

\[
[\text{H}_2\text{O}_2] / \text{mol dm}^{-3}
\]

B.

\[
\text{Rate} / \text{mol dm}^{-3} \text{s}^{-1}
\]

\[
[\text{H}_2\text{O}_2] / \text{mol dm}^{-3}
\]

C.

\[
[\text{H}_2\text{O}_2] / \text{mol dm}^{-3}
\]

\[
\text{Time} / \text{s}
\]

D.

\[
[\text{H}_2\text{O}_2] / \text{mol dm}^{-3}
\]

\[
\text{Time} / \text{s}
\]

23. The rate constant, \( k \), is commonly described by the Arrhenius equation: \( k = Ae^{-\frac{E_a}{RT}} \).

Which of the following statements are correct?

I. A greater \( E_a \) value results in a smaller \( k \) value.
II. Reactions of less complex molecules usually have a greater value of \( A \).
III. The slope (gradient) of \( \ln k \) versus \( \frac{1}{T} \) equals \( E_a \).

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
20. Which graph shows the Maxwell-Boltzmann energy distribution of a same amount of a gas at two temperatures, where $T_2$ is greater than $T_1$?

A. 

B. 

C. 

D. 

21. Which changes increase the rate of this reaction, other conditions remaining constant?

$$\text{CaCO}_3(s) + 2\text{HCl(aq)} \rightarrow \text{CaCl}_2(\text{aq}) + \text{H}_2\text{O(l)} + \text{CO}_2(\text{g})$$

I. Using larger lumps of calcium carbonate
II. Increasing the temperature of the reaction mixture
III. Increasing the concentration of hydrochloric acid

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
22. The rate information below was obtained for the following reaction at a constant temperature.

\[ \text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\Gamma(\text{aq}) \rightarrow 2\text{H}_2\text{O}(l) + \Gamma_2(\text{aq}) \]

<table>
<thead>
<tr>
<th>Initial [\text{H}_2\text{O}_2(\text{aq})] / mol dm(^{-3})</th>
<th>Initial [\text{H}^+(\text{aq})] / mol dm(^{-3})</th>
<th>Initial [\Gamma(\text{aq})] / mol dm(^{-3})</th>
<th>Initial rate of reaction / mol dm(^{-3}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.005</td>
<td>0.05</td>
<td>0.015</td>
<td>1.31 \times 10^{-6}</td>
</tr>
<tr>
<td>0.01</td>
<td>0.05</td>
<td>0.015</td>
<td>2.63 \times 10^{-6}</td>
</tr>
<tr>
<td>0.01</td>
<td>0.05</td>
<td>0.03</td>
<td>5.25 \times 10^{-6}</td>
</tr>
<tr>
<td>0.01</td>
<td>0.1</td>
<td>0.03</td>
<td>5.25 \times 10^{-6}</td>
</tr>
</tbody>
</table>

What is the overall order of the reaction?

A. 0  
B. 1  
C. 2  
D. 3

23. Which reaction is most likely to be spontaneous?

<table>
<thead>
<tr>
<th>Enthalpy change</th>
<th>Entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. exothermic</td>
<td>entropy decreases</td>
</tr>
<tr>
<td>B. exothermic</td>
<td>entropy increases</td>
</tr>
<tr>
<td>C. endothermic</td>
<td>entropy decreases</td>
</tr>
<tr>
<td>D. endothermic</td>
<td>entropy increases</td>
</tr>
</tbody>
</table>
20. The graph shows a plot for a reaction with second-order kinetics. How should the axes be labelled?

<table>
<thead>
<tr>
<th>x-axis</th>
<th>y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>concentration</td>
<td>time</td>
</tr>
<tr>
<td>time</td>
<td>concentration</td>
</tr>
<tr>
<td>rate</td>
<td>concentration</td>
</tr>
<tr>
<td>concentration</td>
<td>rate</td>
</tr>
</tbody>
</table>

21. Which factors affect the rate constant, k, of a reaction?

I. Catalyst
II. Concentration of reactants
III. Temperature

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
19. 100 cm$^3$ of a 1.00 mol dm$^{-3}$ solution of hydrochloric acid is added to 2.00 g of small pieces of calcium carbonate at 20 °C. The volume of carbon dioxide produced against time is plotted to give curve P.

Which change will produce curve Q, given that calcium carbonate is always the limiting reagent?

A. Increasing the volume of the hydrochloric acid to 200 cm$^3$
B. Increasing the mass of calcium carbonate to 4.00 g
C. Increasing the concentration of the hydrochloric acid to 2.00 mol dm$^{-3}$
D. Replacing the 2.00 g of small pieces of calcium carbonate with 2.00 g of larger pieces of calcium carbonate

20. What are the units of the rate constant for a zero-order reaction?

A. s
B. s$^{-1}$
C. mol$^{-1}$ dm$^3$ s$^{-1}$
D. mol dm$^{-3}$ s$^{-1}$
21. The hydrolysis of tertiary bromoalkanes with a warm dilute aqueous sodium hydroxide solution proceeds by a two-step S₉,1 mechanism.

Step I: \[ R-\text{Br} \rightarrow R^+ + \text{Br}^- \]
Step II: \[ R^+ + \text{OH}^- \rightarrow R-	ext{OH} \]

Which description of this reaction is consistent with the above information?

<table>
<thead>
<tr>
<th></th>
<th>Step I</th>
<th>Step II</th>
<th>Rate expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>fast</td>
<td>slow</td>
<td>( \text{rate} = k[R-\text{Br}] )</td>
</tr>
<tr>
<td>B</td>
<td>slow</td>
<td>fast</td>
<td>( \text{rate} = k[R-\text{Br}] )</td>
</tr>
<tr>
<td>C</td>
<td>fast</td>
<td>slow</td>
<td>( \text{rate} = k[R-\text{Br}][\text{OH}^-] )</td>
</tr>
<tr>
<td>D</td>
<td>slow</td>
<td>fast</td>
<td>( \text{rate} = k[R-\text{Br}][\text{OH}^-] )</td>
</tr>
</tbody>
</table>

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19. Nitrogen gas reacts with hydrogen gas according to the following equation.

\[ \text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H = -92 \text{ kJ} \]

Why is the rate of reaction slow at room temperature?

A. The activation energy of the forward reaction is high.
B. The activation energy of the forward reaction is low.
C. The equilibrium constant is very small.
D. The rate of the reverse reaction is greater than the rate of the forward reaction.

20. Which statement about a first-order reaction is correct?

A. The reactant concentration decreases linearly with time.
B. The reactant concentration decreases exponentially with time.
C. The rate of reaction remains constant as the reaction proceeds.
D. The rate of reaction increases exponentially as the reaction proceeds.

21. Consider the rate expression:

\[ \text{Rate} = k[X][Y] \]

Which change decreases the value of the rate constant, \( k \)?

A. Increase in the reaction temperature
B. Decrease in the reaction temperature
C. Increase in the concentration of \( X \) and \( Y \)
D. Decrease in the concentration of \( X \) and \( Y \)
19. Consider the following reaction between hydrogen peroxide, hydrogen ions and iodide ions.

\[ \text{H}_2\text{O}_2(\text{aq}) + 2\text{H}^+(\text{aq}) + 2\Gamma(\text{aq}) \rightarrow \text{I}_2(\text{aq}) + 2\text{H}_2\text{O}(\text{l}) \]

Which changes could be used to investigate the rate of this reaction?

I. Electrical conductivity
II. Mass of solution
III. Colour intensity

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

20. Consider the following reaction between nitrogen monoxide and oxygen.

\[ 2\text{NO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g}) \]

The reaction occurs in two steps:

Step 1: \[ \text{NO}(\text{g}) + \text{NO}(\text{g}) \rightleftharpoons \text{N}_2\text{O}_2(\text{g}) \] \[ \text{fast} \]
Step 2: \[ \text{N}_2\text{O}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{NO}_2(\text{g}) \] \[ \text{slow} \]

What is the rate expression for this reaction?

A. Rate = \( k [\text{NO}]^2 \)
B. Rate = \( k [\text{NO}][\text{O}_2] \)
C. Rate = \( k [\text{NO}]^2[\text{O}_2] \)
D. Rate = \( k [\text{NO}][\text{O}_2]^2 \)

21. What happens to the rate constant, \( k \), and the activation energy, \( E_a \), as the temperature of a chemical reaction is increased?

<table>
<thead>
<tr>
<th>Value of ( k )</th>
<th>Value of ( E_a )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. unchanged</td>
<td>increases</td>
</tr>
<tr>
<td>C. decreases</td>
<td>unchanged</td>
</tr>
<tr>
<td>D. increases</td>
<td>unchanged</td>
</tr>
</tbody>
</table>
20. Which is not affected by an increase in temperature?

A. Rate of reaction  
B. Collision frequency  
C. Collision geometry  
D. % of molecules with $E \geq E_a$

21. Which combination shows a second-order rate expression with the correct rate constant units?

<table>
<thead>
<tr>
<th>Rate expression</th>
<th>$k$ units</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. $rate = k[NH_3][BF_3]$</td>
<td>mol dm$^{-3}$ s$^{-1}$</td>
</tr>
<tr>
<td>B. $rate = k[N_2O_5]$</td>
<td>s$^{-1}$</td>
</tr>
<tr>
<td>C. $rate = k[N_2O_5]$</td>
<td>dm$^3$ mol$^{-1}$ s$^{-1}$</td>
</tr>
<tr>
<td>D. $rate = k[CH_3COCH_3][H^+][I_2]_0$</td>
<td>dm$^2$ mol$^{-1}$ s$^{-1}$</td>
</tr>
</tbody>
</table>
22. Which pair of graphs shows a decomposition reaction of X that obeys first-order kinetics?

A. Rate \[ \text{[X]} \] \[ \text{[X]} \] \[ \text{Time} \]
B. Rate \[ \text{[X]} \] \[ \text{[X]} \] \[ \text{Time} \]
C. Rate \[ \text{[X]} \] \[ \text{[X]} \] \[ \text{Time} \]
D. Rate \[ \text{[X]} \] \[ \text{[X]} \] \[ \text{Time} \]
19. The diagram represents the Maxwell–Boltzmann energy distribution curve of the reactants for a chemical reaction with different activation energies, $E_{a1}$ and $E_{a2}$.

What is the reason why the rate of the reaction with activation energy $E_{a2}$ is greater?

A. More frequent collisions between the particles occur.
B. More energetic collisions between the particles occur.
C. A catalyst has been added.
D. The temperature is higher.

20. X and Y react according to the equation $2X + Y \rightarrow Z$. The reaction can be described by the following mechanism:

\[
\begin{align*}
X + X & \rightarrow X_2 \quad \text{slow} \\
X_2 + Y & \rightarrow Z \quad \text{fast}
\end{align*}
\]

What is the order of the reaction with respect to X and Y?

<table>
<thead>
<tr>
<th></th>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>First</td>
<td>Zero</td>
</tr>
<tr>
<td>B.</td>
<td>First</td>
<td>First</td>
</tr>
<tr>
<td>C.</td>
<td>Second</td>
<td>Zero</td>
</tr>
<tr>
<td>D.</td>
<td>Second</td>
<td>First</td>
</tr>
</tbody>
</table>
21. The rate constant for a reaction is determined at different temperatures. Which diagram represents the relationship between the rate constant, \( k \), and temperature, \( T \), in K?

\[ \text{A.} \quad \frac{k}{T} \quad \text{B.} \quad \frac{k}{T} \]

\[ \text{C.} \quad k \quad \text{D.} \quad k \quad T \]

20. The diagram below shows the energy changes for a reaction with and without a catalyst. Which symbols represent the activation energy, \( E_a \), and the enthalpy change, \( \Delta H \), for the reaction with a catalyst?

\[ \text{Energy} \quad \text{Reactants} \quad \text{Products} \quad \text{Extent of reaction} \]

<table>
<thead>
<tr>
<th>( E_a ) (with a catalyst)</th>
<th>( \Delta H )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ( x )</td>
<td>( z )</td>
</tr>
<tr>
<td>B. ( y )</td>
<td>( z )</td>
</tr>
<tr>
<td>C. ( z )</td>
<td>( x )</td>
</tr>
<tr>
<td>D. ( y - x )</td>
<td>( z )</td>
</tr>
</tbody>
</table>
21. The following experimental rate data were obtained for a reaction carried out at temperature $T$.

$$A(g) + B(g) \rightarrow C(g) + D(g)$$

<table>
<thead>
<tr>
<th>Initial $[A(g)]$ / mol dm$^{-3}$</th>
<th>Initial $[B(g)]$ / mol dm$^{-3}$</th>
<th>Initial rate / mol dm$^{-3}$ s$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3.00 \times 10^{-1}$</td>
<td>$2.00 \times 10^{-1}$</td>
<td>$1.89 \times 10^{-2}$</td>
</tr>
<tr>
<td>$3.00 \times 10^{-1}$</td>
<td>$4.00 \times 10^{-1}$</td>
<td>$1.89 \times 10^{-2}$</td>
</tr>
<tr>
<td>$6.00 \times 10^{-1}$</td>
<td>$4.00 \times 10^{-1}$</td>
<td>$7.56 \times 10^{-2}$</td>
</tr>
</tbody>
</table>

What are the orders with respect to $A(g)$ and $B(g)$?

<table>
<thead>
<tr>
<th>Order with respect to $A(g)$</th>
<th>Order with respect to $B(g)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. zero</td>
<td>second</td>
</tr>
<tr>
<td>B. first</td>
<td>zero</td>
</tr>
<tr>
<td>C. second</td>
<td>zero</td>
</tr>
<tr>
<td>D. second</td>
<td>first</td>
</tr>
</tbody>
</table>

22. Consider the following proposed two-step reaction mechanism at temperature $T$.

Step 1: $2\text{NO}_2(g) \xrightarrow{k_1} \text{NO}(g) + \text{NO}_3(g)$  \textit{Slow}

Step 2: $\text{NO}_3(g) + \text{CO}(g) \xrightarrow{k_2} \text{NO}_2(g) + \text{CO}_2(g)$  \textit{Fast}

Which statements are correct?

I. The overall reaction is $\text{NO}_2(g) + \text{CO}(g) \rightarrow \text{NO}(g) + \text{CO}_2(g)$.

II. Step 1 is the rate-determining step of the reaction.

III. The rate expression for Step 1 is rate $= k_1[\text{NO}_2]^2$.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Topic Chem 6 Q# 149/ IB/Paper 1/2013/s/Time Zone 2/Higher Level/
19. Which statements explain the increase in the rate of a reaction when the temperature is increased?

   I. More particles have energy greater than the activation energy.
   II. The frequency of collisions increases.
   III. The activation energy decreases.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

20. Experimental data shows that a reaction in which $Y$ is a reactant is first order with respect to $Y$. Which graph shows this first-order relationship?

A. 

\[
\begin{array}{c}
\text{[Y]} \\
1 \\
0.5 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Time} \\
\end{array}
\]

B. 

\[
\begin{array}{c}
\text{[Y]} \\
1 \\
0.5 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Time} \\
\end{array}
\]

C. 

\[
\begin{array}{c}
\text{[Y]} \\
1 \\
0.5 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Time} \\
\end{array}
\]

D. 

\[
\begin{array}{c}
\text{[Y]} \\
1 \\
0.5 \\
\end{array}
\]

\[
\begin{array}{c}
\text{Time} \\
\end{array}
\]

21. Which statement about a reaction best describes the relationship between the temperature, $T$, and the rate constant, $k$?

A. As $T$ increases, $k$ decreases linearly.
B. As $T$ increases, $k$ decreases non-linearly.
C. As $T$ increases, $k$ increases linearly.
D. As $T$ increases, $k$ increases non-linearly.
22. Carbon monoxide and nitrogen dioxide react to form carbon dioxide and nitrogen monoxide according to the following equation.

\[
\text{CO(g)} + \text{NO}_2(g) \rightarrow \text{CO}_2(g) + \text{NO}(g)
\]

The reaction occurs in a series of steps. The equation for the rate-determining step is given below.

\[
2\text{NO}_2(g) \rightarrow \text{NO}_3(g) + \text{NO}(g)
\]

What is the rate expression for this reaction?

A. \( \text{rate} = k[\text{CO(g)}][\text{NO}_2(g)] \)

B. \( \text{rate} = k[\text{NO}_2(g)]^2 \)

C. \( \text{rate} = k[\text{NO}_3(g)][\text{NO}(g)] \)

D. \( \text{rate} = k[\text{CO}_2(g)][\text{NO}(g)] \)
19. Which graph best represents the relationship between the average kinetic energy of molecules of a gas and temperature in K?

A.  

B.  

C.  

D.  

20. For the gas phase reaction:

\[ \text{A}_\text{g} + \text{B}_\text{g} \rightarrow \text{C}_\text{g} \]

the experimentally determined rate expression is: \( \text{rate} = k \ [\text{A}] [\text{B}]^2 \)

By what factor will the rate change if the concentration of A is tripled and the concentration of B is halved?

A. 0.75  
B. 1.5  
C. 6  
D. 12
21. Which graph best represents a second-order reaction?

A.  
\[
\text{Concentration of reactant} \\
\text{Time}
\]

B.  
\[
\text{Concentration of reactant} \\
\text{Time}
\]

C.  
\[
\text{Concentration of reactant} \\
\text{Time}
\]

D.  
\[
\text{Concentration of reactant} \\
\text{Time}
\]

19. Which piece of equipment could not be used in an experiment to measure the rate of this reaction?

\[
\text{CH}_3\text{COCH}_3(\text{aq}) + \text{I}_2(\text{aq}) \rightarrow \text{CH}_3\text{COCH}_2\text{I}(\text{aq}) + \text{H}^+(\text{aq}) + \text{I}^-(\text{aq})
\]

A. A colorimeter
B. A gas syringe
C. A stopwatch
D. A pH meter
20. Which graph would be produced by a 2\textsuperscript{nd} order reaction if the rate equation is \( \text{rate} = k[X]^2 \)?

A. 

\[
\begin{array}{c}
| [X] \text{ mol dm}^{-3} | \\
\downarrow \\
\text{Time (s)} \\
\end{array}
\]

B. 

\[
\begin{array}{c}
| [X] \text{ mol dm}^{-3} | \\
\downarrow \\
\text{Time (s)} \\
\end{array}
\]

C. 

\[
\begin{array}{c}
| \text{Rate} \text{ mol dm}^{-3} \text{s}^{-1} | \\
\downarrow \\
| [X] \text{ mol dm}^{-3} | \\
\end{array}
\]

D. 

\[
\begin{array}{c}
| \text{Rate} \text{ mol dm}^{-3} \text{s}^{-1} | \\
\downarrow \\
| [X] \text{ mol dm}^{-3} | \\
\end{array}
\]

21. Which step in a multi-step reaction mechanism will be rate-determining?

A. The first step

B. The last step

C. The step with the highest activation energy

D. The step with the lowest activation energy
18. Which are appropriate units for the rate of a reaction?

A. mol dm$^{-3}$ s$^{-1}$  
B. mol dm$^{-3}$ s
C. mol dm$^{-5}$
D. s

19. Which graph represents a reaction that is second order with respect to X for the reaction $X \rightarrow$ products?

A. [X]  
B. [X]  
C. Rate  
D. [X]
20. Consider the reaction:

$$2\text{NO}(g) + \text{Br}_2(g) \rightarrow 2\text{NOBr}(g)$$

One suggested mechanism is:

$$\text{NO}(g) + \text{Br}_2(g) \xrightleftharpoons[k_i]{k_f} \text{NOBr}_2(g) \quad \text{fast}$$

$$\text{NOBr}_2(g) + \text{NO}(g) \xrightarrow[k_i]{k_f} 2\text{NOBr}(g) \quad \text{slow}$$

Which statements are correct?

I. \(\text{NOBr}_2(g)\) is an intermediate.
II. The second step is the rate-determining step.
III. \(\text{rate} = k[\text{NO}]^2[\text{Br}_2]\)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

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19. The Maxwell–Boltzmann curve below shows the distribution of kinetic energies for the particles in a sample of gas.

![Maxwell–Boltzmann curve](image)

Which is the shape of the curve for the same sample of gas at a higher temperature? All graphs are drawn to the same scale.

A. Number of particles
   ![Graph A](image)

B. Number of particles
   ![Graph B](image)

C. Number of particles
   ![Graph C](image)

D. Number of particles
   ![Graph D](image)
20. The decomposition of \( \text{N}_2\text{O}_5 \) occurs according to the following equation.

\[
2\text{N}_2\text{O}_5 (g) \rightarrow 4\text{NO}_3 (g) + \text{O}_3 (g)
\]

The reaction is first order with respect to \( \text{N}_2\text{O}_5 \). What combination of variables could the axes represent on the graph below?

![Graph with axis labels: x-axis and y-axis]

<table>
<thead>
<tr>
<th>x-axis</th>
<th>y-axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. time</td>
<td>([\text{N}_2\text{O}_5])</td>
</tr>
<tr>
<td>B. ([\text{N}_2\text{O}_5])</td>
<td>time</td>
</tr>
<tr>
<td>C. ([\text{N}_2\text{O}_5])</td>
<td>rate of reaction</td>
</tr>
<tr>
<td>D. rate of reaction</td>
<td>([\text{N}_2\text{O}_5])</td>
</tr>
</tbody>
</table>

21. What is the effect of an increase in temperature on the rate constant of the forward reaction, \( k \), and on the equilibrium constant, \( K_c \), of an exothermic reversible reaction?

A. \( k \) decreases, \( K_c \) increases

B. \( k \) increases, \( K_c \) decreases

C. \( k \) decreases, \( K_c \) decreases

D. \( k \) increases, \( K_c \) increases
22. The graph represents the rates of the forward and backward reactions of a reversible reaction.

Which statement is correct?

A. XWZ represents the rate of the forward reaction.
B. At Y, the rate of the forward and backward reactions is zero.
C. Between W and Z, the concentrations of products and reactants are equal.
D. Between Y and W, the concentration of the reactants increases.
19. A student added 0.20 g of calcium carbonate powder to 100 cm$^3$ of 1.0 mol dm$^{-3}$ hydrochloric acid (an excess) and measured the volume of the gas that was evolved. The graph of the results is shown below.

Which graph would be obtained if 0.20 g of calcium carbonate powder is added to 100 cm$^3$ of 0.5 mol dm$^{-3}$ hydrochloric acid (an excess)?

A. 

B. 

C. 

D.
20. Which statement about the kinetic theory is not correct?

A. The particles in ice vibrate about fixed points.
B. The particles in steam have more energy than the particles in ice.
C. All the particles in water have the same amount of energy at 298 K.
D. Evaporation of water occurs at all temperatures between 273 K and 373 K when the atmospheric pressure is 101 kPa.

21. The rate expression for the reaction between iodine and propanone with an acid catalyst is found to be:

\[ \text{rate} = k[H^+][I_2]^1[\text{CH}_3\text{COCH}_3]^1 \]

What is the overall order of the reaction?

A. 0
B. 1
C. 2
D. 3

22. Which graph represents a reaction that is first order with respect to reactant A.

A.  
B.  
C.  
D.  

Time for reaction to finish
20. Sodium carbonate and hydrochloric acid react according to the equation below.

\[ \text{Na}_2\text{CO}_3(\text{s}) + 2\text{HCl}(\text{aq}) \rightarrow \text{CO}_2(\text{g}) + 2\text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l}) \]

Which conditions will produce the fastest initial rate with 2.0 g of powdered sodium carbonate?

A. 100 cm\(^3\) of 1.0 mol dm\(^{-3}\) hydrochloric acid at 323 K
B. 50 cm\(^3\) of 2.0 mol dm\(^{-3}\) hydrochloric acid at 323 K
C. 100 cm\(^3\) of 1.0 mol dm\(^{-3}\) hydrochloric acid at 348 K
D. 50 cm\(^3\) of 2.0 mol dm\(^{-3}\) hydrochloric acid at 348 K

21. The rate information below was obtained for the following reaction at a constant temperature.

\[ 2\text{NO}_2(\text{g}) + \text{F}_2(\text{g}) \rightarrow 2\text{NO}_2\text{F}(\text{g}) \]

<table>
<thead>
<tr>
<th>[NO(_2)] / mol dm(^{-3})</th>
<th>[F(_2)] / mol dm(^{-3})</th>
<th>Rate / mol dm(^{-3}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2.0 \times 10^{-3})</td>
<td>(1.0 \times 10^{-2})</td>
<td>(4.0 \times 10^{-4})</td>
</tr>
<tr>
<td>(4.0 \times 10^{-3})</td>
<td>(1.0 \times 10^{-2})</td>
<td>(8.0 \times 10^{-4})</td>
</tr>
<tr>
<td>(4.0 \times 10^{-3})</td>
<td>(2.0 \times 10^{-2})</td>
<td>(1.6 \times 10^{-3})</td>
</tr>
</tbody>
</table>

What are the orders of the reaction with respect to NO\(_2\) and F\(_2\)?

A. NO\(_2\) is first order and F\(_2\) is second order
B. NO\(_2\) is second order and F\(_2\) is first order
C. NO\(_2\) is first order and F\(_2\) is first order
D. NO\(_2\) is second order and F\(_2\) is second order
22. Consider the following reaction.

\[ 2\text{NO}(g) + 2\text{H}_2(g) \rightarrow \text{N}_2(g) + 2\text{H}_2\text{O}(g) \]

A proposed reaction mechanism is:

\[ \text{NO}(g) + \text{NO}(g) \rightleftharpoons \text{N}_2\text{O}_2(g) \quad \text{fast} \]
\[ \text{N}_2\text{O}_2(g) + \text{H}_2(g) \rightarrow \text{N}_2\text{O}(g) + \text{H}_2\text{O}(g) \quad \text{slow} \]
\[ \text{N}_2\text{O}(g) + \text{H}_2(g) \rightarrow \text{N}_2(g) + \text{H}_2\text{O}(g) \quad \text{fast} \]

What is the rate expression?

A. \( \text{rate} = k[\text{H}_2][\text{NO}]^2 \)
B. \( \text{rate} = k[\text{N}_2\text{O}_2][\text{H}_2] \)
C. \( \text{rate} = k[\text{NO}]^2[\text{H}_2]^2 \)
D. \( \text{rate} = k[\text{NO}]^2[\text{N}_2\text{O}_2]^2[\text{H}_2] \)

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20. Curve X on the graph below shows the volume of oxygen formed during the catalytic decomposition of a 1.0 mol dm\(^3\) solution of hydrogen peroxide.

\[ 2\text{H}_2\text{O}_2(\text{aq}) \rightarrow \text{O}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) \]

Which change would produce the curve Y?

A. Adding water
B. Adding some 0.1 mol dm\(^{-3}\) hydrogen peroxide solution
C. Using a different catalyst
D. Lowering the temperature
21. Bromine and nitrogen(II) oxide react according to the following equation.

\[ \text{Br}_2(\text{g}) + 2\text{NO}(\text{g}) \rightarrow 2\text{NOBr}(\text{g}) \]

Which rate equation is consistent with the experimental data?

<table>
<thead>
<tr>
<th>[Br\textsubscript{2}] / mol dm\textsuperscript{-3}</th>
<th>[NO] / mol dm\textsuperscript{-3}</th>
<th>Rate / mol dm\textsuperscript{-3}s\textsuperscript{-1}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.10</td>
<td>0.10</td>
<td>1.0\times10^{-6}</td>
</tr>
<tr>
<td>0.20</td>
<td>0.10</td>
<td>4.0\times10^{-6}</td>
</tr>
<tr>
<td>0.20</td>
<td>0.40</td>
<td>4.0\times10^{-6}</td>
</tr>
</tbody>
</table>

A. \( \text{rate} = k [\text{Br}_2]^2 [\text{NO}] \)
B. \( \text{rate} = k [\text{Br}_2] [\text{NO}]^2 \)
C. \( \text{rate} = k [\text{Br}_2]^3 \)
D. \( \text{rate} = k [\text{NO}]^2 \)

22. Consider the reaction between gaseous iodine and gaseous hydrogen.

\[ \text{I}_2(\text{g}) + \text{H}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g}) \quad \Delta H^\circ = -9 \text{ kJ} \]

Why do some collisions between iodine and hydrogen not result in the formation of the product?

A. The I\textsubscript{2} and H\textsubscript{2} molecules do not have sufficient energy.
B. The system is in equilibrium.
C. The temperature of the system is too high.
D. The activation energy for this reaction is very low.

23. Which step is the rate-determining step of a reaction?

A. The step with the lowest activation energy
B. The final step
C. The step with the highest activation energy
D. The first step
19. Which changes increase the rate of the reaction below?

\[ \text{C}_4\text{H}_6(g) + \text{Cl}_2(g) \rightarrow \text{C}_4\text{H}_9\text{Cl}(l) + \text{HCl}(g) \]

I. Increase of pressure
II. Increase of temperature
III. Removal of HCl(g)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

20. Consider the following reaction.

\[ 2\text{P} + \text{Q} \rightarrow \text{R} + \text{S} \]

This reaction occurs according to the following mechanism.

\[ \text{P} + \text{Q} \rightarrow \text{X} \quad \text{slow} \]
\[ \text{P} + \text{X} \rightarrow \text{R} + \text{S} \quad \text{fast} \]

What is the rate expression?

A. \( \text{rate} = k [\text{P}] \)
B. \( \text{rate} = k [\text{P}][\text{X}] \)
C. \( \text{rate} = k [\text{P}][\text{Q}] \)
D. \( \text{rate} = k [\text{P}]^2 [\text{Q}] \)

21. What happens when the temperature of a reaction increases?

A. The activation energy increases.
B. The rate constant increases.
C. The enthalpy change increases.
D. The order of the reaction increases.
18. Which unit could be used for the rate of a chemical reaction?

A. mol
B. moldm$^{-3}$
C. moldm$^{-3}$ s$^{-1}$
D. dm$^3$

21. The following data were obtained for the reaction between gases A and B.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Initial [A] / moldm$^{-3}$</th>
<th>Initial [B] / moldm$^{-3}$</th>
<th>Initial rate / moldm$^{-3}$ min$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1.0 \times 10^{-3}$</td>
<td>$1.0 \times 10^{-3}$</td>
<td>$2.0 \times 10^{-4}$</td>
</tr>
<tr>
<td>2</td>
<td>$2.0 \times 10^{-3}$</td>
<td>$1.0 \times 10^{-3}$</td>
<td>$2.0 \times 10^{-4}$</td>
</tr>
<tr>
<td>3</td>
<td>$2.0 \times 10^{-3}$</td>
<td>$2.0 \times 10^{-3}$</td>
<td>$4.0 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Which relationship represents the rate expression for the reaction?

A. rate = $k [B]^2$
B. rate = $k [A]^2$
C. rate = $k [A]$
D. rate = $k [B]$

22. Consider the following reaction.

$$\text{NO}_2 (g) + \text{CO} (g) \rightarrow \text{NO} (g) + \text{CO}_2 (g)$$

At $T < 227^\circ C$ the rate expression is rate = $k [\text{NO}_2]^2$. Which of the following mechanisms is consistent with this rate expression?

A. \(\text{NO}_2 + \text{NO}_2 \rightleftharpoons \text{N}_2\text{O}_4\) \hspace{2cm} fast \hspace{2cm} \(\text{N}_2\text{O}_4 + 2\text{CO} \rightarrow 2\text{NO} + 2\text{CO}_2\) \hspace{2cm} slow

B. \(\text{NO}_2 + \text{CO} \rightarrow \text{NO} + \text{CO}_2\) \hspace{2cm} slow

C. \(\text{NO}_2 \rightarrow \text{NO} + \text{O}\) \hspace{2cm} slow \hspace{2cm} \(\text{CO} + \text{O} \rightarrow \text{CO}_2\) \hspace{2cm} fast

D. \(\text{NO}_2 + \text{NO}_2 \rightarrow \text{NO}_3 + \text{NO}\) \hspace{2cm} slow \hspace{2cm} \(\text{NO}_3 + \text{CO} \rightarrow \text{NO}_2 + \text{CO}_2\) \hspace{2cm} fast
19. Which experimental procedure could be used to determine the rate of reaction for the reaction between a solution of cobalt chloride, $\text{CoCl}_2(\text{aq})$, and concentrated hydrochloric acid, $\text{HCl}(\text{aq})$?

$$\text{Co(H}_2\text{O)}_6^{2+} (\text{aq}) + 4\text{Cl}^- (\text{aq}) \rightleftharpoons \text{CoCl}_4^{2-} (\text{aq}) + 6\text{H}_2\text{O (l)}$$

A. Measure the change in pH in a given time
B. Measure the change in mass in a given time
C. Use a colorimeter to measure the change in colour in a given time
D. Measure the change in volume of the solution in a given time

20. Powdered manganese(IV) oxide, $\text{MnO}_2(\text{s})$, increases the rate of the decomposition reaction of hydrogen peroxide, $\text{H}_2\text{O}_2(\text{aq})$. Which statements about $\text{MnO}_2$ are correct?

I. The rate is independent of the particle size of $\text{MnO}_2$.
II. $\text{MnO}_2$ provides an alternative reaction pathway for the decomposition with a lower activation energy.
III. All the $\text{MnO}_2$ is present after the decomposition of the hydrogen peroxide is complete.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
Questions 21 and 22 refer to the following reaction.

Sodium thiosulfate solution, Na₂S₂O₃ (aq), and hydrochloric acid, HCl (aq), react spontaneously to produce solid sulfur, S(s), according to the equation below.

\[ \text{S}_2\text{O}_3^{2-} (aq) + 2\text{H}^+ (aq) \rightarrow \text{S} (s) + \text{SO}_2 (aq) + \text{H}_2\text{O} (l) \]

A student experimentally determined the rate expression to be:

\[ \text{rate} = k [\text{S}_2\text{O}_3^{2-} (aq)]^2 \]

21. Which graph is consistent with this information?

A.  
\[
\begin{array}{c|c}
\text{Rate} / \text{mol dm}^{-3} \text{ s}^{-1} & \text{[S}_2\text{O}_3^{2-} (aq)] / \text{mol dm}^{-3} \\
\hline
\end{array}
\]

B.  
\[
\begin{array}{c|c}
\text{Rate} / \text{mol dm}^{-3} \text{ s}^{-1} & \text{[S}_2\text{O}_3^{2-} (aq)] / \text{mol dm}^{-3} \\
\hline
\end{array}
\]

C.  
\[
\begin{array}{c|c}
\text{Rate} / \text{mol dm}^{-3} \text{ s}^{-1} & \text{[S}_2\text{O}_3^{2-} (aq)] / \text{mol dm}^{-3} \\
\hline
\end{array}
\]

D.  
\[
\begin{array}{c|c}
\text{Rate} / \text{mol dm}^{-3} \text{ s}^{-1} & \text{[S}_2\text{O}_3^{2-} (aq)] / \text{mol dm}^{-3} \\
\hline
\end{array}
\]

22. Which reaction could be the rate-determining step?

A.  \[ \text{S}_2\text{O}_3^{2-} (aq) + \text{H}^+ (aq) \rightarrow \text{S}_2\text{O}_2 (aq) + \text{OH}^- (aq) \]

B.  \[ \text{S}_2\text{O}_3^{2-} (aq) + 2\text{H}^+ (aq) \rightarrow \text{S}_2\text{O}_2 (aq) + \text{H}_2\text{O} (l) \]

C.  \[ \text{S}_2\text{O}_3^{2-} (aq) \rightarrow \text{S} (s) + \text{SO}_2^{2-} (aq) \]

D.  \[ 2\text{S}_2\text{O}_3^{2-} (aq) \rightarrow \text{S}_4\text{O}_6^{4+} (aq) \]
19. Hydrochloric acid is reacted with large pieces of calcium carbonate, the reaction is then repeated using calcium carbonate powder. How does this change affect the activation energy and the collision frequency?

<table>
<thead>
<tr>
<th>Activation energy</th>
<th>Collision frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. increases</td>
<td>increases</td>
</tr>
<tr>
<td>B. stays constant</td>
<td>increases</td>
</tr>
<tr>
<td>C. increases</td>
<td>stays constant</td>
</tr>
<tr>
<td>D. stays constant</td>
<td>stays constant</td>
</tr>
</tbody>
</table>

20. Two species, P and Q, react together according to the following equation.

\[ P + Q \rightarrow R \]

The accepted mechanism for this reaction is

\[
P + P \rightleftharpoons P_2 \quad \text{(fast)}
\]
\[ P_2 + Q \rightarrow R + P \quad \text{(slow)}
\]

What is the order with respect to P and Q?

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

21. The activation energy of a reaction may be determined by studying the effect of a particular variable on the reaction rate. Which variable must be changed?

A. pH
B. Concentration
C. Surface area
D. Temperature
20. What is the function of iron in the Haber process?
   
   A. It shifts the position of equilibrium towards the products.
   
   B. It decreases the rate of the reaction.
   
   C. It provides an alternative reaction pathway with a lower activation energy.
   
   D. It reduces the enthalpy change of the reaction.

21. Consider the following reaction.

\[ 5\text{Br}^- (aq) + \text{BrO}_3^- (aq) + 6\text{H}^+ (aq) \rightarrow 3\text{Br}_2 (aq) + 3\text{H}_2\text{O} (l) \]

The rate expression for the reaction is found to be:

\[ \text{rate} = k [\text{Br}^-][\text{BrO}_3^-][\text{H}^+]^2 \]

Which statement is correct?

A. The overall order is 12.

B. Doubling the concentration of all of the reactants at the same time would increase the rate of the reaction by a factor of 16.

C. The units of the rate constant, \( k \), are \( \text{mol dm}^{-3} \text{s}^{-1} \).

D. A change in concentration of \( \text{Br}^- \) or \( \text{BrO}_3^- \) does not affect the rate of the reaction.

22. The rate expression for a reaction is:

\[ \text{rate} = k [X][Y] \]

Which statement is correct?

A. As the temperature increases the rate constant decreases.

B. The rate constant increases with increased temperature but eventually reaches a constant value.

C. As the temperature increases the rate constant increases.

D. The rate constant is not affected by a change in temperature.
23. Consider the following reaction mechanism.

\[
\begin{align*}
\text{Step 1} & \quad \text{H}_2\text{O}_2 + \text{I}^- & \rightarrow & \text{H}_2\text{O} + \text{IO}^- & \quad \text{slow} \\
\text{Step 2} & \quad \text{H}_2\text{O}_2 + \text{IO}^- & \rightarrow & \text{H}_2\text{O} + \text{O}_2 + \text{I}^- & \quad \text{fast}
\end{align*}
\]

Which statement correctly identifies the rate-determining step and the explanation?

A. Step 2 because it is the faster step
B. Step 1 because it is the slower step
C. Step 1 because it is the first step
D. Step 2 because it is the last step

24. Which statement is correct for the equilibrium \( \text{H}_2\text{O} (l) \rightleftharpoons \text{H}_2\text{O} (g) \) in a closed system at 100 °C?

A. All the \( \text{H}_2\text{O} (l) \) molecules have been converted to \( \text{H}_2\text{O} (g) \).
B. The rate of the forward reaction is greater than the rate of the reverse reaction.
C. The rate of the forward reaction is less than the rate of the reverse reaction.
D. The pressure remains constant.

25. Which are definitions of an acid according to the Bronsted-Lowry and Lewis theories?

<table>
<thead>
<tr>
<th>Bronsted-Lowry theory</th>
<th>Lewis theory</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. proton donor</td>
<td>electron pair acceptor</td>
</tr>
<tr>
<td>B. proton acceptor</td>
<td>electron pair acceptor</td>
</tr>
<tr>
<td>C. proton acceptor</td>
<td>electron pair donor</td>
</tr>
<tr>
<td>D. proton donor</td>
<td>electron pair donor</td>
</tr>
</tbody>
</table>
19. What is the best definition of rate of reaction?

A. The time it takes to use up all the reactants
B. The rate at which all the reactants are used up
C. The time it takes for one of the reactants to be used up
D. The increase in concentration of a product per unit time

20. Which factors can affect reaction rate?

I. The state of the reactants
II. The frequency of the collisions between particles
III. The average kinetic energy of the particles

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
21. Equal masses of powdered calcium carbonate were added to separate solutions of hydrochloric acid. The calcium carbonate was in excess. The volume of carbon dioxide produced was measured at regular intervals. Which curves best represent the evolution of carbon dioxide against time for the acid solutions shown in the table below.

<table>
<thead>
<tr>
<th></th>
<th>25 cm$^3$ of 2 mol dm$^{-3}$ HCl</th>
<th>50 cm$^3$ of 1 mol dm$^{-3}$ HCl</th>
<th>25 cm$^3$ of 1 mol dm$^{-3}$ HCl</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>I</td>
<td>III</td>
<td>IV</td>
</tr>
<tr>
<td>B.</td>
<td>I</td>
<td>IV</td>
<td>III</td>
</tr>
<tr>
<td>C.</td>
<td>I</td>
<td>II</td>
<td>III</td>
</tr>
<tr>
<td>D.</td>
<td>II</td>
<td>I</td>
<td>III</td>
</tr>
</tbody>
</table>
Questions 22 and 23 refer to the following reaction.

\[ X_2 + 2Y \rightarrow 2XY \]

The reaction occurs in a series of steps.

\[ X_2 \rightarrow 2X \quad \text{slow} \]
\[ X + Y \rightarrow XY \quad \text{fast} \]

22. What is the rate-determining step for this reaction mechanism?

A. \( X_2 + 2Y \rightarrow 2XY \)
B. \( X_2 + Y \rightarrow XY + X \)
C. \( X_2 \rightarrow 2X \)
D. \( X + Y \rightarrow XY \)

23. What is the rate expression for this reaction?

A. \( \text{rate} = k [XY] \)
B. \( \text{rate} = k [X_2][Y]^2 \)
C. \( \text{rate} = k [X_2] \)
D. \( \text{rate} = k [2X] \)
22. The graph below shows how the concentration of X changes with time during the following reaction:

\[ X \rightarrow Y \]

Which graph shows the change in concentration of Y during the same time period?

A. 

\[
\begin{align*}
\text{[Y] / mol dm}^{-3} \\
0 & \quad 50 & \quad 100 & \quad 150 \\
0 & \quad 50 & \quad 100 & \quad 150 \\
\end{align*}
\]

B. 

\[
\begin{align*}
\text{[Y] / mol dm}^{-3} \\
0 & \quad 50 & \quad 100 & \quad 150 \\
0 & \quad 50 & \quad 100 & \quad 150 \\
\end{align*}
\]

C. 

\[
\begin{align*}
\text{[Y] / mol dm}^{-3} \\
0 & \quad 50 & \quad 100 & \quad 150 \\
0 & \quad 50 & \quad 100 & \quad 150 \\
\end{align*}
\]

D. 

\[
\begin{align*}
\text{[Y] / mol dm}^{-3} \\
0 & \quad 50 & \quad 100 & \quad 150 \\
0 & \quad 50 & \quad 100 & \quad 150 \\
\end{align*}
\]
23. The activation energy for a reaction can be determined graphically using the Arrhenius equation:

\[ k = A e^{\frac{-E_a}{RT}} \]

Which plot gives a straight line graph?

<table>
<thead>
<tr>
<th>Vertical axis</th>
<th>Horizontal axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ( k )</td>
<td>( \frac{1}{T} )</td>
</tr>
<tr>
<td>B. ( k )</td>
<td>( \ln \frac{1}{T} )</td>
</tr>
<tr>
<td>C. ( \ln k )</td>
<td>( \ln \frac{1}{T} )</td>
</tr>
<tr>
<td>D. ( \ln k )</td>
<td>( \frac{1}{T} )</td>
</tr>
</tbody>
</table>

24. Nitrogen dioxide can react with carbon monoxide in the exhaust gases of car engines:

\[ \text{NO}_2(g) + \text{CO}(g) \rightarrow \text{NO}(g) + \text{CO}_2(g) \]

The following mechanism has been proposed:

\[ \text{NO}_2(g) + \text{NO}_2(g) \rightarrow \text{N}_2\text{O}_4(g) \] \hspace{1cm} \text{slow}

\[ \text{N}_2\text{O}_4(g) + \text{CO}(g) \rightarrow \text{NO}_2(g) + \text{CO}_2(g) + \text{NO}(g) \] \hspace{1cm} \text{fast}

What is the rate equation for this mechanism?

A. \( \text{Rate} = k [\text{NO}_2(g)] [\text{CO}(g)] \)

B. \( \text{Rate} = k [\text{NO}_2(g)]^2 \)

C. \( \text{Rate} = k [\text{N}_2\text{O}_4(g)] [\text{CO}(g)] \)

D. \( \text{Rate} = k [\text{NO}_2(g)]^2 [\text{CO}(g)] \)
22. Which statement explains why increasing the temperature increases the rate of a chemical reaction?

A. More molecules have energy equal to or greater than the activation energy.
B. At a higher temperature the activation energy for the reaction is lower.
C. More molecules have the correct collision geometry.
D. The reaction proceeds according to Le Chatelier’s principle.

23. Which statement is correct about the overall order of a chemical reaction?

A. It can be deduced from the stoichiometric coefficients of the equation.
B. It can only be determined experimentally.
C. It is always affected when the concentrations of the reactants are increased.
D. It is always the same as the molecularity.

24. The rate expression for the decomposition of X is

\[ \text{rate} = k \ [X] \]

Values of half-life were measured at intervals during the decomposition. Which of the following shows the correct intervals for the successive half lives (in minutes)?

A. 0.2, 0.4, 0.6, 0.8
B. 0.4, 0.4, 0.4, 0.4
C. 0.8, 0.6, 0.4, 0.2
D. 0.8, 0.4, 0.2, 0.1

25. Consider the following reaction:

\[ \text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g}) \quad \Delta H^0 = -92 \text{kJ} \]

Which of the following affects the value of \( K_c \)?

A. Adding a catalyst
B. Increasing the pressure
C. Increasing the concentrations of nitrogen and hydrogen
D. Increasing the temperature
22. The table shows data for a reaction between X and Y.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>[X] mol dm(^{-3})</th>
<th>[Y] mol dm(^{-3})</th>
<th>Rate of reaction mol dm(^{-3}) s(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.4</td>
<td>0.24</td>
<td>1.2 \times 10^{-4}</td>
</tr>
<tr>
<td>2</td>
<td>0.8</td>
<td>0.24</td>
<td>2.4 \times 10^{-4}</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>0.12</td>
<td>3.0 \times 10^{-5}</td>
</tr>
</tbody>
</table>

The overall order of reaction is:

A. 1

B. 2

C. 3

D. 4

23. Which units could be used for the rate of a chemical reaction?

A. mol dm\(^{-3}\) min

B. mol\(^{-1}\) min\(^{-1}\)

C. dm\(^3\) min

D. mol dm\(^{-3}\) min\(^{-1}\)

24. 10 cm\(^3\) of liquid hexane is placed in a closed 1 dm\(^3\) container at 298K. Which change would increase the equilibrium vapour pressure of the hexane in the container?

A. Putting the container in a refrigerator

B. Adding 10 cm\(^3\) of hexane to the container

C. Reducing the volume of the container to 0.5 dm\(^3\)

D. Putting the container in a water bath at 308 K
25. Which change will increase the equilibrium concentration of sulfur trioxide in this reaction?

\[2\text{SO}_2 (g) + \text{O}_2 (g) \rightleftharpoons 2\text{SO}_3 (g) \quad \Delta H^\circ = \text{negative}\]

A. Decreasing the concentration of oxygen
B. Increasing the pressure
C. Using a catalyst
D. Increasing the temperature

**Topic 6 Mark Scheme**

|-------------------------------|-------|-------|-------|-------|
Q# 157/ IB/P1/2010/w/TZ 0/HL/  
19.  A  
20.  C  
21.  B  
Q# 158/ IB/P1/2010/s/TZ 2/HL/  
18.  C  
21.  D  
22.  D  
Q# 159/ IB/P1/2010/s/TZ 1/HL/  
19.  C  
20.  C  
21.  B  
22.  D  
23.  C  
Q# 160/ IB/P1/2009/w/TZ 0/HL/  
19.  B  
20.  C  
21.  D  
Q# 161/ IB/P1/2009/s/TZ 2/HL/  
20.  C  
21.  B  
22.  C  
23.  B  
24.  B  
Q# 162/ IB/P1/2009/s/TZ 1/HL/  
19.  D  
20.  D  
21.  C  
22.  C  
23.  C  
Q# 163/ IB/P1/2008/w/TZ 0/HL/  
22.  C  
Q# 164/ IB/P1/2008/s/TZ 2/HL/  
22.  B  
Q# 165/ IB/P1/2008/s/TZ 1/HL/  
22.  C  

Topic 7
Topic Chem 7 Q# 166/ IB/Paper 1/2016/w/Time Zone 2/Higher Level/  
24. What happens when the temperature of the following equilibrium system is increased?

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \quad \Delta H^\circ = -91 \text{ kJ} \]

<table>
<thead>
<tr>
<th>Position of equilibrium</th>
<th>Reaction rates of forward and reverse reactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>increase</td>
</tr>
<tr>
<td>B.</td>
<td>decrease</td>
</tr>
<tr>
<td>C.</td>
<td>decrease</td>
</tr>
<tr>
<td>D.</td>
<td>increase</td>
</tr>
</tbody>
</table>

25. A mixture of 0.40 mol of CO(g) and 0.40 mol of H₂(g) was placed in a 1.00 dm³ vessel. The following equilibrium was established:

\[ \text{CO}(g) + 2\text{H}_2(g) \rightleftharpoons \text{CH}_3\text{OH}(g) \]

At equilibrium, the mixture contained 0.25 mol of CO(g). How many moles of H₂(g) and CH₃OH(g) were present at equilibrium?

<table>
<thead>
<tr>
<th>Equilibrium mol of H₂</th>
<th>Equilibrium mol of CH₃OH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 0.25</td>
<td>0.15</td>
</tr>
<tr>
<td>B. 0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>C. 0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>D. 0.10</td>
<td>0.15</td>
</tr>
</tbody>
</table>
20. Graph 1 shows a plot of volume of CO₂(g) against time for the reaction of CaCO₃(s) with 1.00 mol dm⁻³ HCl (aq). The acid is the limiting reagent and entirely covers the lumps of CaCO₃(s).

Which set of conditions is most likely to give the data plotted in graph 2 when the same mass of CaCO₃(s) is reacted with the same volume of HCl(aq) at the same temperature?

<table>
<thead>
<tr>
<th>Size of lumps</th>
<th>Concentration of acid / mol dm⁻³</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. larger</td>
<td>1.00</td>
</tr>
<tr>
<td>B. smaller</td>
<td>0.05</td>
</tr>
<tr>
<td>C. smaller</td>
<td>1.00</td>
</tr>
<tr>
<td>D. larger</td>
<td>0.05</td>
</tr>
</tbody>
</table>

21. The data shows the effect of changing reactant concentrations on the rate of the following reaction at 25°C.

\[ \text{F}_2(g) + 2\text{ClO}_2(g) \rightarrow 2\text{FClO}_2(g) \]

<table>
<thead>
<tr>
<th>Initial [F₂(g)] / mol dm⁻³</th>
<th>Initial [ClO₂(g)] / mol dm⁻³</th>
<th>Initial rate of reaction / mol dm⁻³ s⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.100</td>
<td>0.010</td>
<td>1.20 × 10⁻³</td>
</tr>
<tr>
<td>0.100</td>
<td>0.030</td>
<td>3.60 × 10⁻³</td>
</tr>
<tr>
<td>0.150</td>
<td>0.010</td>
<td>1.80 × 10⁻³</td>
</tr>
</tbody>
</table>

Which is correct for the order of reaction with respect to the fluorine concentration and the overall order of reaction?

<table>
<thead>
<tr>
<th>Order with respect to [F₂(g)]</th>
<th>Overall order</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 2</td>
<td>1</td>
</tr>
<tr>
<td>B. 2</td>
<td>2</td>
</tr>
<tr>
<td>C. 1</td>
<td>1</td>
</tr>
<tr>
<td>D. 1</td>
<td>2</td>
</tr>
</tbody>
</table>
22. Which pair of graphs represents the same order of reaction?

A. 

![Graph A]

B. 

![Graph B]

C. 

![Graph C]

D. 

![Graph D]
23. Which of the terms in the Arrhenius equation takes into account the orientation of the molecules?

\[ k = Ae^{-\frac{E_a}{RT}} \]

A. \( A \)
B. \( E_a \)
C. \( R \)
D. \( T \)

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24. What is the effect of increasing temperature on the equilibrium?

\[ \text{ClNO}_2(g) + \text{NO}(g) \rightleftharpoons \text{ClNO}(g) + \text{NO}_2(g) \quad \Delta H^\circ = -18.4 \text{ kJ} \]

<table>
<thead>
<tr>
<th>Position of equilibrium</th>
<th>( K_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. moves to left</td>
<td>decreases</td>
</tr>
<tr>
<td>B. moves to left</td>
<td>no change</td>
</tr>
<tr>
<td>C. moves to right</td>
<td>no change</td>
</tr>
<tr>
<td>D. moves to right</td>
<td>increases</td>
</tr>
</tbody>
</table>

25. Which is correct for an isolated system in equilibrium?

<table>
<thead>
<tr>
<th>Gibbs free energy</th>
<th>Entropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. maximum</td>
<td>maximum</td>
</tr>
<tr>
<td>B. maximum</td>
<td>minimum</td>
</tr>
<tr>
<td>C. minimum</td>
<td>maximum</td>
</tr>
<tr>
<td>D. minimum</td>
<td>minimum</td>
</tr>
</tbody>
</table>

Topic Chem 7 Q# 169/ IB/Paper 1/2016/s/Specimen Paper/Higher Level/zz

24. Which conditions give the greatest equilibrium yield of methanal, \( \text{H}_2\text{CO}(g) \)?

\[ \text{CO}(g) + \text{H}_2(g) \rightleftharpoons \text{H}_2\text{CO}(g) \quad \Delta H = -1.8 \text{ kJ} \]

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. high</td>
<td>low</td>
</tr>
<tr>
<td>B. high</td>
<td>high</td>
</tr>
<tr>
<td>C. low</td>
<td>high</td>
</tr>
<tr>
<td>D. low</td>
<td>low</td>
</tr>
</tbody>
</table>
25. Which combination of temperature and equilibrium constant is most typical of a reaction going to completion? (Refer to the equation $\Delta G = -RT \ln K$.)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Equilibrium constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. high</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>B. high</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>C. low</td>
<td>&gt; 1</td>
</tr>
<tr>
<td>D. low</td>
<td>&lt; 1</td>
</tr>
</tbody>
</table>

22. Which best describes a reaction in a state of equilibrium?

A. The rates of the forward and reverse reactions are zero and the concentrations of products and reactants are equal.

B. The rate of the forward reaction equals the rate of the reverse reaction and the concentrations of products and reactants are equal.

C. The rates of the forward and reverse reactions are zero and the concentrations of products and reactants are constant.

D. The rate of the forward reaction equals the rate of the reverse reaction and the concentrations of products and reactants are constant.

23. The equilibrium concentrations of $X$, $Y$, $Z$ and $W$ are 1, 2, 4 and 2 mol dm$^{-3}$ respectively.

$$X(g) + 2Y(g) \rightleftharpoons Z(g) + W(g)$$

What is the value of the equilibrium constant, $K_c$?

A. 0.25

B. 0.5

C. 2

D. 4

22. Which combination of temperature and pressure will give the greatest yield of sulfur trioxide?

$$2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad \Delta H = -196 \text{kJ}$$

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. high</td>
<td>low</td>
</tr>
<tr>
<td>B. low</td>
<td>high</td>
</tr>
<tr>
<td>C. high</td>
<td>high</td>
</tr>
<tr>
<td>D. low</td>
<td>low</td>
</tr>
</tbody>
</table>
23. The equation for the reaction between two gases, A and B, is:

\[ 2A(g) + 3B(g) \rightleftharpoons C(g) + 3D(g) \]

When the reaction is at equilibrium at 600 K the concentrations of A, B, C and D are 2, 1, 3 and 2 mol dm\(^{-3}\) respectively. What is the value of the equilibrium constant at 600 K?

A. \( \frac{1}{6} \)

B. \( \frac{9}{7} \)

C. 3

D. 6

22. Carbon monoxide and water react together in the industrial production of hydrogen gas.

\[ CO(g) + H_2O(g) \rightleftharpoons CO_2(g) + H_2(g) \]

What is the impact of decreasing the volume of the equilibrium mixture at a constant temperature?

A. The amount of \( H_2(g) \) remains the same but its concentration decreases.

B. The forward reaction is favoured.

C. The reverse reaction is favoured.

D. The value of \( K_c \) remains unchanged.

22. Which equilibrium reaction shifts to the product side when the temperature is increased at constant pressure and to the reactant side when the total pressure is increased at constant temperature?

A. \( N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \quad \Delta H^\circ < 0 \)

B. \( N_2O_4(g) \rightleftharpoons 2NO_2(g) \quad \Delta H^\circ > 0 \)

C. \( H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \quad \Delta H^\circ < 0 \)

D. \( PCl_3(g) + Cl_2(g) \rightleftharpoons PCl_5(g) \quad \Delta H^\circ > 0 \)
23. A mixture of 2.0 mol of H₂ and 2.0 mol of I₂ is allowed to reach equilibrium in the gaseous state at a certain temperature in a 1.0 dm³ flask. At equilibrium, 3.0 mol of HI are present. What is the value of \( K_c \) for this reaction?

\[ \text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g}) \]

A. \( K_c = \frac{(3.0)^2}{(0.5)^2} \)

B. \( K_c = \frac{3.0}{(0.5)^2} \)

C. \( K_c = \frac{(3.0)^2}{(2.0)^2} \)

D. \( K_c = \frac{(0.5)^2}{(3.0)^2} \)

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8. Which statements explain why a catalyst is used in the Contact process (shown below)?

\[ \text{SO}_2(\text{g}) + \frac{1}{2} \text{O}_2(\text{g}) \rightleftharpoons \text{SO}_3(\text{g}) \]

I. A catalyst lowers the activation energy.

II. A catalyst moves the position of equilibrium towards the product.

III. A catalyst allows the same rate to be achieved at a lower temperature.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III
23. What is the equilibrium constant expression, $K_c$, for this reaction?

$$2\text{NO}(g) + \text{H}_2(g) \rightleftharpoons \text{N}_2\text{O}(g) + \text{H}_2\text{O}(g)$$

A. $K_c = \frac{[\text{N}_2\text{O}][\text{H}_2\text{O}]}{2[\text{NO}][\text{H}_2]}$

B. $K_c = \frac{[\text{NO}]^2[\text{H}_2]}{[\text{N}_2\text{O}][\text{H}_2\text{O}]}$

C. $K_c = \frac{2[\text{NO}][\text{H}_2]}{[\text{N}_2\text{O}][\text{H}_2\text{O}]}$

D. $K_c = \frac{[\text{N}_2\text{O}][\text{H}_2\text{O}]}{[\text{NO}]^2[\text{H}_2]}$

22. Which statement is correct for a reversible reaction when $K_c >> 1$?

A. The reaction almost goes to completion.

B. The reaction hardly occurs.

C. Equilibrium is reached in a very short time.

D. At equilibrium, the rate of the forward reaction is much higher than the rate of the backward reaction.

23. Which of the following will shift the position of equilibrium to the right in the Haber process?

$$\text{N}_2(g) + 3\text{H}_2(g) \rightleftharpoons 2\text{NH}_3(g) \quad \Delta H^\circ = -92.6\text{kJ}$$

I. Decreasing the concentration of $\text{NH}_3(g)$

II. Decreasing the temperature

III. Increasing the pressure

A. I and II only

B. I and III only

C. II and III only

D. I, II and III
23. Hydrogen and iodine react in a closed vessel to form hydrogen iodide.

\[ \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \]

At 350 °C \[ K_c = 60 \]
At 445 °C \[ K_c = 47 \]

Which statement describes and explains the conditions that favour the formation of hydrogen iodide?

A. Increased temperature as the forward reaction is exothermic, and increased pressure as there are two gaseous reactants and only one gaseous product

B. Increased temperature as the forward reaction is endothermic, and pressure has no effect as there are equal amounts, in mol, of gaseous reactants and products

C. Decreased temperature as the forward reaction is exothermic, and decreased pressure as there are two moles of gaseous product but only one mole of each gaseous reactant

D. Decreased temperature as the forward reaction is exothermic, and pressure has no effect as there are equal amounts, in mol, of gaseous reactants and products

22. Which changes occur when the temperature is decreased in the following equilibrium?

\[ 2\text{BrCl}(g) \rightleftharpoons \text{Br}_2(g) + \text{Cl}_2(g) \quad \Delta H^\circ = -14 \text{ kJ} \]

<table>
<thead>
<tr>
<th>Position of equilibrium</th>
<th>Value of ( K_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. shifts to the right</td>
<td>decreases</td>
</tr>
<tr>
<td>B. shifts to the right</td>
<td>increases</td>
</tr>
<tr>
<td>C. shifts to the left</td>
<td>decreases</td>
</tr>
<tr>
<td>D. shifts to the left</td>
<td>increases</td>
</tr>
</tbody>
</table>

23. When gaseous nitrosyl chloride, NOCl(g), decomposes, the following equilibrium is established:

\[ 2\text{NOCl}(g) \rightleftharpoons 2\text{NO}(g) + \text{Cl}_2(g) \]

2.0 mol of NOCl(g) were placed in a 1.0 dm³ container and allowed to reach equilibrium. At equilibrium 1.0 mol of NOCl(g) was present. What is the value of \( K_c \)?

A. 0.50

B. 1.0

C. 1.5

D. 2.0
22. Iron(III) ions, Fe$^{3+}$, react with thiocyanate ions, SCN$^-$, in a reversible reaction to form a red solution. Which changes to the equilibrium will make the solution go red?

$$
\text{Fe}^{3+}(aq) + \text{SCN}^-(aq) \rightleftharpoons [\text{FeSCN}]^{2+}(aq) \quad \Delta H^{\circ} = +\text{ve}
$$

Yellow \hspace{1cm} \text{Red}

I. Increasing the temperature
II. Adding FeCl$_3$
III. Adding a catalyst

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

23. Consider the following reversible reaction:

$$
2\text{NO}_2(g) \rightleftharpoons \text{N}_2\text{O}_4(g)
$$

What is the value of $K_c$ for the reaction when the equilibrium concentrations are $[\text{NO}_2] = 4.0 \text{ mol dm}^{-3}$ and $[\text{N}_2\text{O}_4] = 4.0 \text{ mol dm}^{-3}$?

A. 0.25
B. 0.50
C. 2.0
D. 4.0

Topic Chem 7 Q# 181/ IB/Paper 1/2012/s/Time Zone 2/Higher Level/

21. What happens to the position of equilibrium and the value of $K_c$ when the temperature is increased in the following reaction?

$$
\text{PCl}_3(g) \rightleftharpoons \text{PCl}_5(g) + \text{Cl}_2(g) \quad \Delta H^{\circ} = +87.9 \text{ kJ mol}^{-1}
$$

<table>
<thead>
<tr>
<th>Position of equilibrium</th>
<th>Value of $K_c$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. shifts towards reactants</td>
<td>decreases</td>
</tr>
<tr>
<td>B. shifts towards reactants</td>
<td>increases</td>
</tr>
<tr>
<td>C. shifts towards products</td>
<td>decreases</td>
</tr>
<tr>
<td>D. shifts towards products</td>
<td>increases</td>
</tr>
</tbody>
</table>

Topic Chem 7 Q# 182/ IB/Paper 1/2011/w/Time Zone 0/Higher Level/
23. Which are characteristics of a dynamic equilibrium?
   I. Amounts of products and reactants are constant.
   II. Amounts of products and reactants are equal.
   III. The rate of the forward reaction is equal to the rate of the backward reaction.

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III


23. The reaction below represents the Haber process for the industrial production of ammonia.

   \[ \text{N}_2 (g) + 3\text{H}_2 (g) \rightleftharpoons 2\text{NH}_3 (g) \quad \Delta H^\circ = -92 \text{ kJ} \]

   The optimum conditions of temperature and pressure are chosen as a compromise between those that favour a high yield of ammonia and those that favour a fast rate of production. Economic considerations are also important.

   Which statement is correct?

   A. A higher temperature would ensure a higher yield and a faster rate.
   B. A lower pressure would ensure a higher yield at a lower cost.
   C. A lower temperature would ensure a higher yield and a faster rate.
   D. A higher pressure would ensure a higher yield at a higher cost.

   Topic Chem 7 Q# 184/ IB/Paper 1/2011/s/Time Zone 1/Higher Level/

24. Which statement about chemical equilibria implies they are dynamic?

   A. The position of equilibrium constantly changes.
   B. The rates of forward and backward reactions change.
   C. The reactants and products continue to react.
   D. The concentrations of the reactants and products continue to change.
22. What is the effect of an increase of temperature on the yield and the equilibrium constant for the following reaction?

\[
2\text{H}_2(\text{g}) + \text{CO}(\text{g}) \rightleftharpoons \text{CH}_3\text{OH}(\text{l}) \quad \Delta H^\circ = -128 \text{ kJ}
\]

<table>
<thead>
<tr>
<th></th>
<th>Yield</th>
<th>Equilibrium constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Increases</td>
<td>Increases</td>
</tr>
<tr>
<td>B</td>
<td>Increases</td>
<td>Decreases</td>
</tr>
<tr>
<td>C</td>
<td>Decreases</td>
<td>Increases</td>
</tr>
<tr>
<td>D</td>
<td>Decreases</td>
<td>Decreases</td>
</tr>
</tbody>
</table>

23. 0.50 mol of I\(_2\) (g) and 0.50 mol of Br\(_2\) (g) are placed in a closed flask. The following equilibrium is established.

\[
\text{I}_2(\text{g}) + \text{Br}_2(\text{g}) \rightleftharpoons 2\text{IBr}(\text{g})
\]

The equilibrium mixture contains 0.80 mol of IBr (g). What is the value of \(K_c\)?

A. 0.64
B. 1.3
C. 2.6
D. 64

23. Which statement is correct for a crystal of iron(II) sulfate in a state of equilibrium with a saturated solution of iron(II) sulfate?

A. The colour of the solution darkens as the crystal continues to dissolve.
B. The concentration of the iron(II) sulfate solution increases as the water evaporates.
C. The shape of the iron(II) sulfate crystal does not change.
D. The colour of the solution does not change but the shape of the crystal may change.
22. An increase in temperature increases the amount of chlorine present in the following equilibrium.

\[ \text{PCl}_5(s) \rightleftharpoons \text{PCl}_3(l) + \text{Cl}_2(g) \]

What is the best explanation for this?

A. The higher temperature increases the rate of the forward reaction only.

B. The higher temperature increases the rate of the reverse reaction only.

C. The higher temperature increases the rate of both reactions but the forward reaction is affected more than the reverse.

D. The higher temperature increases the rate of both reactions but the reverse reaction is affected more than the forward.

24. Consider the following reversible reaction.

\[ \text{Cr}_2\text{O}_7^{2-}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons 2\text{CrO}_4^{2-}(aq) + 2\text{H}^+(aq) \]

What will happen to the position of equilibrium and the value of \( K_c \) when more \( \text{H}^+ \) ions are added at constant temperature?

<table>
<thead>
<tr>
<th>Position of equilibrium</th>
<th>Value of ( K_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. shifts to the left</td>
<td>decreases</td>
</tr>
<tr>
<td>B. shifts to the right</td>
<td>increases</td>
</tr>
<tr>
<td>C. shifts to the right</td>
<td>does not change</td>
</tr>
<tr>
<td>D. shifts to the left</td>
<td>does not change</td>
</tr>
</tbody>
</table>
25. The graph below shows how the concentrations of the reactant and product in a reversible reaction change with time.

![Graph showing reactant and product concentrations over time](image)

When is the reaction at equilibrium?

I. Time = 10 s
II. Time = 20 s
III. Time = 55 s

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
27. The equation for a reversible process can be represented in two ways:

\[ \text{H}_2(g) + \text{I}_2(g) \rightleftharpoons 2\text{HI}(g) \quad K_{c_1} \]

\[ \text{HI}(g) \rightleftharpoons \frac{1}{2}\text{H}_2(g) + \frac{1}{2}\text{I}_2(g) \quad K_{c_2} \]

What is the relationship between the equilibrium constants \( K_{c_1} \) and \( K_{c_2} \)?

A. \( K_{c_1} = K_{c_2} \)

B. \( K_{c_1} = \frac{1}{2K_{c_2}} \)

C. \( K_{c_1} = \frac{1}{2K_{c_2}^3} \)

D. \( K_{c_1} = \frac{1}{2K_{c_2}^2} \)

25. Which change will increase the equilibrium concentration of sulfur trioxide in this reaction?

\[ 2\text{SO}_2(g) + \text{O}_2(g) \rightleftharpoons 2\text{SO}_3(g) \quad \Delta H^\circ = \text{negative} \]

A. Decreasing the concentration of oxygen

B. Increasing the pressure

C. Using a catalyst

D. Increasing the temperature

Topic 7 Mark Scheme

Q# 166/ IB/P1/2016/w/TZ 2/HL/
24. A
25. D

Q# 167/ IB/P1/2016/s/TZ 0/HL/
20. C
21. D
22. C
23. A

Q# 168/ IB/P1/2016/s/TZ 0/HL/
24. A
25. C

Q# 169/ IB/P1/2016/s/SpcmP/HL/
24. A
25. A

Q# 170/ IB/P1/2015/w/TZ 2/HL/
22. D

Q# 171/ IB/P1/2015/s/TZ 2/HL/
23. C

Q# 172/ IB/P1/2015/s/TZ 1/HL/
22. B

Q# 173/ IB/P1/2014/w/TZ 0/HL/
22. B

Q# 174/ IB/P1/2014/s/TZ 2/HL/
8. B

Q# 175/ IB/P1/2014/s/TZ 2/HL/
23. D

Q# 176/ IB/P1/2014/s/TZ 1/HL/
22. A

Q# 177/ IB/P1/2013/w/TZ 0/HL/
23. D

Q# 178/ IB/P1/2013/s/TZ 2/HL/
23. D

Q# 179/ IB/P1/2013/s/TZ 1/HL/
22. B

Q# 180/ IB/P1/2012/w/TZ 0/HL/
22. A

Q# 181/ IB/P1/2012/s/TZ 2/HL/
23. A

Q# 182/ IB/P1/2011/w/TZ 0/HL/
23. B

Q# 183/ IB/P1/2011/s/TZ 2/HL/
23. D
Topic 8

**Chem 8 Q# 193/ IB/Paper 1/2016/w/Time Zone 2/Higher Level/**

26. Which species behave as Brønsted–Lowry bases in the following reaction?

\[ H_2SO_4 + HNO_3 \rightleftharpoons H_2NO_3^+ + HSO_4^- \]

A. \( HNO_3 \) and \( HSO_4^- \)
B. \( HNO_3 \) and \( H_2NO_3^+ \)
C. \( H_2SO_4 \) and \( HSO_4^- \)
D. \( H_2NO_3^+ \) and \( HSO_4^- \)

27. What occurs when solid sodium hydrogen carbonate reacts with aqueous sulfuric acid?

A. Bubbles of sulfur dioxide form.
B. Bubbles of both hydrogen and carbon dioxide form.
C. Bubbles of hydrogen form.
D. Bubbles of carbon dioxide form.

28. Which mixture is a buffer solution?

A. 25 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( NH_3 \) (aq) and 50 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( HCl \) (aq)
B. 50 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( NH_3 \) (aq) and 25 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( HCl \) (aq)
C. 25 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( NaOH \) (aq) and 25 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( HCl \) (aq)
D. 50 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( NaOH \) (aq) and 25 cm\(^3\) of 0.10 mol dm\(^{-3}\) \( HCl \) (aq)

29. Which salt solution has the highest pH?

A. \( NH_4Cl \)
B. \( Ca(NO_3)_2 \)
C. \( Na_2CO_3 \)
D. \( K_2SO_4 \)
26. Which is a conjugate Brønsted–Lowry acid-base pair?

\[ \text{CH}_3\text{COOH} (\text{aq}) + \text{H}_2\text{O} (\text{l}) \rightleftharpoons \text{CH}_3\text{COO}^- (\text{aq}) + \text{H}_3\text{O}^+ (\text{aq}) \]

A. \( \text{CH}_3\text{COO}^- / \text{H}_3\text{O}^+ \)
B. \( \text{H}_2\text{O} / \text{CH}_3\text{COO}^- \)
C. \( \text{H}_2\text{O} / \text{H}_3\text{O}^+ \)
D. \( \text{CH}_3\text{COOH} / \text{H}_2\text{O} \)

27. Aqueous solutions of a weak acid and a strong acid of equal concentration are compared. Which statements are correct?

I. The weak acid is less dissociated than the strong acid.
II. The strong acid reacts with a metal oxide but the weak acid does not.
III. The strong acid has greater conductivity than the weak acid.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

28. The diagram represents the bonding in aluminium chloride.

Which statement is correct?

A. The aluminium atoms behave as Lewis acids.
B. The aluminium atoms behave as Lewis bases.
C. One aluminium atom is a Lewis base and the other a Lewis acid.
D. One chlorine atom is a Lewis base and the other a Lewis acid.
29. Which titration curve would occur when a weak acid is added to a strong base?

A.  

B.  

C.  

D.  

Volume of weak acid

Volume of weak acid

Topic Chem 8 Q# 195/ IB/Paper 1/2016/s/Specimen Paper/Higher Level/

26. Which of the following is not amphiprotic?

A. \( \text{H}_2\text{O} \)

B. \( \text{HPO}_4^{2-} \)

C. \( \text{H}_2\text{PO}_4^- \)

D. \( \text{H}_2\text{O}^+ \)
27. The pH of a solution changes from 3 to 5. What happens to the concentration of hydrogen ions?
   A. It increases by a factor of 2.
   B. It increases by a factor of 100.
   C. It decreases by a factor of 2.
   D. It decreases by a factor of 100.

28. Which statement is correct about a Lewis base?
   A. It is an electron pair donor and can act as a nucleophile.
   B. It is an electron pair acceptor and can act as a nucleophile.
   C. It is an electron pair donor and can act as an electrophile.
   D. It is an electron pair acceptor and can act as an electrophile.

29. Which mixture forms a buffer solution with a pH < 7?
   A. 50 cm$^3$ 0.10 mol dm$^{-3}$ NH$_4$Cl (aq) + 50 cm$^3$ 0.10 mol dm$^{-3}$ NH$_3$(aq)
   B. 50 cm$^3$ 0.10 mol dm$^{-3}$ HCl (aq) + 100 cm$^3$ 0.10 mol dm$^{-3}$ NH$_3$(aq)
   C. 50 cm$^3$ 0.10 mol dm$^{-3}$ NaOH (aq) + 100 cm$^3$ 0.10 mol dm$^{-3}$ CH$_3$COOH (aq)
   D. 50 cm$^3$ 0.10 mol dm$^{-3}$ H$_2$SO$_4$(aq) + 100 cm$^3$ 0.10 mol dm$^{-3}$ NH$_3$(aq)

Topic Chem 8 Q# 196/ IB/Paper 1/2015/ w/Time Zone 2/Higher Level

24. Which of the following molecules can act as a Lewis acid but not as a Brønsted–Lowry acid?
   A. BF$_3$
   B. PCl$_3$
   C. NH$_3$
   D. H$_2$O

25. Which is a 0.001 mol dm$^{-3}$ solution of a weak acid?

<table>
<thead>
<tr>
<th>Conductivity</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. poor</td>
<td>5</td>
</tr>
<tr>
<td>B. good</td>
<td>7</td>
</tr>
<tr>
<td>C. poor</td>
<td>10</td>
</tr>
<tr>
<td>D. good</td>
<td>3</td>
</tr>
</tbody>
</table>
26. What is the order of increasing acid strength? Approximate $K_a$ and $pK_a$ values at 298 K are given.

<table>
<thead>
<tr>
<th></th>
<th>$K_a$</th>
<th></th>
<th>$pK_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClCH$_2$COOH</td>
<td>$1 \times 10^{-3}$</td>
<td>C$_6$H$_5$OH</td>
<td>10.0</td>
</tr>
<tr>
<td>CH$_3$CH$_2$COOH</td>
<td>$1 \times 10^{-5}$</td>
<td>C$_6$H$_5$NH$_3^+$</td>
<td>4.6</td>
</tr>
</tbody>
</table>

A. ClCH$_2$COOH < CH$_3$CH$_2$COOH < C$_6$H$_5$NH$_3^+$ < C$_6$H$_5$OH
B. C$_6$H$_5$OH < C$_6$H$_5$NH$_3^+$ < ClCH$_2$COOH < CH$_3$CH$_2$COOH
C. C$_6$H$_5$OH < C$_6$H$_5$NH$_3^+$ < CH$_3$CH$_2$COOH < ClCH$_2$COOH
D. C$_6$H$_5$OH < CH$_3$CH$_2$COOH < C$_6$H$_5$NH$_3^+$ < ClCH$_2$COOH

27. Which solutions, mixed in equal concentrations and volumes, form an acid buffer solution?

A. HCl (aq) + NaCl (aq)
B. CH$_3$CO$_2$H (aq) + CH$_3$CO$_2$Na (aq)
C. CH$_3$CO$_2$H (aq) + NaOH (aq)
D. CH$_3$CO$_2$H (aq) + CH$_3$CH$_2$CO$_2$H (aq)

28. Which salt forms the most acidic solution when dissolved in water?

<table>
<thead>
<tr>
<th>Salt</th>
<th>Ionic radius of cation / $10^{-12}$ m</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. CrCl$_3$</td>
<td>63</td>
</tr>
<tr>
<td>B. FeCl$_2$</td>
<td>76</td>
</tr>
<tr>
<td>C. MgCl$_2$</td>
<td>65</td>
</tr>
<tr>
<td>D. NaCl</td>
<td>98</td>
</tr>
</tbody>
</table>

29. What is the buffer region in the acid–base titration curves below?

![Titration curves](image)
24. Which species **cannot** function as a Lewis acid?

A. BF₃
B. AlCl₃
C. CCl₄
D. H⁺

25. 10.0 cm³ of a 1.00 x 10⁻² mol dm⁻³ aqueous solution of sodium hydroxide is added to a volumetric flask and the total volume is made up to 1.00 dm³ with distilled water. The resulting solution is then thoroughly mixed.

What is the pH of the diluted solution?

A. 9
B. 10
C. 12
D. 14

26. The strengths of four acids are:

<table>
<thead>
<tr>
<th>Acid</th>
<th>pKa</th>
</tr>
</thead>
<tbody>
<tr>
<td>glycine</td>
<td>pKa = 9.87</td>
</tr>
<tr>
<td>chloroethanoic acid</td>
<td>Kₐ = 1.38 x 10⁻³</td>
</tr>
<tr>
<td>phenol</td>
<td>Kₐ = 1.00 x 10⁻¹⁰</td>
</tr>
<tr>
<td>butanoic acid</td>
<td>pKa = 4.82</td>
</tr>
</tbody>
</table>

What is the order of **increasing** acid strength?

A. chloroethanoic acid < butanoic acid < phenol < glycine
B. glycine < phenol < chloroethanoic acid < butanoic acid
C. phenol < chloroethanoic acid < butanoic acid < glycine
D. phenol < glycine < butanoic acid < chloroethanoic acid

27. The pKₐ of ethanoic acid is 4.8 at 298K. Which combination will produce a buffer solution with a pH of 4.8 at 298K?

A. 20.0 cm³ of 1.0 mol dm⁻³ CH₃COOH and 10.0 cm³ of 1.0 mol dm⁻³ NaOH
B. 20.0 cm³ of 1.0 mol dm⁻³ CH₃COOH and 20.0 cm³ of 1.0 mol dm⁻³ NaOH
C. 10.0 cm³ of 1.0 mol dm⁻³ CH₃COOH and 20.0 cm³ of 1.0 mol dm⁻³ NaOH
D. 14.8 cm³ of 1.0 mol dm⁻³ CH₃COOH and 10.0 cm³ of 1.0 mol dm⁻³ NaOH
28. Which compound forms an acidic solution when dissolved in water?
   A. FeCl₃
   B. CH₃NH₂
   C. NaNO₃
   D. Na₂CO₃

29. For which titration can the end point **not** be determined accurately by using an acid-base indicator?
   A. NH₃(aq) + CH₃COOH(aq)
   B. NaOH(aq) + HNO₃(aq)
   C. NH₃(aq) + HNO₃(aq)
   D. NaOH(aq) + CH₃COOH(aq)

24. Which gas in the atmosphere causes the pH of unpolluted rain to be approximately 6?
   A. Carbon dioxide
   B. Sulfur dioxide
   C. Oxygen
   D. Nitrogen

25. Which compound is a strong acid?
   A. NH₃
   B. HNO₃
   C. H₂CO₃
   D. CH₃COOH

26. The forward reaction of this equilibrium is endothermic.

   \[ \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \quad K_w = 1.0 \times 10^{-14} \text{ at } 25^\circ\text{C} \]

   What is correct about water at 50 °C?
   A. \([\text{H}^+] > [\text{OH}^-]\)
   B. \([\text{H}^+] < [\text{OH}^-]\)
   C. pH < 7.0
   D. pH – 7.0
27. Which equation represents a reaction for which a base dissociation constant expression, \(K_b\), can be written?

A. \(\text{CH}_3\text{COO}^-\text{H}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{CH}_3\text{COO}^-(aq) + \text{NH}_4^+(aq)\)

B. \(\text{HF}(aq) \rightleftharpoons \text{H}^+(aq) + \text{F}^-(aq)\)

C. \(\text{HCN}(aq) + \text{OH}^-(aq) \rightleftharpoons \text{CN}^-(aq) + \text{H}_2\text{O}(l)\)

D. \(\text{NH}_3(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{NH}_4^+(aq) + \text{OH}^-(aq)\)

28. An equal amount of each of the following salts is added separately to the same volume of water. Which salt will have the greatest effect on the pH of water?

A. \(\text{Al(NO}_3)_3\)

B. \(\text{Na}_2\text{SO}_4\)

C. \(\text{RbCl}\)

D. \(\text{KBr}\)

29. Which mixture will form a buffer in aqueous solution?

A. 0.10 mol \(\text{NH}_3\) + 0.20 mol HCl

B. 0.10 mol \(\text{NH}_3\) + 0.20 mol NaOH

C. 0.10 mol NaOH + 0.20 mol KCl

D. 0.20 mol \(\text{NH}_3\) + 0.10 mol HCl

24. Which definition of a base is correct?

A. A Lewis base accepts a proton.

B. A Brønsted–Lowry base accepts an electron pair.

C. A Brønsted–Lowry base donates an electron pair.

D. A Lewis base donates an electron pair.
25. A student adds 0.3 g of magnesium metal to equal volumes of hydrochloric acid and ethanoic acid of the same concentrations in separate flasks. Which statement is correct?

A. Hydrochloric acid reacts more rapidly as it has a higher pH than ethanoic acid.
B. A greater total volume of H₂ gas is produced with hydrochloric acid than with ethanoic acid.
C. The same total volume of H₂ gas is produced with both hydrochloric acid and ethanoic acid.
D. Ethanoic acid reacts more slowly because it has a lower pH than hydrochloric acid.

26. Which compound will produce an aqueous solution which has a pH greater than 7?

A. CuSO₄
B. FeCl₃
C. Na₂CO₃
D. NH₄NO₃

27. Methylamine acts as a weak base when it reacts with water. For a diluted aqueous solution, what is the K_b expression for this reaction?

A. \( K_b = \frac{[\text{CH}_3\text{NH}_2^+][\text{OH}^-]}{[\text{CH}_3\text{NH}_3]^+} \)
B. \( K_b = \frac{[\text{CH}_3\text{NH}_2][\text{H}_2\text{O}]}{[\text{CH}_3\text{NH}_3^+][\text{OH}^-]} \)
C. \( K_b = \frac{[\text{CH}_3\text{NH}_2^+][\text{OH}^-]}{[\text{CH}_3\text{NH}_2][\text{H}_2\text{O}]} \)
D. \( K_b = \frac{[\text{CH}_3\text{NH}_2]}{[\text{CH}_3\text{NH}_3^+][\text{OH}^-]} \)
28. A buffer solution is formed by mixing equal volumes of 1.00 mol dm$^{-3}$ propanoic acid and 0.500 mol dm$^{-3}$ potassium propanoate.

What is the concentration, in mol dm$^{-3}$, of $[\text{H}^+(\text{aq})]$ in this buffer solution? ($K_a$ for propanoic acid is $1.30 \times 10^{-5}$.)

A. $2.60 \times 10^{-5}$
B. $1.95 \times 10^{-5}$
C. $1.30 \times 10^{-5}$
D. $0.650 \times 10^{-5}$

29. The acid–base indicator phenol red, HIn, changes colour from yellow to red over a pH range of 6.6–8.2. Which statement is correct?

A. In a strongly acidic solution $[\text{HIn}] \approx [\text{In}^-]$.
B. The $pK_a$ of phenol red is between 6.6 and 8.2.
C. The In$^-$ ions are yellow.
D. Phenol red would be a suitable indicator for the titration of a strong acid and a weak base.

Topic Chem 8 Q# 200/ IB/Paper 1/2014/s/Time Zone 2/Higher Level/

25. Which compound reacts with calcium oxide, CaO?

A. $\text{K}_2\text{O}$
B. $\text{Na}_2\text{O}$
C. $\text{SO}_2$
D. $\text{MgO}$

26. What is the conjugate base of phenol, $\text{C}_6\text{H}_5\text{OH}$?

A. $\text{C}_6\text{H}_5\text{H}_3^-$—OH
B. $\text{C}_6\text{H}_5^-\text{O}^-\text{H}_2$
C. $\text{C}_6\text{H}_5^-\text{O}^-$
D. $\text{C}_6\text{H}_6^-$—OH
27. Which compounds can be mixed together as aqueous solutions of equal volume and concentration to form an acidic buffer solution?

A. Sodium hydrogensulfate and sulfuric acid
B. Sodium propanoate and propanoic acid
C. Ammonium chloride and ammonia solution
D. Sodium chloride and hydrochloric acid

28. Which statements about an acid–base indicator are correct?

I. It can be a weak acid.
II. It is a substance in which the conjugate acid/base pair are different colours.
III. It can be a weak base.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

29. What is the expression for the ionic product constant of water, $K_w$?

A. $K_w = K_a \times K_b$
B. $K_w = K_a + K_b$
C. $K_w = \frac{K_a}{K_b}$
D. $K_w = K_a - K_b$
30. Which graph would be obtained by adding 0.10 mol dm$^{-3}$ HCl(aq) to 25 cm$^3$ of 0.10 mol dm$^{-3}$ NaOH(aq)?

A.  

![Graph A](image1.png)

B.  

![Graph B](image2.png)

C.  

![Graph C](image3.png)

D.  

![Graph D](image4.png)

24. In which reaction does H$_2$O act as a Lewis base but not as a Brønsted–Lowry base.

A.  

H$_2$O + NH$_4^+$ → H$_3$O$^+$ + NH$_3$

B.  

H$_2$O + CaO → Ca$^{2+}$ + 2OH$^-$

C.  

H$_2$O + [Fe(H$_2$O)$_6$]$_2^+$ → Fe[(OH)(H$_2$O)$_5$]$^{3+}$ + H$_3$O$^+$

D.  

6H$_2$O + [Ni(NH$_3$)$_4$]$_2^+$ → 6NH$_3$ + [Ni(H$_2$O)$_5$]$_2^+$

25. A solution of 50 cm$^3$ hydrochloric acid has a pH of 4. What is the final pH if 450 cm$^3$ of water is added?

A. 3

B. 4

C. 5

D. 6
26. The pKₐ of HS⁻ is 7.08. What is its conjugate acid and what is the Kₐ value of the acid?

<table>
<thead>
<tr>
<th>Conjugate acid</th>
<th>Kₐ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. H₂S</td>
<td>10⁻⁴.92</td>
</tr>
<tr>
<td>B. H₃S</td>
<td>6.92</td>
</tr>
<tr>
<td>C. S²⁻</td>
<td>10⁻⁴.01</td>
</tr>
<tr>
<td>D. S²⁻</td>
<td>6.92</td>
</tr>
</tbody>
</table>

27. Which mixture of solutions can be used to prepare a buffer solution?

A. 50.0 cm³ 0.100 mol dm⁻³ HCl and 100.0 cm³ 0.100 mol dm⁻³ NH₃
B. 50.0 cm³ 0.100 mol dm⁻³ HCl and 50.0 cm³ 0.100 mol dm⁻³ NH₃
C. 50.0 cm³ 0.100 mol dm⁻³ HCl and 100.0 cm³ 0.100 mol dm⁻³ NH₄Cl
D. 50.0 cm³ 0.100 mol dm⁻³ HCl and 50.0 cm³ 0.100 mol dm⁻³ NH₄Cl

28. A weak acid is titrated with a strong base. Which statement is true for the titration curve?

A. A is the equivalence point.
B. The pH at A equals the pKₐ of the acid.
C. The pH at B equals 7.
D. C is in the buffer region.
29. Methyl orange is an indicator which changes its colour from red to yellow in a pH range of 3.2 - 4.4. For which titration would methyl orange be a suitable indicator?

A. Iodine and sodium thiosulfate solution
B. Hydrochloric acid and ammonia solution
C. Ethanoic acid and sodium hydroxide solution
D. Ethanoic acid and ammonia solution

25. What are the conjugate acid–base pairs in the following reaction?

\[ \text{HCO}_3^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{OH}^- (aq) + \text{H}_2\text{CO}_3(aq) \]

<table>
<thead>
<tr>
<th>Brønsted–Lowry acid</th>
<th>Brønsted–Lowry base</th>
<th>Conjugate acid</th>
<th>Conjugate base</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. HCO$_3$^- (aq)</td>
<td>H$_2$O (l)</td>
<td>H$_2$CO$_3$ (aq)</td>
<td>OH$^-$ (aq)</td>
</tr>
<tr>
<td>B. H$_2$CO$_3$ (aq)</td>
<td>OH$^-$ (aq)</td>
<td>HCO$_3$^- (aq)</td>
<td>H$_2$O (l)</td>
</tr>
<tr>
<td>C. H$_2$O (l)</td>
<td>HCO$_3$^- (aq)</td>
<td>H$_2$CO$_3$ (aq)</td>
<td>OH$^-$ (aq)</td>
</tr>
<tr>
<td>D. H$_2$O (l)</td>
<td>HCO$_3$^- (aq)</td>
<td>OH$^-$ (aq)</td>
<td>H$_2$CO$_3$ (aq)</td>
</tr>
</tbody>
</table>

26. Which group of three compounds contains only weak acids and bases?

<table>
<thead>
<tr>
<th></th>
<th>Ba(OH)$_2$</th>
<th>CH$_3$NH$_2$</th>
<th>CH$_3$COOH</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.</td>
<td>CH$_3$CH$_2$CH$_2$COOH</td>
<td>CH$_3$CH$_2$NH$_2$</td>
<td>HCOOH</td>
</tr>
<tr>
<td>C.</td>
<td>NH$_3$</td>
<td>HNO$_3$</td>
<td>CH$_3$CH$_2$COOH</td>
</tr>
<tr>
<td>D.</td>
<td>NH$_3$</td>
<td>NaOH</td>
<td>H$_2$CO$_3$</td>
</tr>
</tbody>
</table>

27. What is the relationship between p$K_a$, p$K_b$, and p$K_w$ for a conjugate acid–base pair?

A. p$K_a = pK_w + pK_b$
B. p$K_a = pK_w - pK_b$
C. p$K_a \times pK_b = pK_w$
D. $\frac{pK_w}{pK_b} = pK_w$
28. The table below shows data for the $K_a$ and $pK_b$ values for some acids and bases at 298 K.

<table>
<thead>
<tr>
<th>Acid</th>
<th>$K_a$</th>
<th>Base</th>
<th>$pK_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HClO</td>
<td>$2.9 \times 10^{-2}$</td>
<td>NH$_3$</td>
<td>4.75</td>
</tr>
<tr>
<td>C$_6$H$_5$CH$_2$COOH</td>
<td>$4.9 \times 10^{-5}$</td>
<td>C$_6$H$_5$NH$_2$</td>
<td>9.13</td>
</tr>
</tbody>
</table>

Which two formulas represent the weakest acid and the weakest base in the table?
A. HClO and C$_6$H$_5$NH$_2$
B. C$_6$H$_5$CH$_2$COOH and NH$_3$
C. C$_6$H$_5$CH$_2$COOH and C$_6$H$_5$NH$_2$
D. HClO and NH$_3$

29. Which pair of compounds could be used to make a buffer solution (assuming appropriate molar ratios)?
A. KCl and HCl
B. NaCl and HCl
C. KHSO$_4$ and H$_2$SO$_4$
D. CH$_3$COONa and CH$_3$COOH

30. Which salts form acidic solutions when dissolved in water?
   I. NH$_4$Cl
   II. Cr(NO$_3$)$_3$
   III. CH$_3$COONa
A. I and II only
B. I and III only
C. II and III only
D. I, II and III
26. Which of the following is an example of a Lewis acid–base reaction, but not a Brønsted–Lowry acid–base reaction?

A. \(2\text{CrO}_4^{2-}(aq) + 2\text{H}^+(aq) \rightarrow \text{Cr}_2\text{O}_7^{2-}(aq) + \text{H}_2\text{O}(l)\)

B. \(\text{Co(H}_2\text{O})_6^{2+}(aq) + 4\text{HCl}(aq) \rightarrow \text{CoCl}_4^{2-}(aq) + 4\text{H}^+(aq) + 6\text{H}_2\text{O}(l)\)

C. \(\text{NH}_3(aq) + \text{H}^+(aq) \rightarrow \text{NH}_4^+(aq)\)

D. \(\text{CH}_3\text{COO}^-(aq) + \text{H}_2\text{O}(l) \rightarrow \text{CH}_3\text{COOH}(aq) + \text{OH}^-(aq)\)

27. Which list contains only strong bases?

A. ammonia, sodium hydroxide, ethylamine

B. potassium hydroxide, ammonia, sodium hydroxide

C. lithium hydroxide, potassium hydroxide, barium hydroxide

D. ammonia, ethylamine, barium hydroxide

28. The \(pK_a\) value of ammonia is 4.75 at 298 K. What is the \(pK_a\) value of the ammonium ion?

A. \(\frac{10^{-14}}{4.75}\)

B. \(\frac{14.00}{4.75}\)

C. \(14.00 - 4.75\)

D. \(\frac{10^{-14}}{10^{-4.75}}\)

29. The \(K_a\) values of four weak acids W, X, Y and Z are listed below.

\[
\begin{align*}
\text{W} & \quad K_a = 1.35 \times 10^{-3} \\
\text{X} & \quad K_a = 4.47 \times 10^{-2} \\
\text{Y} & \quad K_a = 9.33 \times 10^{-6} \\
\text{Z} & \quad K_a = 1.47 \times 10^{-5}
\end{align*}
\]
What is the correct order of increasing strength as acids?

A. $X < W < Z < Y$
B. $W < Z < X < Y$
C. $Y < X < Z < W$
D. $Y < Z < W < X$

24. In which equilibria are the conjugate acid–base pairs correctly labelled?

I. $\text{CO}_3^{2-}(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{HCO}_3^-(aq) + \text{OH}^- (aq)$
   Base 1   Acid 2   Acid 1   Base 2

II. $\text{HCO}_3^- (aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{CO}_3(aq) + \text{OH}^- (aq)$
   Base 1   Acid 2   Acid 1   Base 2

III. $\text{NH}_4^+(aq) + \text{H}_2\text{O}(l) \rightleftharpoons \text{H}_3\text{O}^+(aq) + \text{NH}_3(aq)$
    Acid 1   Base 2   Acid 2   Base 1

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

25. A solution of acid HX has a pH = 1 and a solution of acid HY has a pH = 3. Which statement must be correct?

A. HX is a stronger acid than HY.
B. HY is a stronger acid than HX.
C. The $[\text{H}^+]$ in the solution of HX is 100 times greater than the $[\text{H}^+]$ in the solution of HY.
D. The $[\text{H}^+]$ in the solution of HY is 100 times greater than the $[\text{H}^+]$ in the solution of HX.
26. The values of $K_w$, the ionic product constant of water, are:

<table>
<thead>
<tr>
<th>$K_w$</th>
<th>T / °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>$6.4\times10^{-15}$</td>
<td>18</td>
</tr>
<tr>
<td>$1.0\times10^{-14}$</td>
<td>25</td>
</tr>
</tbody>
</table>

Which statements are correct?

I. The $[\text{OH}^-]$ in water is less than the $[\text{H}^+]$ at 18 °C.
II. The ionization of water is an endothermic process.
III. The pH of water is lower at 25 °C than at 18 °C.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

27. For which equilibrium can an expression for a base dissociation constant, $K_b$, for the forward reaction be written?

A. $\text{NH}_3 + \text{H}_2\text{O} \rightleftharpoons \text{NH}_4^+ + \text{H}_2\text{O}$
B. $\text{F}^- + \text{H}_2\text{O} \rightleftharpoons \text{HF} + \text{OH}^-$
C. $\text{NH}_4^+ + \text{OH}^- \rightleftharpoons \text{NH}_3 + \text{H}_2\text{O}$
D. $\text{HF} + \text{OH}^- \rightleftharpoons \text{H}_2\text{O} + \text{F}^-$

28. Which of the following mixtures, in an aqueous solution, will produce a buffer solution?

I. 50 cm$^3$ of 0.1 mol dm$^{-3}$ CH$_3$COONa and 50 cm$^3$ of 0.1 mol dm$^{-3}$ CH$_3$COOH
II. 50 cm$^3$ of 0.1 mol dm$^{-3}$ NH$_3$ and 50 cm$^3$ of 0.1 mol dm$^{-3}$ NH$_4$Cl
III. 50 cm$^3$ of 0.1 mol dm$^{-3}$ NaOH and 50 cm$^3$ of 0.2 mol dm$^{-3}$ CH$_3$COOH

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
29. The colours of three indicators are shown in the table below.

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Colour at low pH</th>
<th>Colour at high pH</th>
<th>pH range at which colour change takes place</th>
</tr>
</thead>
<tbody>
<tr>
<td>methyl orange</td>
<td>red</td>
<td>yellow</td>
<td>3.2–4.4</td>
</tr>
<tr>
<td>bromothymol blue</td>
<td>yellow</td>
<td>blue</td>
<td>6.0–7.6</td>
</tr>
<tr>
<td>phenolphthalein</td>
<td>colourless</td>
<td>pink</td>
<td>8.2–10.0</td>
</tr>
</tbody>
</table>

Equal volumes of these three indicators were mixed and the mixture was added to a solution of pH = 5.0. What colour would be seen?

A. Yellow
B. Orange
C. Green
D. Blue

24. Which substance can act as a Lewis acid but not as a Brønsted–Lowry acid?

A. HCl
B. CH₂COOH
C. BF₃
D. CF₃COOH

25. Which row correctly describes 1.0 mol dm⁻³ NaOH (aq)?

<table>
<thead>
<tr>
<th>pH</th>
<th>Colour in universal indicator solution</th>
<th>Electrical conductivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>14</td>
<td>purple</td>
</tr>
<tr>
<td>B.</td>
<td>10</td>
<td>green</td>
</tr>
<tr>
<td>C.</td>
<td>14</td>
<td>red</td>
</tr>
<tr>
<td>D.</td>
<td>10</td>
<td>blue</td>
</tr>
</tbody>
</table>

26. For pure water at 50 °C, $K_w = 5.48 \times 10^{-14}$. What is the pH of this water?

A. 4.8
B. 6.6
C. 7.0
D. 8.2
27. Which is the strongest acid?

<table>
<thead>
<tr>
<th>Acid</th>
<th>$pK_a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. chloroethanoic</td>
<td>2.87</td>
</tr>
<tr>
<td>B. iodoethanoic</td>
<td>3.18</td>
</tr>
<tr>
<td>C. benzoic</td>
<td>4.20</td>
</tr>
<tr>
<td>D. pentanoic</td>
<td>4.83</td>
</tr>
</tbody>
</table>

28. Which salts will dissolve in water to give solutions with a pH above 7?

I. $\text{Na}_2\text{CO}_3$
II. $\text{CH}_3\text{COONa}$
III. $\text{Na}_2\text{SO}_4$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

29. During a titration, 0.1 mol dm$^{-3}$ sodium hydroxide is added to 0.1 mol dm$^{-3}$ ethanoic acid. Which indicator would be the best to use as an end point indicator in this titration?

<table>
<thead>
<tr>
<th>Indicator</th>
<th>pH range of indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. methyl orange</td>
<td>3.2–4.4</td>
</tr>
<tr>
<td>B. bromophenol blue</td>
<td>3.0–4.6</td>
</tr>
<tr>
<td>C. bromothymol blue</td>
<td>6.0–7.6</td>
</tr>
<tr>
<td>D. phenolphthalein</td>
<td>8.2–10.0</td>
</tr>
</tbody>
</table>
23. Which reaction represents an acid–base reaction according to the Lewis theory but not according to the Brønsted–Lowry theory?

A. $\text{CO}_3^{2-}(aq) + \text{H}_3\text{O}^+(aq) \rightleftharpoons \text{H}_2\text{O}(l) + \text{HCO}_3^-(aq)$

B. $\text{CH}_3\text{COOH}(aq) + \text{NH}_3(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{CH}_3\text{COO}^-(aq)$

C. $\text{NH}_3(aq) + \text{HF}(aq) \rightleftharpoons \text{NH}_4^+(aq) + \text{F}^-(aq)$

D. $\text{CuSO}_4(s) + 5\text{H}_2\text{O}(l) \rightleftharpoons \text{CuSO}_4 \cdot 5\text{H}_2\text{O}(s)$

24. Four aqueous solutions are listed below.

W. 0.100 mol dm$^{-3}$ HNO$_3(aq)$

X. 0.001 mol dm$^{-3}$ HNO$_3(aq)$

Y. 0.100 mol dm$^{-3}$ KOH(aq)

Z. 0.001 mol dm$^{-3}$ KOH(aq)

What is the correct order of increasing pH of these solutions?

A. W < X < Y < Z

B. W < X < Z < Y

C. X < W < Y < Z

D. X < W < Z < Y
25. Penicillin G (benzyl penicillin) contains a number of different functional groups and has the following structure:

![Penicillin G structure](image)

It is a weak monoprotic acid ($pK_a = 2.79$ at 298 K). At 298 K, the ionic product constant for water, $K_w = 1.00 \times 10^{-14}$. What is the value of $pK_b$ for the conjugate base of penicillin G and which functional groups are present in penicillin G?

<table>
<thead>
<tr>
<th>pK$_b$</th>
<th>Selected functional groups in penicillin G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 11.21</td>
<td>carboxylic acid, amine</td>
</tr>
<tr>
<td>B. 2.79</td>
<td>carboxylic acid, amide</td>
</tr>
<tr>
<td>C. 11.21</td>
<td>ketone, alcohol</td>
</tr>
<tr>
<td>D. 11.21</td>
<td>carboxylic acid, benzene ring</td>
</tr>
</tbody>
</table>
26. Which mixtures are buffer solutions?
   
   I. KHSO₄(aq) and H₂SO₄(aq)
   II. CH₃COONa(aq) and CH₃COOH(aq)
   III. HCOOK(aq) and HCOOH(aq)
   
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

27. Which titration curve is produced by the titration of 25 cm³ of 1.00 mol dm⁻³ NaOH with 1.00 mol dm⁻³ CH₃COOH?

A. ![Graph A]
B. ![Graph B]
C. ![Graph C]
D. ![Graph D]
24. Which are conjugate acid/base pairs according to the Bronsted–Lowry theory?

I. $\text{NH}_4^+ / \text{NH}_3$
II. $\text{HCOOH} / \text{HCOO}^-$
III. $\text{H}_2\text{SO}_4 / \text{SO}_4^{2-}$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

25. An aqueous solution $X$ reacts with a solid $Y$, to produce a flammable gas. Which of the following suggestions could substances $X$ and $Y$ be?

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>nitric acid, $\text{HNO}_3$</td>
<td>calcium carbonate, $\text{CaCO}_3$</td>
</tr>
<tr>
<td>sulfuric acid, $\text{H}_2\text{SO}_4$</td>
<td>zinc, $\text{Zn}$</td>
</tr>
<tr>
<td>hydrochloric acid, $\text{HCl}$</td>
<td>copper, $\text{Cu}$</td>
</tr>
<tr>
<td>sodium hydroxide solution, $\text{NaOH}$</td>
<td>aluminum oxide, $\text{Al}_2\text{O}_3$</td>
</tr>
</tbody>
</table>

26. Which is correct for a weak acid, $\text{HA}$, with concentration $0.01 \text{ mol dm}^{-3}$ at $298\text{K}$?

A. $[\text{H}^+] < 1 \times 10^{-2}$
B. pH $\approx 2$
C. $[\text{OH}^-] < 1 \times 10^{-12}$
D. pOH $> 12$
27. Which salt has the lowest pH when dissolved in water?

A. KNO₃
B. CH₃COONa
C. Na₂CO₃
D. [Fe(H₂O)₆]Cl₂

28. Which of the following mixtures would result in the pKₐ of the acid being obtained from a direct pH measurement of the resulting solution?

A. 25 cm³ 0.1 mol dm⁻³ HCl and 25 cm³ 0.1 mol dm⁻³ NaCl
B. 25 cm³ 0.1 mol dm⁻³ NaOH and 25 cm³ 0.1 mol dm⁻³ CH₃COOH
C. 12.5 cm³ 0.1 mol dm⁻³ CH₃COOH and 25 cm³ 0.1 mol dm⁻³ NaOH
D. 12.5 cm³ 0.1 mol dm⁻³ NaOH and 25 cm³ 0.1 mol dm⁻³ CH₃COOH

29. An aqueous solution of a weak acid containing an indicator is titrated with a strong base, resulting in the following titration curve.

At which pH does the buffer region occur?

A. Between 4.5 and 5.5
B. Between 7.5 and 9.5
C. At 9.5
D. At 12
25. Which descriptions are correct for both a Brønsted–Lowry acid and a Lewis acid?

<table>
<thead>
<tr>
<th>Brønsted–Lowry acid</th>
<th>Lewis acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. proton donor</td>
<td>electron pair donor</td>
</tr>
<tr>
<td>B. proton donor</td>
<td>electron pair acceptor</td>
</tr>
<tr>
<td>C. proton acceptor</td>
<td>electron pair donor</td>
</tr>
<tr>
<td>D. proton acceptor</td>
<td>electron pair acceptor</td>
</tr>
</tbody>
</table>

26. What is the pH of the solution formed when 10 cm$^3$ of HCl(aq) with pH 1.0 is added to 990 cm$^3$ of water?

A. 1.5
B. 2.0
C. 2.5
D. 3.0

27. Consider the equation for the dissociation of water:

$$\text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \quad \Delta H^\circ = +57.3 \text{kJ mol}^{-1}$$

Which statement is correct?

A. The pH of pure water is always 7.
B. At temperatures above 298 K the pH of pure water is below 7.
C. At temperatures above 298 K the pH of pure water is above 7.
D. $K_w$ decreases with increasing temperature.

28. Which combination of 1 mol dm$^{-3}$ solutions produces an acidic buffer?

A. 50 cm$^3$ HCl(aq) and 150 cm$^3$ NH$_3$(aq)
B. 100 cm$^3$ CH$_3$COOH(aq) and 50 cm$^3$ HCl(aq)
C. 100 cm$^3$ CH$_3$COOH(aq) and 50 cm$^3$ NaOH(aq)
D. 50 cm$^3$ CH$_3$COOH(aq) and 50 cm$^3$ NaOH(aq)
29. Which salt dissolves in water to form an acidic solution?
   A. Potassium ethanoate
   B. Calcium ethanoate
   C. Ammonium chloride
   D. Sodium carbonate

25. Which is not a conjugate acid-base pair?
   A. HNO₃ and NO₃⁻
   B. CH₃COOH and CH₃COO⁻
   C. H₂O⁺ and OH⁻
   D. HSO₄⁻ and SO₄²⁻

26. The pH of a solution changes from pH = 2 to pH = 5. What happens to the concentration of the hydrogen ions during this pH change?
   A. It decreases by a factor of 1000
   B. It increases by a factor of 1000
   C. It decreases by a factor of 100
   D. It increases by a factor of 100

27. Based on information in the table below, which acid is the strongest?

<table>
<thead>
<tr>
<th>Acid</th>
<th>pKₐ</th>
<th>Kₐ</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. HA</td>
<td>2.0</td>
<td>–</td>
</tr>
<tr>
<td>B. HB</td>
<td>–</td>
<td>1×10⁻³</td>
</tr>
<tr>
<td>C. HC</td>
<td>4.0</td>
<td>–</td>
</tr>
<tr>
<td>D. HD</td>
<td>–</td>
<td>1×10⁻⁵</td>
</tr>
</tbody>
</table>
28. Which combination will form a buffer solution?

A. 100 cm$^3$ of 0.10 mol dm$^{-3}$ hydrochloric acid with 50 cm$^3$ of 0.10 mol dm$^{-3}$ sodium hydroxide.

B. 100 cm$^3$ of 0.10 mol dm$^{-3}$ ethanoic acid with 50 cm$^3$ of 0.10 mol dm$^{-3}$ sodium hydroxide.

C. 50 cm$^3$ of 0.10 mol dm$^{-3}$ hydrochloric acid with 100 cm$^3$ of 0.10 mol dm$^{-3}$ sodium hydroxide.

D. 50 cm$^3$ of 0.10 mol dm$^{-3}$ ethanoic acid with 100 cm$^3$ of 0.10 mol dm$^{-3}$ sodium hydroxide.

29. The graph below shows the titration curve of 25 cm$^3$ of 0.100 mol dm$^{-3}$ of hydrochloric acid with sodium hydroxide, of 0.100 mol dm$^{-3}$ concentration. The indicator methyl orange was used to determine the equivalence point. Methyl orange has a pH range of 3.2–4.4.

If the hydrochloric acid was replaced by ethanoic acid of the same volume and concentration, which property of the titration would remain the same?

A. The initial pH

B. The pH at the equivalence point

C. The volume of strong base, NaOH, needed to reach the equivalence point

D. The colour of the titration mixture just before the equivalence point is reached
26. Which salts will produce an acidic solution when dissolved in water?

I. CH₃COOK
II. NH₄NO₃
III. Al₂(SO₄)₃

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

27. Consider the equilibrium below.

\[ \text{CH}_3\text{CH}_2\text{COOH (aq) + H}_2\text{O (l)} \rightleftharpoons \text{CH}_3\text{CH}_2\text{COO}^- \text{ (aq) + H}_3\text{O}^+ \text{ (aq)} \]

Which species represent a conjugate acid-base pair?

A. CH₃CH₂COOH and H₂O
B. H₂O and CH₃CH₂COO⁻
C. H₃O⁺ and H₂O
D. CH₃CH₂COO⁻ and H₃O⁺

28. The $K_b$ value for a base is $5.0 \times 10^{-2}$ mol dm$^{-3}$ at 298 K. What is the $K_a$ value for its conjugate acid at this temperature?

A. $5.0 \times 10^{-1}$
B. $2.0 \times 10^{-5}$
C. $2.0 \times 10^{-12}$
D. $2.0 \times 10^{-13}$
29. Which compounds can be mixed together as solutions of equal volume and concentration to form a buffer solution?

A. Nitric acid and potassium hydroxide
B. Nitric acid and potassium nitrate
C. Propanoic acid and potassium hydroxide
D. Propanoic acid and potassium propanoate

24. What is the conjugate base of $\text{H}_2\text{CO}_3$ according to the Bronsted-Lowry theory?

A. $\text{CO}_3^{2-}$
B. $\text{HCO}_3^-$
C. $\text{H}_2\text{CO}_3^+$
D. $\text{CO}_2$

25. A solution of acid A has a pH of 1 and a solution of acid B has a pH of 2. Which statement must be correct?

A. Acid A is stronger than acid B
B. $[\text{A}] > [\text{B}]$
C. The concentration of $\text{H}^+$ ions in A is higher than in B
D. The concentration of $\text{H}^+$ ions in B is twice the concentration of $\text{H}^+$ ions in A

26. Which mixtures act as buffer solutions?

I. 100 cm$^3$ 0.1 mol dm$^{-3}$ ethanoic acid and 100 cm$^3$ 0.1 mol dm$^{-3}$ sodium ethanoate
II. 100 cm$^3$ 0.1 mol dm$^{-3}$ ethanoic acid and 50 cm$^3$ 0.1 mol dm$^{-3}$ sodium hydroxide
III. 100 cm$^3$ 0.1 mol dm$^{-3}$ ethanoic acid and 100 cm$^3$ 0.5 mol dm$^{-3}$ sodium hydroxide

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
27. Which solutions have a pH less than 7?

I. Na₂CO₃(aq)
II. [Fe(H₂O)₆]Cl₃(aq)
III. (NH₄)₂SO₄(aq)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

28. Equal volumes and concentrations of hydrochloric acid and ethanoic acid are titrated with sodium hydroxide solutions of the same concentration. Which statement is correct?

A. The initial pH values of both acids are equal.
B. At the equivalence points, the solutions of both titrations have pH values of 7.
C. The same volume of sodium hydroxide is needed to reach the equivalence point.
D. The pH values of both acids increase equally until the equivalence points are reached.

29. Bromophenol blue changes from yellow to blue over the pH range of 3.0 to 4.6. Which statement is correct?

A. Molecules of bromophenol blue, HIn, are blue.
B. At pH < 3.0, a solution of bromophenol blue contains more ions, In⁻, than molecules, HIn.
C. The pKₐ of bromophenol blue is between 3.0 and 4.6.
D. Bromophenol blue is a suitable indicator to titrate ethanoic acid with potassium hydroxide solution.
24. Which species behave as Brønsted-Lowry acids in the following reversible reaction?

\[ \text{H}_2\text{PO}_4^- (aq) + \text{CN}^- (aq) \rightleftharpoons \text{HCN (aq)} + \text{HPO}_4^{2-} (aq) \]

A. HCN and CN\(^-\)
B. HCN and HPO\(_4^{2-}\)
C. H\(_3\)PO\(_4^-\) and HPO\(_4^{2-}\)
D. HCN and H\(_3\)PO\(_4^-\)

25. Which of the following are weak acids in aqueous solution?

I. CH\(_3\)COOH
II. H\(_2\)CO\(_3\)
III. HCl

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

26. \(pK_w\) for water at 10 °C = 14.54. What is the pH of pure water at this temperature?

A. 6.73
B. 7.00
C. 7.27
D. 7.54
27. What is $K_w$ for the aqueous fluoride ion given that $K_w$ is $1.0 \times 10^{-14}$ and $K_s$ for HF is $6.8 \times 10^{-4}$ at 298 K?

A. $\frac{1}{6.8 \times 10^{-4}}$

B. $(6.8 \times 10^{-4})(1.0 \times 10^{-14})$

C. $\frac{1.0 \times 10^{-14}}{6.8 \times 10^{-4}}$

D. $6.8 \times 10^{-4}$

28. Which of the following could be added to a solution of ethanoic acid to prepare a buffer?

A. Sodium hydroxide

B. Hydrochloric acid

C. Sodium chloride

D. More ethanoic acid

29. Which aqueous solution has a pH less than 7?

A. $\text{KNO}_3$ (aq)

B. $\text{Na}_2\text{CO}_3$ (aq)

C. $[\text{Fe(H}_2\text{O})_6\text{]Cl}_3$ (aq)

D. $\text{CH}_3\text{COONa}$ (aq)

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25. Which statement about acids is correct?

A. A Brønsted-Lowry acid donates an electron pair.

B. A Lewis acid donates a proton.

C. A Brønsted-Lowry acid accepts a proton.

D. A Lewis acid accepts an electron pair.
26. A student has equal volumes of 1.0 mol dm\(^{-3}\) sodium hydroxide and ammonia solutions. Which statement about the solutions is correct?

A. Sodium hydroxide has a lower electrical conductivity than ammonia.
B. Sodium hydroxide has a higher hydrogen ion concentration than ammonia.
C. Sodium hydroxide has a higher pH than ammonia.
D. Sodium hydroxide has a higher hydroxide ion concentration than ammonia.

27. What is the \(K_\text{b}\) expression for the reaction of ethylamine with water?

A. \(K_\text{b} = [\text{CH}_3\text{CH}_2\text{NH}_3^+][\text{OH}^-]\)
B. \(K_\text{b} = \frac{[\text{CH}_3\text{CH}_2\text{NH}_3^+][\text{OH}^-]}{[\text{CH}_3\text{CH}_2\text{NH}_2]}\)
C. \(K_\text{b} = \frac{[\text{CH}_3\text{CH}_2\text{NH}_3^+][\text{H}_2\text{O}]}{[\text{CH}_3\text{CH}_2\text{NH}_2]}\)
D. \(K_\text{b} = [\text{CH}_3\text{CH}_2\text{NH}_3][\text{H}_2\text{O}]\)

28. When these 1.0 mol dm\(^{-3}\) acidic solutions are arranged in order of increasing strength (weakest first), what is the correct order?

acid in solution X \(K_a = 1.74 \times 10^{-5}\) mol dm\(^{-3}\) at 298 K
acid in solution Y \(K_a = 1.38 \times 10^{-3}\) mol dm\(^{-3}\) at 298 K
acid in solution Z \(K_a = 1.78 \times 10^{-5}\) mol dm\(^{-3}\) at 298 K

A. X < Z < Y
B. X < Y < Z
C. Z < X < Y
D. Y < X < Z
29. Consider an acid-base indicator solution.

\[ \text{HIn (aq)} \rightleftharpoons \text{H}^+ (aq) + \text{In}^- (aq) \]

colour A    colour B

What is the effect on this acid-base indicator when sodium hydroxide solution is added to it?

A. Equilibrium shifts to the right and more of colour B is seen.
B. Equilibrium shifts to the left and more of colour B is seen.
C. Equilibrium shifts to the right and more of colour A is seen.
D. Equilibrium shifts to the left and more of colour A is seen.

24. According to the Brønsted-Lowry theory, how does each species act in the equilibrium below?

\[ \text{CH}_3\text{COOH} + \text{H}_2\text{SO}_4 \rightleftharpoons \text{CH}_3\text{COOH}_2^+ + \text{HSO}_4^- \]

<table>
<thead>
<tr>
<th></th>
<th>CH₃COOH</th>
<th>H₂SO₄</th>
<th>CH₃COOH⁺</th>
<th>HSO₄⁻</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>acid</td>
<td>base</td>
<td>base</td>
<td>acid</td>
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<tr>
<td>B.</td>
<td>acid</td>
<td>base</td>
<td>acid</td>
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<tr>
<td>C.</td>
<td>base</td>
<td>acid</td>
<td>base</td>
<td>acid</td>
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<tr>
<td>D.</td>
<td>base</td>
<td>acid</td>
<td>acid</td>
<td>base</td>
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</table>

25. If 20 cm³ samples of 0.1 mol dm⁻³ solutions of the acids below are taken, which acid would require a different volume of 0.1 mol dm⁻³ sodium hydroxide for complete neutralization?

A. Nitric acid
B. Sulfuric acid
C. Ethanoic acid
D. Hydrochloric acid
26. Which mixture of acid and alkali would produce a buffer solution?

<table>
<thead>
<tr>
<th></th>
<th>Acid</th>
<th>Alkali</th>
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</thead>
<tbody>
<tr>
<td>A.</td>
<td>40 cm$^3$ 0.1 mol dm$^{-3}$ HCl</td>
<td>60 cm$^3$ 0.1 mol dm$^{-3}$ NaOH</td>
</tr>
<tr>
<td>B.</td>
<td>60 cm$^3$ 0.1 mol dm$^{-3}$ HCl</td>
<td>40 cm$^3$ 0.1 mol dm$^{-3}$ NaOH</td>
</tr>
<tr>
<td>C.</td>
<td>40 cm$^3$ 0.1 mol dm$^{-3}$ HCl</td>
<td>60 cm$^3$ 0.1 mol dm$^{-3}$ NH$_3$</td>
</tr>
<tr>
<td>D.</td>
<td>60 cm$^3$ 0.1 mol dm$^{-3}$ HCl</td>
<td>40 cm$^3$ 0.1 mol dm$^{-3}$ NH$_3$</td>
</tr>
</tbody>
</table>

27. Which aqueous solution would have a pH > 7?

A. Sodium sulfate
B. Ammonium nitrate
C. Sodium ethanoate
D. Aluminium nitrate

28. Which indicator would be the most appropriate for titrating aqueous ethylamine, CH$_3$CH$_2$NH$_3$ with nitric acid, HNO$_3$?

A. Bromophenol blue ($pK_a = 4.1$)
B. Bromothymol blue ($pK_a = 7.3$)
C. Phenol red ($pK_a = 8.0$)
D. Thymolphthalein ($pK_a = 10.0$)


25. Which are definitions of an acid according to the Brønsted-Lowry and Lewis theories?

<table>
<thead>
<tr>
<th>Brønsted-Lowry theory</th>
<th>Lewis theory</th>
</tr>
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<tbody>
<tr>
<td>A. proton donor</td>
<td>electron pair acceptor</td>
</tr>
<tr>
<td>B. proton acceptor</td>
<td>electron pair acceptor</td>
</tr>
<tr>
<td>C. proton acceptor</td>
<td>electron pair donor</td>
</tr>
<tr>
<td>D. proton donor</td>
<td>electron pair donor</td>
</tr>
</tbody>
</table>
26. 100 cm$^3$ of a NaOH solution of pH 12 is mixed with 900 cm$^3$ of water. What is the pH of the resulting solution?

A. 1  
B. 3  
C. 11  
D. 13

27. Ammonia acts as a weak base when it reacts with water. What is the $K_b$ expression for this reaction?

A. $\frac{[NH_4^+][OH^-]}{[NH_3][H_2O]}$  
B. $\frac{[NH_3][H_2O]}{[NH_4^+][OH^-]}$  
C. $\frac{[NH_3]}{[NH_4^+][OH^-]}$  
D. $\frac{[NH_4^+][OH^-]}{[NH_3]}$

28. The indicator, HIn is used in a titration between an acid and base. Which statement about the dissociation of the indicator, HIn is correct?

$$\text{HIn} \ (\text{aq}) \rightleftharpoons H^+ \ (\text{aq}) + \text{In}^- \ (\text{aq})$$

\begin{align*}
\text{colour A} & \quad \text{colour B} \\
& \quad \\
\text{A. In a strongly alkaline solution, colour B would be observed.} \\
\text{B. In a strongly acidic solution, colour B would be observed.} \\
\text{C. [In$^-$] is greater than [HIn] at the equivalence point.} \\
\text{D. In a weakly acidic solution colour B would be observed.}
\end{align*}
29. At the same concentration, which acid would have the lowest pH?

A. HNO₂  \( K_a = 5.6 \times 10^{-4} \) mol dm\(^{-3} \)
B. HF  \( K_a = 6.8 \times 10^{-4} \) mol dm\(^{-3} \)
C. C₆H₅COOH  \( K_a = 6.3 \times 10^{-5} \) mol dm\(^{-3} \)
D. HCN  \( K_a = 4.9 \times 10^{-10} \) mol dm\(^{-3} \)

26. When equal volumes of four 0.1 mol dm\(^{-3} \) solutions are arranged in order of increasing pH (lowest pH first), what is the correct order?

A. CH₃COOH < HNO₃ < CH₃CH₂NH₂ < KOH
B. HNO₃ < CH₃COOH < CH₃CH₂NH₂ < KOH
C. CH₃CH₂NH₂ < HNO₃ < CH₃COOH < KOH
D. KOH < CH₃CH₂NH₂ < CH₃COOH < HNO₃

27. What is the correct expression for the ionic product constant of water, \( K_w \)?

A. \( K_w = \frac{[H^+]}{[OH^-]} \)
B. \( K_w = \frac{[H_2O]}{[H^+][OH^-]} \)
C. \( K_w = [H^+] + [OH^-] \)
D. \( K_w = [H^+][OH^-] \)

28. Which mixtures could act as buffers?

I. NaOH (aq) and HCl (aq)
II. NaOH (aq) and CH₃COOH (aq)
III. HCl (aq) and CH₃COONa (aq)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
29. What is the approximate pH of a 0.01 mol dm\(^{-2}\) ammonia solution?

A. 2
B. More than 2 but less than 7
C. More than 7 but less than 12
D. 12

28. Which combinations form buffer solutions?

I. 50 cm\(^3\) of 0.1 mol dm\(^{-3}\) CH\(_3\)COOH(aq) + 25 cm\(^3\) of 0.1 mol dm\(^{-3}\) NaOH (aq)
II. 50 cm\(^3\) of 0.1 mol dm\(^{-3}\) CH\(_3\)COOH(aq) + 50 cm\(^3\) of 0.1 mol dm\(^{-3}\) NaOH (aq)
III. 50 cm\(^3\) of 0.1 mol dm\(^{-3}\) CH\(_3\)COOH(aq) + 50 cm\(^3\) of 0.1 mol dm\(^{-3}\) CH\(_3\)COONa (aq)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

29. What is the definition of a Bronsted-Lowry acid?

A. A substance which accepts protons
B. A substance which reacts with OH\(^-\) ions
C. A substance which has a pH below 7
D. A substance which donates H\(^+\) ions

30. Which species can act as an acid according to the Lewis theory but not according to the Bronsted-Lowry theory?

A. NCl\(_3\)
B. HCl
C. H\(_3\)O
D. BF\(_3\)
31. Which salt produces the most acidic aqueous solution?
   A. KCl
   B. FeCl₃
   C. CH₃COONa
   D. NaNO₃

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27. Consider the ionization of water at 25°C:
   \[ \text{H}_2\text{O}(l) \rightleftharpoons \text{H}^+(aq) + \text{OH}^-(aq) \quad K_w = 1.0 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \]
   However, at 37°C, \( K_w = 2.4 \times 10^{-14} \text{ mol}^2 \text{ dm}^{-6} \). What can be deduced from this?
   A. The pH value of pure water decreases when heated.
   B. The enthalpy of ionization of water is negative.
   C. The [OH⁻] at 37°C is lower than 25°C.
   D. The conductivity of water at 37°C is lower than at 25°C.

28. What pair of solutions can be used to prepare a buffer solution?
   A. CH₃COONa (aq) / NaOH (aq)
   B. NH₃ (aq) / NH₄NO₃ (aq)
   C. NH₄Cl (aq) / HCl (aq)
   D. HNO₃ (aq) / NaNO₃ (aq)

29. Which equations represent acid-base reactions according to the Lewis theory?
   I. \( 2\text{H}_2(g) + \text{O}_2(g) \rightarrow 2\text{H}_2\text{O}(l) \)
   II. \( \text{Cu}^{2+}(aq) + 4\text{NH}_3(aq) \rightarrow [\text{Cu(NH}_3)_4]^{2+}(aq) \)
   III. \( \text{H}^+(aq) + \text{NH}_3(aq) \rightarrow \text{NH}_4^+(aq) \)
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
30. Which of the following compounds will produce an alkaline solution when dissolved in water?

A. NaCl
B. NH₄Cl
C. CH₃COONa
D. CH₃COONH₄

31. Which of the following are conjugate acid-base pairs?

I. H₂O (l) / OH⁻(aq)
II. NH₄⁺(aq) / NH₃(aq)
III. HCl(aq) / NaOH(aq)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

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26. Which species act as Brønsted–Lowry bases in the following reactions?

CH₃NH₃⁺ + H₂O ⇌ CH₃NH₂ + OH⁻
NH₄⁺ + H₂O ⇌ NH₃ + OH⁻

I. CH₃NH₂
II. CH₃NH₂⁺
III. NH₄⁺

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

27. The ionic product constant of water at 45°C is 4×10⁻¹⁴ mol² dm⁻⁶. Which statement is correct about pure water at 45°C?

A. pH = 7
B. [H⁺] = [OH⁻]
C. [OH⁻] > [H⁺]
D. [H⁺] > [OH⁻]
28. A weak monoprotic acid is 10% dissociated in a solution of concentration 0.01 mol dm$^{-3}$. What is the pH value of the solution?
   A. 0.1
   B. 1.0
   C. 2.0
   D. 3.0

29. Which change increases the pH of a solution from 3 to 6?
   A. Doubling the [H$^+$]
   B. Halving the [OH$^-$]
   C. Decreasing the [H$^+$] by a factor of 1000
   D. Decreasing the [OH$^-$] by a factor of 1000

30. Which pair of compounds, in aqueous solution, could be used to make a buffer solution?
   A. CH$_3$COOH and HCl
   B. HCl and NaOH
   C. HCl and NH$_4$Cl
   D. HCOOH and NaOH

Topic 8 Mark Scheme
Q# 195/IB/P1/2016/s/SpcmP/HL/  Q# 196/IB/P1/2015/w/TZ 2/HL/  Q# 197/IB/P1/2015/s/TZ 2/HL/

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Topic 9

30. Which is a correct statement for the reaction below?

\[ 2\text{MnO}_4^-\text{(aq)} + 6\text{H}^+\text{(aq)} + 5\text{NO}_2^-\text{(aq)} \rightarrow 2\text{Mn}^{2+}\text{(aq)} + 5\text{NO}_3^-\text{(aq)} + 3\text{H}_2\text{O (l)} \]

A. MnO$_4^-$ is the reducing agent and the oxidation number of Mn increases.
B. MnO$_4^-$ is the oxidizing agent and the oxidation number of Mn decreases.
C. NO$_2^-$ is the reducing agent and the oxidation number of N decreases.
D. NO$_2^-$ is the oxidizing agent and the oxidation number of N increases.
31. A voltaic cell is constructed from zinc and copper half-cells. Zinc is more reactive than copper. Which statement is correct when this cell produces electricity?

A. Electrons flow from the copper half-cell to the zinc half-cell.
B. The concentration of Cu²⁺(aq) increases.
C. Electrons flow through the salt bridge.
D. Negative ions flow through the salt bridge from the copper half-cell to the zinc half-cell.

32. Which signs for both \( E^{\circ}_{\text{cell}} \) and \( \Delta G^{\circ} \) result in a spontaneous redox reaction occurring under standard conditions?

<table>
<thead>
<tr>
<th>( E^{\circ}_{\text{cell}} )</th>
<th>( \Delta G^{\circ} )</th>
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<tr>
<td>+</td>
<td>+</td>
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<tr>
<td>−</td>
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<tr>
<td>+</td>
<td>−</td>
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33. An iron rod is electroplated with silver. Which is a correct condition for this process?

A. The silver electrode is the positive electrode.
B. The iron rod is the positive electrode.
C. The electrolyte is iron(II) sulfate.
D. Oxidation occurs at the negative electrode.
30. Applying IUPAC rules, what is the name of MnO₂?
   A. Magnesium(II) oxide
   B. Manganese(II) oxide
   C. Magnesium(IV) oxide
   D. Manganese(IV) oxide

31. Which statement is correct for a voltaic but not for an electrolytic cell?
   A. An electrolyte is required.
   B. The anode is where oxidation occurs.
   C. Ions move in the electrolyte.
   D. Electrons flow from the negative electrode to the positive electrode.

32. Which compound forms both hydrogen and oxygen at the electrodes when a concentrated aqueous solution is electrolyzed?
   A. KI
   B. NaCl
   C. H₂SO₄
   D. AgNO₃

33. z mol of copper is deposited from CuSO₄(aq) by a current, i, in time t. What is the amount of silver, in mol, deposited by electrolysis from AgNO₃(aq) by a current, i/2, in time 2t?
   A. \( \frac{Z}{4} \)
   B. \( \frac{Z}{2} \)
   C. Z
   D. 2Z
30. The equations below represent reactions involved in the Winkler method for determining the concentration of dissolved oxygen in water:

\[
2\text{Mn(OH)}_2(s) + \text{O}_2(aq) \rightarrow 2\text{MnO(OH)}_2(s)
\]

\[
\text{MnO(OH)}_2(s) + 2\text{H}_2\text{SO}_4(aq) \rightarrow \text{Mn(SO}_4)_2(s) + 3\text{H}_2\text{O(l)}
\]

\[
\text{Mn(SO}_4)_2(s) + 2\text{I}^- (aq) \rightarrow \text{Mn}^{2+}(aq) + \text{I}_2(aq) + 2\text{SO}_4^{2-}(aq)
\]

\[
2\text{S}_2\text{O}_3^{2-}(aq) + \text{I}_2(aq) \rightarrow 2\text{S}_2\text{O}_5^{2-}(aq) + 2\text{I}^-(aq)
\]

What is the amount, in mol, of thiosulfate ions, \( \text{S}_2\text{O}_3^{2-}(aq) \), needed to react with the iodine, \( \text{I}_2(aq) \), formed by 1.00 mol of dissolved oxygen?

A. 2.00  
B. 3.00  
C. 4.00  
D. 6.00

31. What are the products when molten sodium chloride is electrolysed?

<table>
<thead>
<tr>
<th>Cathode</th>
<th>Anode</th>
</tr>
</thead>
<tbody>
<tr>
<td>hydrogen</td>
<td>chlorine</td>
</tr>
<tr>
<td>sodium</td>
<td>chlorine</td>
</tr>
<tr>
<td>sodium</td>
<td>chlorine</td>
</tr>
<tr>
<td>chlorine</td>
<td>sodium</td>
</tr>
</tbody>
</table>

32. \( E^\circ \) values for some half-equations are given below.

\[
\text{Mn}^{2+}(aq) + 2e^- \rightleftharpoons \text{Mn}(s) \quad E^\circ = -1.18 \text{ V}
\]

\[
\text{Fe}^{2+}(aq) + 2e^- \rightleftharpoons \text{Fe}(s) \quad E^\circ = -0.45 \text{ V}
\]

\[
\text{Pb}^{2+}(aq) + 2e^- \rightleftharpoons \text{Pb}(s) \quad E^\circ = -0.13 \text{ V}
\]

Which reaction is spontaneous under standard conditions?

A. \( \text{Fe}^{2+}(aq) + \text{Mn}(s) \rightarrow \text{Fe}(s) + \text{Mn}^{2+}(aq) \)
B. \( \text{Mn}^{2+}(aq) + \text{Pb}(s) \rightarrow \text{Mn}(s) + \text{Pb}^{2+}(aq) \)
C. \( \text{Fe}^{2+}(aq) + \text{Pb}(s) \rightarrow \text{Fe}(s) + \text{Pb}^{2+}(aq) \)
D. \( \text{Mn}^{2+}(aq) + \text{Fe}(s) \rightarrow \text{Mn}(s) + \text{Fe}^{2+}(aq) \)
33. 50.0 cm$^3$ of 0.50 mol dm$^{-3}$ aqueous copper(II) sulfate, CuSO$_4$(aq), is electrolysed using a current of 0.50 A for 30 minutes. What mass of copper, in g, is deposited on the cathode? (M(Cu) = 64 g mol$^{-1}$; Faraday's constant (F) = 96500 C mol$^{-1}$.)

A. $\frac{50.0 \times 0.50 \times 64}{1000}$

B. $\frac{0.50 \times 30 \times 64}{96500 \times 2}$

C. $\frac{0.50 \times 30 \times 60 \times 64}{96500 \times 2}$

D. $\frac{50.0 \times 0.50 \times 64}{1000 \times 2}$

30. Which element undergoes reduction in the following reaction?

$(\text{NH}_4)_2\text{Cr}_2\text{O}_7(s) \rightarrow \text{N}_2(g) + 4\text{H}_2\text{O}(l) + \text{Cr}_2\text{O}_3(s)$

A. Cr

B. H

C. N

D. O

31. Which best describes reduction?

A. Increase in oxidation number and gain of electrons

B. Increase in oxidation number and loss of electrons

C. Decrease in oxidation number and gain of electrons

D. Decrease in oxidation number and loss of electrons

32. What is $E^\circ_\text{V}$, in V, for the following reaction?

$\text{VO}^{2+}(aq) + 2\text{H}^+(aq) + \text{V}^{3+}(aq) \rightarrow 2\text{V}^{3+}(aq) + \text{H}_2\text{O}(l)$

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Standard electrode potential, $E^\circ / V$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{V}^{2+}(aq) + 2e^- \rightleftharpoons \text{V}(s)$</td>
<td>-1.18</td>
</tr>
<tr>
<td>$\text{V}^{3+}(aq) + e^- \rightleftharpoons \text{V}^{2+}(aq)$</td>
<td>-0.26</td>
</tr>
<tr>
<td>$\text{VO}^{2+}(aq) + 2\text{H}^+(aq) + e^- \rightleftharpoons \text{V}^{3+}(aq) + \text{H}_2\text{O}(l)$</td>
<td>+0.34</td>
</tr>
<tr>
<td>$\text{VO}_2^{+}(aq) + 2\text{H}^+(aq) + e^- \rightleftharpoons \text{VO}^{2+}(aq) + \text{H}_2\text{O}(l)$</td>
<td>+1.00</td>
</tr>
</tbody>
</table>

A. -0.60

B. +0.08

C. +0.60

D. +1.26
33. What product is formed at the positive electrode (anode) when 0.001 mol dm\(^{-2}\) \(\text{H}_2\text{SO}_4\) (aq) is electrolysed?

A. Hydrogen
B. Oxygen
C. Sulfur
D. Sulfur dioxide

Topic Chem 9 Q# 224/ IB/Paper 1/2015/s/Time Zone 2/Higher Level/

30. Which is a redox reaction?

A. \([\text{Cu}([\text{H}_2\text{O}])_{2}]^{2+}\) (aq) + 4\(\text{Cl}^{-}\) (aq) \(\rightarrow\) \([\text{CuCl}_2]\)\(^{2-}\) (aq) + 4\(\text{H}_2\text{O}\) (l)
B. \(\text{Ag}^{+}\) (aq) + \(\text{Cl}^{-}\) (aq) \(\rightarrow\) \(\text{AgCl}\) (s)
C. \(\text{Zn}\) (s) + 2\(\text{HCl}\) (aq) \(\rightarrow\) \(\text{ZnCl}_2\) (aq) + \(\text{H}_2\) (g)
D. 2\(\text{K}_2\text{Cr}_2\text{O}_7\) (aq) + 2\(\text{HCl}\) (aq) \(\rightarrow\) \(\text{K}_2\text{Cr}_2\text{O}_7\) (aq) + \(\text{H}_2\text{O}\) (l) + 2\(\text{KCl}\) (aq)

31. What is the coefficient for \(\text{I}^{-}\) when the following equation is balanced using the smallest possible whole numbers?

\[\text{IO}_3^{-}\) (aq) + _____ \(\text{I}^{-}\) (aq) + _____ \(\text{H}^{+}\) (aq) \(\rightarrow\) _____ \(\text{I}_2\) (aq) + _____ \(\text{H}_2\text{O}\) (l)

A. 1
B. 2
C. 3
D. 5

32. The standard electrode potentials for three reactions involving copper and copper ions are:

\[\text{Cu}^{2+}\) (aq) + \(\text{e}^{-}\) \(\rightleftharpoons\) \(\text{Cu}\) (aq) \(E^\circ = +0.15\text{ V}\)

\[\text{Cu}^{2+}\) (aq) + 2\(\text{e}^{-}\) \(\rightleftharpoons\) \(\text{Cu}\) (s) \(E^\circ = +0.34\text{ V}\)

\[\text{Cu}^{+}\) (aq) + \(\text{e}^{-}\) \(\rightleftharpoons\) \(\text{Cu}\) (s) \(E^\circ = +0.52\text{ V}\)

Which statement is correct?

A. \(\text{Cu}^{2+}\) ions are a better oxidizing agent than \(\text{Cu}^{+}\) ions.
B. Copper metal is a better reducing agent than \(\text{Cu}^{+}\) ions.
C. \(\text{Cu}^{+}\) ions will spontaneously form copper metal and \(\text{Cu}^{2+}\) ions in solution.
D. Copper metal can be spontaneously oxidized by \(\text{Cu}^{2+}\) ions to form \(\text{Cu}^{+}\) ions.
33. The same quantity of electricity is passed through separate dilute aqueous solutions of sulfuric acid and copper(II) sulfate using platinum electrodes under the same conditions. Which statement is correct?

A. The same volume of oxygen is obtained in both cases.
B. The same volume of hydrogen is obtained in both cases.
C. The amount of copper deposited at the negative electrode in the copper(II) sulfate solution is half the amount of hydrogen gas formed at the negative electrode in the sulfuric acid solution.
D. The pH of both solutions increases as the electrolysis proceeds.

36. Which represents a redox reaction?

A. NaH (s) + H₂O (l) → NaOH (aq) + H₂(g)
B. CaCO₃(s) → CaO(s) + CO₂(g)
C. CuCl₂(aq) + K₂S(aq) → CuS (s) + 2KCl (aq)
D. HCl(aq) + NH₃(aq) → NH₄⁺Cl⁻(aq)

31. Two half-cells are connected via a salt bridge to make a voltaic cell. Which statement about this cell is correct?

A. Oxidation occurs at the positive electrode (cathode).
B. It is also known as an electrolytic cell.
C. Ions flow through the salt bridge.
D. It requires a power supply to operate.

32. Which signs are correct for a spontaneous redox reaction?

<table>
<thead>
<tr>
<th>Standard electrode potential, E°</th>
<th>Standard free energy change, ΔG°</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. +</td>
<td>-</td>
</tr>
<tr>
<td>B. -</td>
<td>+</td>
</tr>
<tr>
<td>C. -</td>
<td>-</td>
</tr>
<tr>
<td>D. +</td>
<td>+</td>
</tr>
</tbody>
</table>
33. Consider the standard electrode potentials:

\[
\begin{align*}
\text{Fe}^{2+}(aq) + 2e^- & \rightleftharpoons \text{Fe}(s) \quad E^\circ = 0.45\text{V} \\
\frac{1}{2}\text{Cl}_2(g) + e^- & \rightleftharpoons \text{Cl}^-(aq) \quad E^\circ = 1.36\text{V}
\end{align*}
\]

What is the standard cell potential, in V, for the reaction?

\[
\text{Cl}_2(g) + \text{Fe}(s) \rightarrow 2\text{Cl}^-(aq) + \text{Fe}^{2+}(aq)
\]

A. +0.91 \\
B. +1.81 \\
C. +2.27 \\
D. +3.17

30. Which statement is correct for the following reaction?

\[
2\text{ClO}_3^-(aq) + \text{SO}_2(aq) + \text{H}^+(aq) \rightarrow 2\text{ClO}_2(g) + \text{HSO}_4^-(aq)
\]

A. \(\text{ClO}_3^-\) is the oxidizing agent and it undergoes reduction. \\
B. \(\text{ClO}_3^-\) is the reducing agent and it undergoes oxidation. \\
C. \(\text{SO}_2\) is the oxidizing agent and it undergoes oxidation. \\
D. \(\text{SO}_2\) is the reducing agent and it undergoes reduction.

31. Which species are produced at each electrode during the electrolysis of molten lead(II) bromide, PbBr₂(l)?

<table>
<thead>
<tr>
<th>Negative electrode (cathode)</th>
<th>Positive electrode (anode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Br⁻(l)</td>
<td>Pb²⁺(l)</td>
</tr>
<tr>
<td>B. Pb²⁺(l)</td>
<td>Br⁻(l)</td>
</tr>
<tr>
<td>C. Br₂(g)</td>
<td>Pb(l)</td>
</tr>
<tr>
<td>D. Pb(l)</td>
<td>Br₂(g)</td>
</tr>
</tbody>
</table>

Topic Chem 9 Q# 226/ IB/Paper 1/2014/w/Time Zone 0/Higher Level/
32. Consider the following standard electrode potentials.

\[
\begin{align*}
\text{Sn}^{2+} \text{(aq)} + 2e^- &\rightleftharpoons \text{Sn} \text{(s)} \quad E^\circ = -0.14 \text{ V} \\
\text{H}^+ \text{(aq)} + e^- &\rightleftharpoons \frac{1}{2}\text{H}_2 \text{(g)} \quad E^\circ = 0.00 \text{ V} \\
\text{Fe}^{2+} \text{(aq)} + e^- &\rightleftharpoons \text{Fe}^{3+} \text{(aq)} \quad E^\circ = +0.77 \text{ V}
\end{align*}
\]

Which species will reduce \(\text{H}^+\) to \(\text{H}_2\) under standard conditions?

A. \(\text{Fe}^{2+}\) (aq)
B. \(\text{Sn}^{2+}\) (aq)
C. \(\text{Sn}\) (s)
D. \(\text{Fe}^{3+}\) (aq)

33. A number of molten metal chlorides are electrolysed, using the same current for the same length of time. Which metal will be produced in the greatest amount, in mol?

A. Mg
B. Al
C. K
D. Ca

Topic Chem 9 Q# 227/ IB/Paper 1/2014/s/Time Zone 2/Higher Level/

31. Which species are the oxidizing and reducing agents in the following reaction?

\[
\text{SO}_3^{2-} \text{(aq)} + \text{PbO}_2 \text{(s)} + \text{H}_2\text{O} \text{(l)} \rightarrow \text{SO}_4^{2-} \text{(aq)} + \text{Pb(OH)}_2 \text{(s)}
\]

<table>
<thead>
<tr>
<th>Oxidizing agent</th>
<th>Reducing agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. (\text{PbO}_2)</td>
<td>(\text{H}_2\text{O})</td>
</tr>
<tr>
<td>B. (\text{SO}_3^{2-})</td>
<td>(\text{PbO}_2)</td>
</tr>
<tr>
<td>C. (\text{H}_2\text{O})</td>
<td>(\text{SO}_3^{2-})</td>
</tr>
<tr>
<td>D. (\text{PbO}_2)</td>
<td>(\text{SO}_3^{2-})</td>
</tr>
</tbody>
</table>
32. Zinc is more reactive than copper. In this voltaic cell, which species is reduced and in which direction do negative ions flow in the salt bridge?

![Voltaic cell diagram]

<table>
<thead>
<tr>
<th>Species reduced</th>
<th>Direction of negative ion flow in salt bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu^{2+}</td>
<td>from copper half-cell to zinc half-cell</td>
</tr>
<tr>
<td>Cu^{2+}</td>
<td>from zinc half-cell to copper half-cell</td>
</tr>
<tr>
<td>Zn^{2+}</td>
<td>from copper half-cell to zinc half-cell</td>
</tr>
<tr>
<td>Zn^{2+}</td>
<td>from zinc half-cell to copper half-cell</td>
</tr>
</tbody>
</table>

33. Which components are used to make the standard hydrogen electrode?

A. H_2 (g), H^+ (aq), Pt (s)
B. H_2 (g), H^+ (aq), Ni (s)
C. H_2 (g), HO^- (aq), Pt (s)
D. H_2 (g), HO^- (aq), Ni (s)
34. What is the cell potential, in V, of the reaction below?

\[ \text{I}_2 + 2\text{S}_2\text{O}_3^{2-} \rightarrow 2\text{I}^- + \text{S}_4\text{O}_6^{2-} \]

\[ \frac{1}{2}\text{S}_4\text{O}_6^{2-} (aq) + e^- \rightleftharpoons \text{S}_2\text{O}_3^{2-} (aq) \quad E^\circ = +0.09 \text{ V} \]

\[ \text{I}_2 (aq) + 2e^- \rightleftharpoons 2\text{I}^- (aq) \quad E^\circ = +0.54 \text{ V} \]

A. +0.63
B. +0.45
C. −0.45
D. −0.63

Topic Chem 9 Q# 228/IB/Paper 1/2014/s/Time Zone 1/Higher Level/

30. At which side of the equation are electrons, H⁺ ions and H₂O needed to complete the half-equation?

\[ \text{MnO}_4^- (aq) \rightarrow \text{Mn}^{2+} (aq) \]

<table>
<thead>
<tr>
<th>Electrons</th>
<th>H⁺ ions</th>
<th>H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. reactant side</td>
<td>reactant side</td>
<td>product side</td>
</tr>
<tr>
<td>B. reactant side</td>
<td>product side</td>
<td>reactant side</td>
</tr>
<tr>
<td>C. product side</td>
<td>reactant side</td>
<td>product side</td>
</tr>
<tr>
<td>D. product side</td>
<td>product side</td>
<td>reactant side</td>
</tr>
</tbody>
</table>

31. What are the correct names for KMnO₄ and K₂Cr₂O₇, using oxidation numbers?

A. Potassium permanganate and potassium dichromate
B. Potassium manganate(IV) and potassium chromate(VII)
C. Potassium permanganate(IV) and potassium dichromate(VII)
D. Potassium manganate(VII) and potassium dichromate(VI)

32. What is an industrial use of electrolysis?

A. The production of graphite
B. The production of iron
C. The production of electric energy
D. Electroplating
33. The overall equation of a voltaic cell is:

\[
\text{Ni} (s) + 2\text{Ag}^+ (aq) \rightleftharpoons \text{Ni}^{2+} (aq) + 2\text{Ag} (s) \quad E^0 = 1.06 \text{V}
\]

The standard electrode potential for \( \text{Ni}^{2+} (aq) + 2e^- \rightleftharpoons \text{Ni} (s) \), is \(-0.26 \text{V}\). What is the standard electrode potential for the silver half-cell, \( \text{Ag}^+ (aq) + e^- \rightleftharpoons \text{Ag} (s) \), in V?

A. \(-1.32\)
B. \(-0.80\)
C. \(+0.80\)
D. \(+1.32\)

31. What is the name of \( \text{MnO}_2 \)?

A. Manganese(II) oxide
B. Magnesium(II) oxide
C. Manganese(IV) oxide
D. Magnesium(IV) oxide

32. Consider the following reaction.

\[
2\text{Cr(OH)}_3 (s) + 6\text{ClO}^- (aq) \rightarrow 2\text{CrO}_4^{2-} (aq) + 3\text{Cl}_2 (g) + 2\text{OH}^- (aq) + 2\text{H}_2\text{O} (l)
\]

Which statement is correct?

A. \( \text{Cr(OH)}_3 \) is the oxidizing agent and the oxidation number of chromium changes from +3 to +6.
B. \( \text{Cr(OH)}_3 \) is the reducing agent and undergoes reduction.
C. \( \text{ClO}^- \) is the oxidizing agent and the oxidation number of chlorine changes from +1 to 0.
D. \( \text{ClO}^- \) is the reducing agent and the oxidation number of chlorine changes from −1 to 0.
33. Consider the following two standard electrode potentials at 298 K.

\[
\begin{align*}
\text{Sn}^{2+} \text{(aq)} + 2e^- & \rightleftharpoons \text{Sn} \text{(s)} & E^\circ = -0.14 \text{V} \\
\text{Fe}^{3+} \text{(aq)} + e^- & \rightleftharpoons \text{Fe}^{2+} \text{(aq)} & E^\circ = +0.77 \text{V}
\end{align*}
\]

What is the equation and cell potential for the spontaneous reaction that occurs?

A. \(2\text{Fe}^{3+} \text{(aq)} + \text{Sn}^{2+} \text{(aq)} \rightarrow 2\text{Fe}^{2+} \text{(aq)} + \text{Sn} \text{(s)}\) \(E^\circ = -0.91 \text{V}\)

B. \(2\text{Fe}^{3+} \text{(aq)} + \text{Sn} \text{(s)} \rightarrow 2\text{Fe}^{2+} \text{(aq)} + \text{Sn}^{2+} \text{(aq)}\) \(E^\circ = +0.91 \text{V}\)

C. \(2\text{Fe}^{3+} \text{(aq)} + \text{Sn}^{2+} \text{(aq)} \rightarrow 2\text{Fe}^{2+} \text{(aq)} + \text{Sn} \text{(s)}\) \(E^\circ = +0.91 \text{V}\)

D. \(2\text{Fe}^{3+} \text{(aq)} + \text{Sn} \text{(s)} \rightarrow 2\text{Fe}^{2+} \text{(aq)} + \text{Sn}^{2+} \text{(aq)}\) \(E^\circ = +1.68 \text{V}\)

34. What happens during the electrolysis of concentrated aqueous potassium chloride?

I. Reduction takes place at the negative electrode (cathode).

II. Hydrogen gas is evolved at the negative electrode (cathode).

III. The pH of the electrolyte increases.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Topic Chem 9 Q# 230/ IB/Paper 1/2013/s/Time Zone 2/Higher Level/

30. Which is the oxidizing agent in the following reaction?

\[5\text{SO}_2(g) + 2\text{IO}_3^-(aq) + 4\text{H}_2\text{O}(l) \rightarrow 5\text{SO}_4^{2-}(aq) + \text{I}_2(aq) + 8\text{H}^+(aq)\]

A. \text{SO}_2

B. \text{IO}_3^-

C. \text{H}_2\text{O}

D. \text{SO}_4^{2-}
31. The overall reaction in the voltaic cell below is:

\[ \text{Ni(s)} + \text{Pb}^{2+}(aq) \rightarrow \text{Ni}^{2+}(aq) + \text{Pb}(s) \]

Which statement is correct for the nickel half-cell?

A. Nickel is the positive electrode (cathode) and is reduced.
B. Nickel is the negative electrode (anode) and is reduced.
C. Nickel is the positive electrode (cathode) and is oxidized.
D. Nickel is the negative electrode (anode) and is oxidized.

32. Which statement is correct for electroplating an object with gold?

A. The object must be the negative electrode (cathode).
B. The negative electrode (cathode) must be gold.
C. The object must be the positive electrode (anode).
D. The gold electrode must be pure.

Topic Chem 9 Q# 231/ IB/Paper 1/2013/s/Time Zone 1/Higher Level/
30. Which statement is correct about a reducing agent?

A. It is reduced by gaining electrons.
B. It is oxidized by gaining electrons.
C. It is oxidized by losing electrons.
D. It is reduced by losing electrons.
31. An aqueous solution of a metal salt is electrolysed. Which factor will have no effect on the mass of the metal deposited on the negative electrode (cathode), if all other variables remain constant?

A. Size of metal ion
B. Relative atomic mass of metal
C. Current
D. Charge on metal ion

32. Which are correct statements about a voltaic cell?

I. A spontaneous redox reaction occurs which converts chemical energy to electrical energy.
II. Oxidation occurs at the negative electrode (anode).
III. Electricity is conducted by the movement of electrons through the salt bridge.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

33. The standard electrode potentials of some half-reactions are given below.

\[ \text{Sn}^{2+} (aq) + 2e^- \leftrightarrow \text{Sn}^{2+} (aq) \quad E^\circ = +0.15 \text{ V} \]
\[ \frac{1}{2} \text{I}_2 (s) + e^- \leftrightarrow \text{I}^- (aq) \quad E^\circ = +0.54 \text{ V} \]
\[ \text{Fe}^{3+} (aq) + e^- \leftrightarrow \text{Fe}^{2+} (aq) \quad E^\circ = +0.77 \text{ V} \]

Which of the following reactions will occur spontaneously?

A. Iodine reduces \( \text{Fe}^{3+} \) to \( \text{Fe}^{2+} \)
B. Iodine reduces \( \text{Sn}^{4+} \) to \( \text{Sn}^{2+} \)
C. Iodine oxidizes \( \text{Fe}^{3+} \) to \( \text{Fe}^{2+} \)
D. Iodine oxidizes \( \text{Sn}^{2+} \) to \( \text{Sn}^{4+} \)
30. What is the correct systematic name of MnO₂?

A. Manganese(II) oxide

B. Manganese(IV) oxide

C. Magnesium(II) oxide

D. Magnesium(IV) oxide

31. A voltaic cell is made by connecting zinc and lead half-cells. The overall equation for the reaction occurring in the cell is shown below.

\[ \text{Zn}(s) + \text{Pb}^{2+}(aq) \rightarrow \text{Pb}(s) + \text{Zn}^{2+}(aq) \]

Which statements are correct when the cell produces electricity?

I. The zinc is oxidized.

II. Electrons move from zinc to lead in the external circuit.

III. The mass of the lead electrode increases.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

32. Consider the following standard electrode potential values:

\[ \text{Fe}^{3+}(aq) + e^- \rightleftharpoons \text{Fe}^{2+}(aq) \quad E^\circ = +0.77 \text{ V} \]

\[ \text{MnO}_4^- (aq) + 8\text{H}^+ (aq) + 5e^- \rightleftharpoons \text{Mn}^{2+} (aq) + 4\text{H}_2\text{O}(l) \quad E^\circ = +1.51 \text{ V} \]

What is the cell potential, in V, for this reaction?

\[ \text{MnO}_4^- (aq) + 8\text{H}^+ (aq) + 5\text{Fe}^{2+} (aq) \rightarrow \text{Mn}^{2+} (aq) + 4\text{H}_2\text{O}(l) + 5\text{Fe}^{3+} (aq) \]

A. -2.28

B. -0.74

C. +0.74

D. +2.28
33. Consider the following standard electrode potential values:

\[
\begin{align*}
Ca^{2+}(aq) + 2e^- & \rightleftharpoons Ca(s) \quad E^0 = -2.87 \text{ V} \\
Fe^{2+}(aq) + 2e^- & \rightleftharpoons Fe(s) \quad E^0 = -0.45 \text{ V} \\
Ni^{2+}(aq) + 2e^- & \rightleftharpoons Ni(s) \quad E^0 = -0.26 \text{ V} \\
Fe^{3+}(aq) + e^- & \rightleftharpoons Fe^{2+}(aq) \quad E^0 = +0.77 \text{ V}
\end{align*}
\]

Which reaction is spontaneous?

A. \( Ca^{2+}(aq) + Ni(s) \rightarrow Ca(s) + Ni^{2+}(aq) \)

B. \( 3Fe^{2+}(aq) \rightarrow Fe(s) + 2Fe^{3+}(aq) \)

C. \( Fe(s) + 2Fe^{2+}(aq) \rightarrow 3Fe^{2+}(aq) \)

D. \( Fe^{2+}(aq) + Ni(s) \rightarrow Fe(s) + Ni^{2+}(aq) \)

Topic Chem 9 Q# 233/ IB/Paper 1/2012/s/Time Zone 2/Higher Level/

28. Consider the following reaction:

\[3Sn^{2+}(aq) + Cr_2O_7^{2-}(aq) + 2H^+(aq) \rightarrow 2Cr^{3+}(aq) + 3SnO_2(s) + H_2O(l)\]

Which statement is correct?

A. \( Sn^{2+} \) is the oxidizing agent because it undergoes oxidation.

B. \( Sn^{2+} \) is the reducing agent because it undergoes oxidation.

C. \( Cr_2O_7^{2-} \) is the oxidizing agent because it undergoes oxidation.

D. \( Cr_2O_7^{2-} \) is the reducing agent because it undergoes oxidation.

29. What occurs during the operation of a voltaic cell based on the following overall reaction?

\[2Ag^+(aq) + Cu(s) \rightarrow 2Ag(s) + Cu^{2+}(aq)\]

<table>
<thead>
<tr>
<th></th>
<th>External circuit</th>
<th>Ion movement in solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>electrons move from ( Cu(s) ) to ( Ag(s) )</td>
<td>( Ag^+(aq) ) move towards ( Cu(s) )</td>
</tr>
<tr>
<td>B.</td>
<td>electrons move from ( Ag(s) ) to ( Cu(s) )</td>
<td>( Ag^+(aq) ) move towards ( Ag(s) )</td>
</tr>
<tr>
<td>C.</td>
<td>electrons move from ( Cu(s) ) to ( Ag(s) )</td>
<td>( Ag^+(aq) ) move towards ( Ag(s) )</td>
</tr>
<tr>
<td>D.</td>
<td>electrons move from ( Ag(s) ) to ( Cu(s) )</td>
<td>( Cu^{2+}(aq) ) move towards ( Cu(s) )</td>
</tr>
</tbody>
</table>
30. Consider the following standard electrode potentials:

\[ \text{Sn}^{4+} \text{(aq)} + 2e^- \rightleftharpoons \text{Sn}^{2+} \text{(aq)} \quad E^0 = +0.13 \text{ V} \]
\[ \text{Pb}^{2+} \text{(aq)} + 2e^- \rightleftharpoons \text{Pb(s)} \quad E^0 = -0.13 \text{ V} \]

What is the value of the cell potential, in V, for the spontaneous reaction that occurs when the two half-cells are connected together?

A. -0.26  
B. 0.00  
C. +0.13  
D. +0.26

31. Two electrolytic cells are connected in series and the same current passes through each cell. The first cell contains silver electrodes in silver nitrate solution. The second cell contains copper electrodes in copper(II) sulfate solution. In one experiment 1.00 g of silver is deposited in the first cell. What mass of copper, in g, is deposited in the second cell?

A. \( \frac{1.00}{107.87} \)  
B. \( \frac{1.00}{63.55} \)  
C. \( \frac{1.00}{107.87} \times \frac{63.55}{2} \)  
D. \( \frac{1.00}{107.87} \times 63.55 \)

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30. The equation for the redox reaction between acidified dichromate and iodide ions is shown below.

\[ \text{Cr}_2\text{O}_7^{2-} \text{(aq)} + 6\text{I}^- \text{(aq)} + 14\text{H}^+ \text{(aq)} \rightarrow 2\text{Cr}^{3+} \text{(aq)} + 3\text{I}_2 \text{(aq)} + 7\text{H}_2\text{O} \text{(l)} \]

Which is the reduction half-equation?

A. \( 6\text{I}^- \text{(aq)} + 6e^- \rightarrow 3\text{I}_2 \text{(aq)} \)  
B. \( 6\text{I}^- \text{(aq)} \rightarrow 3\text{I}_2 \text{(aq)} + 6e^- \)  
C. \( \text{Cr}_2\text{O}_7^{2-} \text{(aq)} + 14\text{H}^+ \text{(aq)} + 6e^- \rightarrow 2\text{Cr}^{3+} \text{(aq)} + 7\text{H}_2\text{O} \text{(l)} \)  
D. \( \text{Cr}_2\text{O}_7^{2-} \text{(aq)} + 14\text{H}^+ \text{(aq)} \rightarrow 2\text{Cr}^{3+} \text{(aq)} + 7\text{H}_2\text{O} \text{(l)} + 6e^- \)
31. The equation for the overall reaction in a voltaic cell is:

\[ \text{Cu}^{2+} \text{(aq)} + \text{Zn} \text{(s)} \rightarrow \text{Cu} \text{(s)} + \text{Zn}^{2+} \text{(aq)} \]

Which statements are correct for this cell?

I. Cu is the positive electrode.
II. Negative ions flow from the zinc solution to the copper solution.
III. Chemical energy is converted into electrical energy during this reaction.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

32. Which statement is correct for the following spontaneous reaction?

\[ 2\text{Fe}^{3+} \text{(aq)} + 2\text{Br}^- \text{(aq)} \rightarrow 2\text{Fe}^{2+} \text{(aq)} + \text{Br}_2 \text{(aq)} \]

A. \( \Delta E^{\circ} < 0 \) and \( \text{Br}_2 \) is a better oxidizing agent than \( \text{Fe}^{3+} \).
B. \( \Delta E^{\circ} < 0 \) and \( \text{Br}^- \) is a better reducing agent than \( \text{Fe}^{2+} \).
C. \( \Delta E^{\circ} > 0 \) and \( \text{Fe}^{3+} \) is a better oxidizing agent than \( \text{Br}_2 \).
D. \( \Delta E^{\circ} > 0 \) and \( \text{Fe}^{2+} \) is a better reducing agent than \( \text{Br}^- \).

33. Which combination of electrodes and electrolyte could be used to plate a spoon with silver?

<table>
<thead>
<tr>
<th>Negative electrode (cathode)</th>
<th>Positive electrode (anode)</th>
<th>Electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. silver</td>
<td>spoon</td>
<td>sulfuric acid solution</td>
</tr>
<tr>
<td>B. spoon</td>
<td>silver</td>
<td>sulfuric acid solution</td>
</tr>
<tr>
<td>C. silver</td>
<td>spoon</td>
<td>silver nitrate solution</td>
</tr>
<tr>
<td>D. spoon</td>
<td>silver</td>
<td>silver nitrate solution</td>
</tr>
</tbody>
</table>
30. What is the correct \textit{decreasing} order of reactivity of the metals X, Y and Z based on the following equations?

\[ XCl + Y \rightarrow YCl + X \]
\[ YCl + Z \rightarrow YCl + Z \]
\[ ZCl + X \rightarrow XCl + Z \]

A. \( X > Y > Z \)
B. \( Y > Z > X \)
C. \( Z > Y > X \)
D. \( Y > X > Z \)

31. Four electrolytic cells are constructed. Which cell would produce the greatest mass of metal at the negative electrode (cathode)?

<table>
<thead>
<tr>
<th>Electrolyte</th>
<th>Current / A</th>
<th>Time / s</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 1.0 moldm(^{-3}) CuSO(_4) (aq)</td>
<td>1.0</td>
<td>500</td>
</tr>
<tr>
<td>B. 1.0 moldm(^{-3}) AgNO(_3) (aq)</td>
<td>2.0</td>
<td>250</td>
</tr>
<tr>
<td>C. 1.0 moldm(^{-3}) CuSO(_4) (aq)</td>
<td>1.0</td>
<td>750</td>
</tr>
<tr>
<td>D. 1.0 moldm(^{-3}) AgNO(_3) (aq)</td>
<td>1.5</td>
<td>250</td>
</tr>
</tbody>
</table>

32. Which is \textbf{not} a requirement for the standard hydrogen electrode?

A. Pressure of 101 kPa
B. 1 moldm\(^{-3}\) sulfuric acid
C. Temperature of 298 K
D. An inert electrode such as platinum
30. What happens to iodine when iodate ions, $\text{IO}_3^-$, are converted to iodine molecules, $\text{I}_2$?

A. It undergoes reduction and its oxidation number changes from $-1$ to $0$

B. It undergoes oxidation and its oxidation number changes from $-1$ to $0$

C. It undergoes reduction and its oxidation number changes from $+5$ to $0$

D. It undergoes oxidation and its oxidation number changes from $+5$ to $0$

31. Consider the following reactions of three unknown metals X, Y and Z.

$$2\text{XNO}_3(aq) + \text{Y(s)} \rightarrow 2\text{X(s)} + \text{Y(NO}_3)_2(aq)$$

$$\text{Y(NO}_3)_2(aq) + \text{Z(s)} \rightarrow \text{No reaction}$$

$$2\text{XNO}_3(aq) + \text{Z(s)} \rightarrow 2\text{X(s)} + 2\text{Z(NO}_3)_2(aq)$$

What is the order of increasing reactivity of the metals (least reactive first)?

A. $\text{X} < \text{Y} < \text{Z}$

B. $\text{X} < \text{Z} < \text{Y}$

C. $\text{Z} < \text{Y} < \text{X}$

D. $\text{Y} < \text{Z} < \text{X}$

32. The standard electrode potentials for two metals are given below.

$$\text{Al}^{3+}(aq) + 3e^- \rightleftharpoons \text{Al(s)} \quad E^\circ = -1.66 \text{ V}$$

$$\text{Ni}^{2+}(aq) + 2e^- \rightleftharpoons \text{Ni(s)} \quad E^\circ = -0.23 \text{ V}$$

What is the equation and cell potential for the spontaneous reaction that occurs?

A. $2\text{Al}^{3+}(aq) + 3\text{Ni(s)} \rightarrow 2\text{Al(s)} + 3\text{Ni}^{2+}(aq) \quad E^\circ = 1.89 \text{ V}$

B. $2\text{Al(s)} + 3\text{Ni}^{2+}(aq) \rightarrow 2\text{Al}^{3+}(aq) + 3\text{Ni(s)} \quad E^\circ = 1.89 \text{ V}$

C. $2\text{Al}^{3+}(aq) + 3\text{Ni(s)} \rightarrow 2\text{Al(s)} + 3\text{Ni}^{2+}(aq) \quad E^\circ = 1.43 \text{ V}$

D. $2\text{Al(s)} + 3\text{Ni}^{2+}(aq) \rightarrow 2\text{Al}^{3+}(aq) + 3\text{Ni(s)} \quad E^\circ = 1.43 \text{ V}$
33. The same quantity of electricity was passed through separate molten samples of sodium bromide, NaBr, and magnesium chloride, MgCl₂. Which statement is true about the amounts, in mol, that are formed?

A. The amount of Mg formed is equal to the amount of Na formed.

B. The amount of Mg formed is equal to the amount of Cl₂ formed.

C. The amount of Mg formed is twice the amount of Cl₂ formed.

D. The amount of Mg formed is twice the amount of Na formed.

30. Consider the following standard electrode potentials.

\[ \text{Zn}^{2+} (aq) + 2e^- \rightleftharpoons \text{Zn} (s) \quad E^\circ = -0.76 \text{ V} \]

\[ \text{Cl}_2 (g) + 2e^- \rightleftharpoons 2\text{Cl}^- (aq) \quad E^\circ = +1.36 \text{ V} \]

\[ \text{Mg}^{2+} (aq) + 2e^- \rightleftharpoons \text{Mg} (s) \quad E^\circ = -2.37 \text{ V} \]

What will happen when zinc powder is added to an aqueous solution of magnesium chloride?

A. No reaction will take place.

B. Chlorine gas will be produced.

C. Magnesium metal will form.

D. Zinc chloride will form.

31. Which species could be reduced to form NO₂?

A. N₂O

B. NO₃⁻

C. HNO₂

D. NO
32. What are the features of a standard hydrogen electrode?

I. A temperature of 298 K
II. A carbon electrode
III. Hydrogen gas at 1.01 × 10^5 Pa (1 atm) pressure

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

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30. Consider the following reaction.

\[ \text{MnO}_4^- (aq) + 8H^+ (aq) + 5\text{Fe}^{3+} (aq) \rightarrow \text{Mn}^{2+} (aq) + 5\text{Fe}^{3+} (aq) + 4\text{H}_2\text{O} (l) \]

Which statement is correct?

A. \( \text{MnO}_4^- \) is the oxidizing agent and it loses electrons.
B. \( \text{MnO}_4^- \) is the reducing agent and it loses electrons.
C. \( \text{MnO}_4^- \) is the oxidizing agent and it gains electrons.
D. \( \text{MnO}_4^- \) is the reducing agent and it gains electrons.

31. The following equations indicate reactions that occur spontaneously.

\[ \text{Fe} (s) + \text{NiCl}_2 (aq) \rightarrow \text{FeCl}_2 (aq) + \text{Ni} (s) \]
\[ \text{Zn} (s) + \text{FeCl}_2 (aq) \rightarrow \text{ZnCl}_2 (aq) + \text{Fe} (s) \]
\[ \text{Ni} (s) + \text{PbCl}_2 (aq) \rightarrow \text{NiCl}_2 (aq) + \text{Pb} (s) \]

Which is the increasing order of the reactivity of the metals?

A. \( \text{Fe} < \text{Ni} < \text{Zn} < \text{Pb} \)
B. \( \text{Pb} < \text{Ni} < \text{Fe} < \text{Zn} \)
C. \( \text{Ni} < \text{Zn} < \text{Pb} < \text{Fe} \)
D. \( \text{Zn} < \text{Fe} < \text{Ni} < \text{Pb} \)
32. A voltaic cell is made by connecting two half-cells represented by the half-equations below.

\[
\begin{align*}
\text{Mn}^{2+} (aq) + 2e^- & \rightarrow \text{Mn} (s) \quad E^\circ = -1.19 \text{ V} \\
\text{Pb}^{2+} (aq) + 2e^- & \rightarrow \text{Pb} (s) \quad E^\circ = -0.13 \text{ V}
\end{align*}
\]

Which statement is correct about this voltaic cell?

A. Mn is oxidized and the voltage of the cell is 1.06 V.
B. Pb is oxidized and the voltage of the cell is 1.06 V.
C. Mn is oxidized and the voltage of the cell is 1.32 V.
D. Pb is oxidized and the voltage of the cell is 1.32 V.

33. For the electrolysis of aqueous copper(II) sulfate, which of the following statements is correct?

A. Cu and O\textsubscript{2} are produced in a mol ratio of 1:1
B. H\textsubscript{2} and O\textsubscript{2} are produced in a mol ratio of 1:1
C. Cu and O\textsubscript{2} are produced in a mol ratio of 2:1
D. H\textsubscript{2} and O\textsubscript{2} are produced in a mol ratio of 2:1

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30. What is the reducing agent in the reaction below?

\[
2\text{MnO}_4^- (aq) + \text{Br}^- (aq) + \text{H}_2\text{O} (l) \rightarrow 2\text{MnO}_2 (s) + \text{BrO}_3^- (aq) + 2\text{OH}^- (aq)
\]

A. Br\textsuperscript{-}
B. BrO\textsubscript{3}^- 
C. MnO\textsubscript{4}^- 
D. MnO\textsubscript{2}
31. Which changes could take place at the positive electrode (cathode) in a voltaic cell?
   
   I. Zn$^{2+}$ (aq) to Zn (s)
   II. Cl$_2$ (g) to Cl$^-$ (aq)
   III. Mg (s) to Mg$^{2+}$ (aq)

   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

32. Consider the following standard electrode potentials.

   \[
   \text{Cr}^{3+} (aq) + 3e^- \rightarrow \text{Cr} (s) \quad E^\circ = -0.74 \text{ V}
   \]
   \[
   \text{Fe}^{2+} (aq) + e^- \rightarrow \text{Fe}^{3+} (aq) \quad E^\circ = +0.77 \text{ V}
   \]

   What will be the cell potential, in V, of a voltaic cell in which the following reaction takes place?

   \[
   \text{Cr} (s) + 3\text{Fe}^{2+} (aq) \rightarrow 3\text{Fe}^{3+} (aq) + \text{Cr}^{3+} (aq)
   \]

   A. -1.51
   B. -0.03
   C. +0.03
   D. +1.51

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30. Consider the following reaction.

   \[
   2\text{FeSO}_4 (aq) + \text{H}_2\text{O}_2 (aq) + \text{H}_2\text{SO}_4 (aq) \rightarrow \text{Fe}_2(\text{SO}_4)_3 (aq) + 2\text{H}_2\text{O} (l)
   \]

   Which species is the oxidizing agent and which is the reducing agent?

<table>
<thead>
<tr>
<th>Oxidizing agent</th>
<th>Reducing agent</th>
</tr>
</thead>
<tbody>
<tr>
<td>\text{FeSO}_4 (aq)</td>
<td>\text{H}_2\text{O}_2 (aq)</td>
</tr>
<tr>
<td>\text{H}_2\text{O}_2 (aq)</td>
<td>\text{FeSO}_4 (aq)</td>
</tr>
<tr>
<td>\text{FeSO}_4 (aq)</td>
<td>\text{H}_2\text{O}_2 (aq)</td>
</tr>
<tr>
<td>\text{H}_2\text{SO}_4 (aq)</td>
<td>\text{H}_2\text{O}_2 (aq)</td>
</tr>
</tbody>
</table>
31. What conditions are necessary to directly measure a standard electrode potential ($E^\circ$)?

I. A half-cell with an electrode in a 1.0 mol dm$^{-3}$ solution of its ions.
II. Connection to a standard hydrogen electrode.
III. A voltmeter between half-cells to measure potential difference.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

32. What condition is necessary for the electroplating of silver, Ag, onto a steel spoon?

A. The spoon must be the positive electrode.
B. The silver electrode must be the negative electrode.
C. The spoon must be the negative electrode.
D. The electrolyte must be acidified.

29. Which compound contains nitrogen with an oxidation number of +3?

A. NH$_4$Cl
B. HNO$_3$
C. N$_2$O$_4$
D. KNO$_2$
30. In the electrolytic cell shown, at which electrode will chlorine form, and what is the process taking place there?

![Electrolytic cell diagram]

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. P</td>
<td>reduction</td>
</tr>
<tr>
<td>B. Q</td>
<td>reduction</td>
</tr>
<tr>
<td>C. P</td>
<td>oxidation</td>
</tr>
<tr>
<td>D. Q</td>
<td>oxidation</td>
</tr>
</tbody>
</table>

31. Which are necessary conditions for the standard hydrogen electrode to have an $E^\circ$ of exactly zero?

I. Temperature = 298 K  
II. $[H^+] = 1 \text{ mol dm}^{-3}$  
III. $[H_2] = 1 \text{ mol dm}^{-3}$

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III
32. How do the products compare at each electrode when aqueous 1 mol dm$^{-3}$ magnesium bromide and molten magnesium bromide are electrolysed?

\[
\begin{align*}
Mg^{2+} (aq) + 2e^- & \quad \Leftrightarrow \quad Mg(s) & \quad E^o = -2.37 \\
\frac{1}{2}Br_2(l) + e^- & \quad \Leftrightarrow \quad Br^-(aq) & \quad E^o = +1.07 \\
\frac{1}{4}O_2(g) + 2H^+ (aq) + 2e^- & \quad \Leftrightarrow \quad H_2O(l) & \quad E^o = +1.23
\end{align*}
\]

<table>
<thead>
<tr>
<th>Positive electrode (Anode)</th>
<th>Negative electrode (Cathode)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. same</td>
<td>same</td>
</tr>
<tr>
<td>B. same</td>
<td>different</td>
</tr>
<tr>
<td>C. different</td>
<td>same</td>
</tr>
<tr>
<td>D. different</td>
<td>different</td>
</tr>
</tbody>
</table>


30. Which species is oxidized in the following reaction?

\[
2Ag^+(aq) + Cu(s) \rightarrow 2Ag(s) + Cu^{2+}(aq)
\]

A. Ag$^+$
B. Cu
C. Ag
D. Cu$^{2+}$

31. Which list represents the halogens in increasing order of oxidizing strength (weakest oxidizing agent first)?

A. Cl$_2$ I$_2$ Br$_2$
B. I$_2$ Br$_2$ Cl$_2$
C. I$_2$ Cl$_2$ Br$_2$
D. Cl$_2$ Br$_2$ I$_2$
32. What is the cell potential, in V, for the reaction that occurs when the following two half-cells are connected?

\[
\begin{align*}
\text{Fe}^{2+} (aq) + 2e^- & \rightleftharpoons \text{Fe} (s) \quad E^0 = -0.44 \text{ V} \\
\text{C}_5\text{O}_7^{2-} (aq) + 14\text{H}^+ (aq) + 6e^- & \rightleftharpoons 2\text{Cr}^{3+} (aq) + 7\text{H}_2\text{O} (l) \quad E^0 = +1.33 \text{ V}
\end{align*}
\]

A. $+0.01$
B. $+0.89$
C. $+1.77$
D. $+2.65$

30. What happens at the negative electrode in a voltaic cell and in an electrolytic cell?

<table>
<thead>
<tr>
<th>Voltaic cell</th>
<th>Electrolytic cell</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. oxidation</td>
<td>reduction</td>
</tr>
<tr>
<td>B. reduction</td>
<td>oxidation</td>
</tr>
<tr>
<td>C. oxidation</td>
<td>oxidation</td>
</tr>
<tr>
<td>D. reduction</td>
<td>reduction</td>
</tr>
</tbody>
</table>

31. Which conditions are usually stated for a standard hydrogen electrode?

I. Hydrogen gas at a pressure of $1.01 \times 10^5 \text{ Pa}$ (1 atm)
II. 1.0 mol dm$^{-3}$ solution of any acid
III. Temperature of 25°C (298 K)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
32. Consider these standard electrode potentials.

\[ \text{Mg}^{2+} (aq) + 2e^- \rightleftharpoons \text{Mg} (s) \quad E^0 = -2.36 \text{ V} \]
\[ \text{Zn}^{2+} (aq) + 2e^- \rightleftharpoons \text{Zn} (s) \quad E^0 = -0.76 \text{ V} \]

What is the cell potential for the voltaic cell produced when the two half-cells are connected?

A. \(-1.60 \text{ V}\)
B. \(+1.60 \text{ V}\)
C. \(-3.12 \text{ V}\)
D. \(+3.12 \text{ V}\)

32. In which compound does manganese have the highest oxidation number?

A. \(\text{MnCl}_2\)
B. \(\text{MnO}_2\)
C. \(\text{Mn}_2\text{O}_3\)
D. \(\text{MnSO}_4\)

33. Which statement about the electrolysis of molten sodium bromide is correct?

A. Bromide ions lose electrons at the negative electrode.
B. Bromide ions gain electrons at the positive electrode.
C. Bromide ions gain electrons at the negative electrode.
D. Bromide ions move even if there is no current.

34. What is the coefficient for \(\text{H}^+\) in the following equation?

\[ 3\text{Cu} (s) + _\_ \text{NO}_3^- (aq) + _\_ \text{H}^+ (aq) \rightarrow _\_ \text{Cu}^{2+} (aq) + _\_ \text{NO} (g) + _\_ \text{H}_2\text{O} (l) \]

A. 4
B. 8
C. 12
D. 16
35. Which conditions apply to the standard hydrogen electrode?

I. Hydrogen at a pressure of $1.01 \times 10^5$ Pa (1 atm)
II. Hydrogen at a temperature of 298 K
III. $1.00 \text{ mol dm}^{-3} \text{ H}_2\text{SO}_4(aq)$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

32. What is the oxidation number of vanadium in the compound NaVO$_2$?

A. $-1$
B. 0
C. +2
D. +5

33. Which statement about electrochemical cells is correct?

A. The reaction in a voltaic cell is spontaneous.
B. The reaction in an electrolytic cell is spontaneous.
C. The reaction in a voltaic cell uses electrical energy.
D. The reaction in an electrolytic cell produces electrical energy.
34. What is the coefficient for H\(^+\) (aq), when this redox equation is balanced using whole numbers?

\[ \text{Cr}_2\text{O}_7^{2-} (aq) + 3\text{Cl}^- (aq) + 14\text{H}^+ (aq) \rightarrow 2\text{Cr}^{3+} (aq) + 3\text{Cl}_2 (g) + 7\text{H}_2\text{O} (l) \]

A. 7  
B. 2  
C. 14  
D. 1

35. Dilute sulfuric acid is electrolyzed using inert electrodes. What product, and in what relative amount, is produced at each electrode?

<table>
<thead>
<tr>
<th>Positive electrode</th>
<th>Negative electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 1 mol H(_2)</td>
<td>2 mol O(_2)</td>
</tr>
<tr>
<td>B. 1 mol O(_2)</td>
<td>2 mol H(_2)</td>
</tr>
<tr>
<td>C. 2 mol H(_2)</td>
<td>1 mol O(_2)</td>
</tr>
<tr>
<td>D. 2 mol O(_2)</td>
<td>1 mol H(_2)</td>
</tr>
</tbody>
</table>

31. During the electrolysis of aqueous sulfuric acid, 1g of hydrogen gas forms at the negative electrode. What mass in grams of oxygen forms at the positive electrode in the same time?

A. 4  
B. 8  
C. 16  
D. 32

32. Which is the strongest oxidizing agent?

A. I\(_2\)  
B. I\(^-\)  
C. F\(_2\)  
D. F\(^-\)
33. The following are standard electrode potentials.

\[
\begin{align*}
\text{Zn}^{2+} (aq) + 2e^- & \rightleftharpoons \text{Zn}(s) \quad E^\circ = -0.76 \text{ V} \\
\text{Mn}^{2+} (aq) + 2e^- & \rightleftharpoons \text{Mn}(s) \quad E^\circ = -1.18 \text{ V}
\end{align*}
\]

What is the \( E^\circ \) for this reaction?

\[
\text{Mn}(s) + \text{ZnSO}_4 (aq) \rightarrow \text{MnSO}_4 (aq) + \text{Zn}(s)
\]

A. \(-0.42 \text{ V}\)
B. \(+0.42 \text{ V}\)
C. \(-1.94 \text{ V}\)
D. \(+1.94 \text{ V}\)

34. Which compound cannot be easily oxidized using acidified potassium dichromate(VI) solution?

A. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}\)
B. \(\text{CH}_3\text{CH}({\text{OH}})\text{CH}_3\)
C. \((\text{CH}_3)_2\text{CHCH}_2\text{OH}\)
D. \((\text{CH}_3)_3\text{COH}\)

35. In which reaction does hydrogen act as an oxidizing agent?

A. \(\text{Ca} + \text{H}_2 \rightarrow \text{CaH}_2\)
B. \(\text{F}_2 + \text{H}_2 \rightarrow 2\text{HF}\)
C. \(\text{C}_2\text{H}_2 + \text{H}_2 \rightarrow \text{C}_2\text{H}_4\)
D. \(\text{O}_2 + 2\text{H}_2 \rightarrow 2\text{H}_2\text{O}\)
### Topic 9 Mark Scheme

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</table>
34. The structure of a drug used to treat symptoms of Alzheimer’s disease is shown below. Which functional groups are present in this molecule?

A. Hydroxyl and ester
B. Hydroxide and ether
C. Hydroxyl and ether
D. Hydroxide and ester
35. Which monomer is used to form the polymer with the following repeating unit?

\[
\begin{array}{c}
\text{H} \\
\text{H} \\
\text{C} - \text{C} \\
\text{CH}_3 \\
\text{CH}_3 \\
\end{array}
\]

A. \( \text{CH}_2\text{CH}=\text{CHCH}_3 \)
B. \( \text{CH}_3\text{CH}=\text{CHCH}_3 \)
C. \( \text{CH}_2\text{CH}_2\text{CH}=\text{CH}_3 \)
D. \( \text{(CH}_2)_2\text{C}=\text{CH}_2 \)

36. Which is correct for the conversion of propanal to propyl methanoate?

\[
\text{CH}_3\text{CH}=\text{CHCH}_3 \xrightarrow{\text{Step 1, \text{Reagent 1}}} \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{Step 2, Concentrated H}_2\text{SO}_4 \text{ and methanoic acid}}} \text{HCO}_2\text{CH}_2\text{CH}_2\text{CH}_3
\]

<table>
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<tr>
<th>Reagent for step 1</th>
<th>Reaction type in step 1</th>
<th>Reaction type in step 2</th>
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<tr>
<td>A. ( \text{H}_2\text{O} )</td>
<td>hydration</td>
<td>addition</td>
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</table>
| B. \( \text{K}_2\text{Cr}_2\text{O}_7, \text{dilute H}_2\text{SO}_4 \) | oxidation               | nucleophi
c reduction (condensation) |
| C. \( \text{NaBH}_4 \) | reduction               | oxidation               |
| D. \( \text{NaBH}_4 \) | reduction               | nucleophilic substitution (condensation) |

37. Which statement is correct for a pair of enantiomers under the same conditions?

A. A racemic mixture of the enantiomers is optically active.
B. They have the same chemical properties in all their reactions.
C. They have the same melting and boiling points.
D. They rotate the plane of plane-polarized light by different angles.
34. What is the general formula of the alkyne series?
   A. \( C_nH_n \)
   B. \( C_nH_{2n-2} \)
   C. \( C_nH_{2n} \)
   D. \( C_nH_{2n+2} \)

35. Which statement is correct about the major reaction between 1-chloropropane, \( CH_2CH_2CH_2Cl \), and dilute sodium hydroxide solution, \( NaOH(aq) \)?
   A. The rate equation is second order.
   B. The hydroxide ion acts as a Brønsted–Lowry base.
   C. The reaction has two distinct steps.
   D. Water is a product.

36. Which molecule can be both reduced by sodium borohydride, \( NaBH_4 \), and oxidized by warm acidified potassium dichromate(VI)?
   A. \( CH_3CHO\text{H}CH_2CH_3 \)
   B. \( (CH_3)_2CCHO \)
   C. \( (CH_3)_2COH \)
   D. \( (CH_3)_2COC(CH_3)_3 \)

37. Which molecule contains a chiral carbon?
   A. \( CH_2CHO\text{H}CH_2CH_3 \)
   B. \( (CH_3)_2CCHO \)
   C. \( (CH_3)_2COH \)
   D. \( (CH_3)_2COC(CH_3)_3 \)

38. A measuring cylinder was used to obtain a known volume of a liquid. The volume was read from the top of the meniscus and the liquid completely emptied into a flask. The exact same process was then repeated. Which statement is correct about the overall described procedure and the volumes measured?
   A. There is a systematic error and the volumes measured are accurate.
   B. There is a random error and the volumes measured are accurate.
   C. There is a random error and the volumes measured are inaccurate.
   D. There is a systematic error and the volumes measured are inaccurate.
33. Which molecule has an index of hydrogen deficiency (IHD) = 1?
   A. C₆H₆
   B. C₂Cl₂
   C. C₂H₂N
   D. C₂H₂O

34. Which is propyl propanoate?
   A. CH₃CH₂CH₂OOCCH₂CH₃
   B. CH₂CH₂CH₂COOCH₂CH₃
   C. CH₂CH₂CH₂COCH₂CH₃
   D. CH₂CH₂CH₂OCH₂CH₂CH₃
35. Which could form an addition polymer?
   
   A. $\text{H}_2\text{NCH}_2\text{CHCH}_2\text{NH}_2$
   
   B. $\text{H}_2\text{N(CH}_2\text{)}_2\text{CO}_2\text{H}$
   
   C. $\text{HO(CH}_2\text{)}_2\text{CO}_2\text{H}$
   
   D. $\text{H}_2\text{N(CH}_2\text{)}_2\text{NH}_2$

36. Which benzene derivative can be formed from methylbenzene by electrophilic substitution?

   A. 
   
   ![Image of benzene derivative A with CH2Cl substituent]
   
   B. 
   
   ![Image of benzene derivative B with CH3 and CH2H substituents]
   
   C. 
   
   ![Image of benzene derivative C with CH3 and NO2 substituents]
   
   D. 
   
   ![Image of benzene derivative D with CH2NH2 substituent]

37. Which compound has two enantiomeric forms?

   A. $\text{CH}_3\text{CH}_2\text{CBr}_2\text{CH}_3$
   
   B. $\text{CH}_3\text{CH}_2\text{CHBrCH}_3$
   
   C. $\text{CH}_3(\text{CH}_2)_2\text{CH}_2\text{Br}$
   
   D. $\text{CH}_3\text{CH}_2\text{CHBrCH}_2\text{CH}_3$

34. Which pair of compounds can be distinguished by reacting them with dilute bromine water in the dark?

   A. $\text{CH}_3\text{CH}_2\text{COOH}$ and $\text{CH}_3\text{CH}_2\text{CHO}$
   
   B. $\text{CH}_3\text{CH}_2\text{CHCHCH}_3$ and $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$
   
   C. $\text{CH}_3\text{CH}_2\text{CH(CH}_3)_2$ and $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
   
   D. $\text{CH}_3\text{CH}_2\text{CHCHBrCH}_3$ and $\text{CH}_3\text{CH}_2\text{CHBrCH}_2\text{CH}_3$
35. Which compound is most soluble in water?
   A. CH₃CH₂CHO
   B. CH₄CH₂CH₂CHO
   C. CH₃CH₂CO₂H
   D. CH₄CH₂CH₂CO₂H

36. Which are features of successive members of a homologous series?
   I. Similar chemical properties
   II. Same general formula
   III. Differ by −CH₂−
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

37. Which formula represents propanenitrile?
   A. CH₃CH₂CN
   B. CH₃CH₂CH₂CN
   C. CH₃CH₂CH₂NH₂
   D. CH₃CH(NH₂)CH₃

38. Which haloenoalkane reacts fastest with warm NaOH (aq)?
   A. (CH₃)₂CCl
   B. (CH₃)₂CBr
   C. CH₃CH₂CH₂CH₂Cl
   D. CH₃CH₂CH₂CH₂Br
39. Which is the geometric isomer of cis-1,2-dichlorocyclopropane?

A. 

B. 

C. 

D. 

34. Which of the following functional groups are present in aspirin?

A. Hydroxyl (alcohol) and ester

B. Carboxyl (carboxylic acid) and ester

C. Carboxyl (carboxylic acid) and carbonyl (ketone)

D. Hydroxyl (alcohol) and carbonyl (ketone)
35. Which statements are correct for the reaction of ethene with bromine in the absence of ultraviolet light?

   I. It is an addition reaction.
   II. The organic product is colourless.
   III. The organic product is saturated.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

36. Applying IUPAC rules, what is the name of CH$_3$CH(CH$_3$)$_2$CONH$_2$?

A. Aminobutanone
B. 1-amino-2-methylpropanone
C. 2-methylpropanamide
D. Butanamide

37. What is the correct order for the increasing rate of hydrolysis of halogenoalkanes by dilute aqueous sodium hydroxide?

A. CH$_3$CH(CH$_3$)CH$_2$Cl < CH$_3$CHClCH$_2$CH$_3$ < (CH$_3$)$_3$CCl < (CH$_3$)$_3$CBr
B. (CH$_3$)$_2$CBr < (CH$_3$)$_3$CCl < CH$_3$CHClCH$_2$CH$_3$ < CH$_3$CH(CH$_3$)$_2$Cl
C. (CH$_3$)$_2$CCl < (CH$_3$)$_3$CBr < CH$_3$CHClCH$_2$CH$_3$ < CH$_3$CH(CH$_3$)$_2$Cl
D. CH$_3$CHClCH$_2$CH$_3$ < CH$_3$CH(CH$_3$)$_2$Cl < (CH$_3$)$_2$CBr < (CH$_3$)$_3$CCl

38. Which pairs of compounds can react together to undergo condensation polymerization reactions?

   I. HOOC--C$_2$H$_4$--COOH and C$_2$H$_5$OH
   II. H$_2$N--(CH$_3$)$_2$--NH$_2$ and HOOC--(CH$_3$)$_2$--COOH
   III. H$_2$N--CH$_2$--COOH and H$_2$N--CH(CH$_3$)--COOH

A. I and II only
B. I and III only
C. II and III only
D. I, II and III
39. How many four-membered ring isomers are there of dichlorocyclobutane, \( \text{C}_2\text{H}_4\text{Cl}_2 \)?
   
   A. 3  
   B. 4  
   C. 5  
   D. 6  

34. Applying IUPAC rules, what is the name of the compound?

   \[
   \begin{align*}
   &\text{CH}_3 \\
   \text{CH}_2 &\text{CH} \quad \text{CH} \quad \text{C} \\ 
   &\text{CH}_2
   \end{align*}
   \]

   A. 1-ethyl-1,3-dimethylbut-2-ene  
   B. 2-ethyl-4-methylpent-3-ene  
   C. 2-methyl-4-ethylpent-3-ene  
   D. 2,4-dimethylhex-2-ene  

35. What is the product of the addition of chlorine, \( \text{Cl}_2 \), to propene, \( \text{C}_3\text{H}_6 \)?

   A. 1,1-dichloropropane  
   B. 2,2-dichloropropane  
   C. 1,2-dichloropropane  
   D. 1,3-dichloropropane  

36. What should be changed to alter the rate of nucleophilic substitution of tertiary halogenoalkanes?

   A. The nucleophile  
   B. The concentration of the nucleophile  
   C. The concentration of the tertiary halogenoalkane  
   D. The size of the reaction flask
37. Which compound could be $X$ in the two-stage reaction pathway?

$$\text{C}_2\text{H}_6 \rightarrow X \rightarrow \text{C}_2\text{H}_5\text{NH}_2$$

A. $\text{C}_2\text{H}_4$
B. $\text{C}_2\text{H}_5\text{Cl}$
C. $\text{C}_2\text{H}_4\text{Cl}_2$
D. $\text{C}_2\text{H}_5\text{OH}$

38. Which pair are geometric isomers?

A. [Diagrams of geometric isomers A and B]
B. [Diagrams of geometric isomers C and D]
C. [Diagrams of geometric isomers E and F]
D. [Diagrams of geometric isomers G and H]

39. Which reagent(s) can be used to convert $\text{CH}_3\text{CH}_2\text{CN}$ to $\text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2$?

A. $\text{H}_2$ only
B. $\text{H}_2\text{O}$ only
C. $\text{H}_2$ in the presence of Ni
D. $\text{H}_2\text{O}$ in the presence of $\text{H}^+$
34. Which product is formed when bromine water is added to propene, \( \text{CH}_2\text{CHCH}_3 \)?

A. \( \text{CH}_3\text{CBr}_2\text{CH}_3 \)

B. \( \text{CH}_2\text{BrCH}_2\text{CH}_2\text{Br} \)

C. \( \text{CH}_3\text{CHBrCH}_2\text{Br} \)

D. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{Br} \)

35. Which equation represents a propagation step in the reaction of methane with bromine?

A. \( \text{CH}_4 \rightarrow \text{CH}_2 \cdot + \text{H} \cdot \)

B. \( \text{CH}_4 + \text{Br} \cdot \rightarrow \text{CH}_3 \cdot + \text{HBr} \)

C. \( \text{CH}_4 + \text{Br} \cdot \rightarrow \text{CH}_3\text{Br} + \text{H} \cdot \)

D. \( \text{CH}_3 \cdot + \text{Br} \cdot \rightarrow \text{CH}_2\text{Br} \)

36. Which of these repeating units is present in the polymer poly(propene)?

A. \[
\begin{array}{cc}
\text{H} & \text{H} \\
\text{C} & \text{C} \\
\text{H} & \text{H}
\end{array}
\]

B. \[
\begin{array}{cc}
\text{H} & \text{H} \\
\text{C} & \text{C} \\
\text{CH}_3 & \text{CH}_3
\end{array}
\]

C. \[
\begin{array}{cc}
\text{CH}_3 & \text{H} \\
\text{C} & \text{C} \\
\text{H} & \text{CH}_3
\end{array}
\]

D. \[
\begin{array}{cc}
\text{H} & \text{H} \\
\text{C} & \text{C} \\
\text{H} & \text{CH}_3
\end{array}
\]
37. Chloroethane, \( \text{C}_2\text{H}_5\text{Cl} \), reacts with concentrated ammonia, \( \text{NH}_3 \), to form ethanamine, \( \text{C}_2\text{H}_5\text{NH}_2 \). Which statement about the mechanism of this reaction is correct?

A. The reaction follows an \( S_{N}1 \) mechanism.
B. Homolytic fission of the carbon-chlorine bond occurs in chloroethane.
C. The reaction is unimolecular.
D. There is no charge on the transition state.

38. Which combination of monomers produces a condensation polymer with the repeating unit below?

\[
\text{OC} \quad \text{COOCH}_2\text{CH}_2\text{O} \quad n
\]

A. \( \text{C}_2\text{H}_4\text{COOH} \) and \( \text{HOCH}_2\text{CH}_2\text{OH} \)
B. \( \text{C}_2\text{H}_4\text{COOH} \) and \( \text{CH}_3\text{CH}_2\text{OH} \)
C. \( \text{C}_2\text{H}_4(\text{COOH})_2 \) and \( \text{CH}_3\text{CH}_2\text{OH} \)
D. \( \text{C}_2\text{H}_4(\text{COOH})_2 \) and \( \text{HOCH}_2\text{CH}_2\text{OH} \)

39. Which type(s) of stereoisomerism, if any, is/are present in the molecule \( \text{CH}_2=\text{CHCHBrCH}_3 \)?

A. Optical only
B. Geometric only
C. Optical and geometric
D. Neither optical nor geometric

Topic: Chem 10 Q# 254/ IB/Paper 1/2014/s/Time Zone 2/Higher Level/

35. In organic reaction mechanisms, what does a curly arrow represent?

A. The movement of a pair of electrons towards a nucleophile
B. The movement of a pair of electrons towards a positively charged species
C. The movement of a pair of electrons away from a positively charged species
D. The movement of a pair of electrons towards a Lewis base
36. Which properties are features of a homologous series?
   I. Same general formula
   II. Similar chemical properties
   III. Gradation in physical properties
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III

37. What does a polarimeter measure?
   A. Colour of reaction mixture
   B. Polarity of a molecule
   C. Configuration of a molecule as R or S
   D. Rotation of plane-polarized light

38. Which compound can exist as stereoisomers?
   A. 1,2-dichloroethane
   B. 1,1-dichloroethene
   C. Butan-2-ol
   D. Propan-2-ol

39. What is the structural formula of the ester formed by reacting propanoic acid with 2-methylbutan-2-ol under appropriate conditions?
   A. 
   B. 
   C. 
   D. 

Topic Chem 10 Q# 255/ IB/Paper 1/2014/s/Time Zone 1/Higher Level/
34. What is the IUPAC name for \((\text{CH}_2)_2\text{COH(CH}_3)_2\text{CH}_3\)?

A. Hexan-3-ol  
B. 2-methylpentan-2-ol  
C. 2-methylpentan-3-ol  
D. Dimethylpentan-1-ol

35. Which type of halogenoalkane is the substance shown below, and which type of nucleophilic reaction does it undergo with an aqueous sodium hydroxide solution?

![Molecule Diagram]

<table>
<thead>
<tr>
<th>Type of halogenoalkane</th>
<th>Type of nucleophilic reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. primary</td>
<td>(S_N 1)</td>
</tr>
<tr>
<td>B. tertiary</td>
<td>(S_N 1)</td>
</tr>
<tr>
<td>C. primary</td>
<td>(S_N 2)</td>
</tr>
<tr>
<td>D. tertiary</td>
<td>(S_N 2)</td>
</tr>
</tbody>
</table>

36. Which reaction produces only butan-2-ol?

A. Addition of water to but-2-ene  
B. Addition of water to but-1-ene  
C. Reaction of 2-bromobutane with alcoholic sodium hydroxide  
D. Reaction of 1-bromobutane with alcoholic sodium hydroxide
37. Which functional groups are present in \( \text{C}_8\text{H}_2\text{CONHCH}_3 \)?

\[ \text{CONHCH}_3 \]

A. amide and benzene ring (phenyl)
B. amine, benzene ring (phenyl) and carbonyl
C. benzene ring (phenyl) and carbonyl
D. amine and benzene ring (phenyl)

38. Which two compounds can form a polyester?

A. \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{C} \quad \text{OH} \\
\text{C} & \quad \text{O} \\
\text{O} & \quad \text{C} \quad \text{C} \quad \text{OH}
\end{align*}
\]

and \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{C} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H}
\end{align*}
\]

B. \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{OH} \\
\text{C} & \quad \text{O} \\
\text{O} & \quad \text{C} \quad \text{C} \quad \text{C} \quad \text{OH}
\end{align*}
\]

and \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{C} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H}
\end{align*}
\]

C. \[
\begin{align*}
\text{H} & \quad \text{C} \quad \text{C} \quad \text{OH} \\
\text{C} & \quad \text{O} \\
\text{O} & \quad \text{C} \quad \text{C} \quad \text{OH}
\end{align*}
\]

and \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{C} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H}
\end{align*}
\]

D. \[
\begin{align*}
\text{H} & \quad \text{C} \quad \text{C} \quad \text{OH} \\
\text{C} & \quad \text{O} \\
\text{O} & \quad \text{C} \quad \text{C} \quad \text{OH}
\end{align*}
\]

and \[
\begin{align*}
\text{HO} & \quad \text{C} \quad \text{C} \\
\text{H} & \quad \text{H} \\
\text{H} & \quad \text{H}
\end{align*}
\]
39. Which statement about isomerism is correct?

A. But-1-ene and but-2-ene are geometrical isomers.
B. But-1-ene has two geometrical isomers.
C. Butan-1-ol and butan-2-ol are optical isomers.
D. Butan-2-ol has two optical isomers.

35. What is the name of \((\text{CH}_3)_2\text{COCCH}_3\), applying IUPAC rules?

A. 2,2-dimethylbutan-3-one
B. 3,3-dimethylbutan-2-one
C. 2,2-dimethylbutanal
D. 3,3-dimethylbutanal

36. Which functional groups are present in \(\text{C}_6\text{H}_2\text{CONHC}_6\text{H}_3\)?

A. Benzene ring (phenyl), amine
B. Benzene ring (phenyl), ketone, amine
C. Benzene ring (phenyl), amide
D. Alkene, amide

37. What is the product of the reaction when \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{CN}\) is reduced by hydrogen, using a nickel catalyst under the appropriate conditions?

A. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2\)
B. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2\)
C. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3\)
D. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3\)
38. What is the major organic product formed from the reaction of \((\text{CH}_3)_2\text{CBr}\) with a concentrated, ethanolic solution of KOH?

A. \((\text{CH}_3)_2\text{COH}\)

B. \((\text{CH}_3)_2\text{CCH}_3\)

C. \((\text{CH}_3)_2\text{CO}\)

D. \((\text{CH}_3)_2\text{CHO}\)

39. What is the organic product of the reaction between butan-1-ol and ethanoic acid on heating using concentrated sulfuric acid?

A. Butyl methanoate

B. Butyl ethanoate

C. Ethyl butanoate

D. Ethyl propanoate

33. What are possible products of the incomplete combustion of propan-2-ol?

A. carbon monoxide, hydrogen and carbon

B. carbon dioxide, carbon and hydrogen

C. carbon, carbon monoxide and water

D. carbon dioxide and water only

34. Which equation represents a propagation step in the mechanism for the reaction between ethane, \(\text{C}_2\text{H}_6\), and chlorine, \(\text{Cl}_2\), in the presence of sunlight/UV?

A. \(\text{C}_2\text{H}_6 + \text{Cl}\cdot \rightarrow \text{C}_2\text{H}_5\cdot + \text{HCl}\)

B. \(\text{C}_2\text{H}_6 + \text{Cl}\cdot \rightarrow \text{C}_2\text{H}_5\text{Cl} + \text{H}\cdot\)

C. \(\text{Cl}_2 \rightarrow 2\text{Cl}\cdot\)

D. \(\text{C}_2\text{H}_5\cdot + \text{Cl}\cdot \rightarrow \text{C}_2\text{H}_5\text{Cl}\)

35. What is the name of \(\text{CH}_2\text{CH}_3\text{CH}_2\text{CN}\) applying IUPAC rules?

A. Butanamine

B. Butanamide

C. Propanenitrile

D. Butanenitrile
36. 1-bromobutane, CH₂CH₂CH₂CH₂Br, can be converted to 1-aminopentane, CH₂CH₂CH₂CH₂CH₂NH₂, in a two-step process.

\[
\begin{align*}
\text{CH₂CH₂CH₂CH₂Br} & \xrightarrow{\text{I}} \text{CH₂CH₂CH₂CH₂CN} \\
\text{CH₂CH₂CH₂CH₂CN} & \xrightarrow{\text{II}} \text{CH₂CH₂CH₂CH₂CH₂NH₂}
\end{align*}
\]

What are the reagents I and II?

<table>
<thead>
<tr>
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<th>II</th>
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<tbody>
<tr>
<td>A</td>
<td>ammonia</td>
<td>hydrogen with nickel</td>
</tr>
<tr>
<td>B</td>
<td>ammonia</td>
<td>hydrochloric acid</td>
</tr>
<tr>
<td>C</td>
<td>potassium cyanide</td>
<td>ammonia</td>
</tr>
<tr>
<td>D</td>
<td>potassium cyanide</td>
<td>hydrogen with nickel</td>
</tr>
</tbody>
</table>

37. Which halogenoalkane reacts the fastest with hydroxide ions in a nucleophilic substitution reaction?

A. 1-chlorobutane
B. 2-chloro-2-methylpropane
C. 1-iodobutane
D. 2-iodo-2-methylpropane

38. Ethylamine, CH₃CH₂NH₃⁺, reacts with propanoic acid, CH₃CH₂COOH. Initially a salt is formed which, when heated at 200 °C, can form an organic product. What is the structural formula of the organic product?

A. CH₃CH₂NHCOCH₂CH₃
B. CH₃CH₂NHCOOCH₂CH₃
C. CH₃CH₂COONHCH₂CH₃
D. CH₃CH₂COOCH₂CH₃
39. Which structure is a geometric isomer of cis-1,2-dichlorocyclobutane?

A.  

B.  

C.  

D.  

34. What is the name of the following compound applying IUPAC rules?

A. *cis*-4-methylhex-2-ene  
B. *cis*-4-ethylpent-2-ene  
C. *trans*-4-methylhex-2-ene  
D. *trans*-4-ethylpent-2-ene
35. Which steps are involved in the free-radical mechanism of the bromination of ethane in the presence of ultraviolet radiation?

I. \( \text{C}_2\text{H}_6 + \text{Br}^* \rightarrow \text{C}_2\text{H}_5^* + \text{HBr} \)

II. \( \text{C}_2\text{H}_5^* + \text{Br}_2 \rightarrow \text{C}_2\text{H}_2\text{Br} + \text{Br}^* \)

III. \( \text{C}_2\text{H}_5^* + \text{Br}_2 \rightarrow \text{C}_2\text{H}_3\text{Br} \)

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III

36. Which substance can be polymerized to produce the polymer below?

\[
\text{CH}_3 \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{CH}_3 \quad \text{H} \quad \text{H} \quad \text{H} \\
\text{H} \quad \text{H} \quad \text{CH}_3 \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{CH}_3 \quad \text{H}
\]

A. But-1-ene  
B. But-2-ene  
C. Propene  
D. 2-methylpropene

37. Which factors affect the rate of nucleophilic substitution in halogenoalkanes?

I. The nature of the attacking nucleophile

II. The identity of the halogen

III. The structure of the halogenoalkane

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III
38. Which molecule exhibits optical isomerism?
   A. 3-chloropentane
   B. 2-chlorobutane
   C. 1,3-dichloropropane
   D. 2-chloro-2-methylpropane

39. What is a use of the organic product formed when an alcohol and a carboxylic acid react together?
   A. Pesticide
   B. Lubricant
   C. Flavourings in food
   D. Fertilizer

34. Which compound has the lowest boiling point?
   A. \((\text{CH}_3)\text{COH}\)
   B. \(\text{CH}_2(\text{CH}_2)_2\text{OH}\)
   C. \((\text{CH}_3)_4\text{C}\)
   D. \(\text{CH}_3(\text{CH}_2)_2\text{CH}_3\)

35. Which compound would decolourize bromine water in the dark?
   A. \(\text{CH}_3\text{COCH}_2\text{CH}_3\)
   B. \(\text{CH}_3(\text{CH}_2)_4\text{OH}\)
   C. \(\text{CH}_3\text{CHCHCH}_3\)
   D. \(\text{CH}_3(\text{CH}_2)_2\text{CH}_3\)
36. Which statement about the oxidation of alcohols is correct?
   A. Oxidation of propan-1-ol produces propanone.
   B. Mild oxidation of butan-1-ol produces butanal.
   C. Strong oxidation of pentan-2-ol produces pentanoic acid.
   D. Mild oxidation of butan-2-ol produces butanal.

37. Which haloenoalkane will react most quickly with sodium hydroxide?
   A. CH₃CH₂CH₂CH₂Cl
   B. CH₃CH₂CH₂CH₂Br
   C. (CH₂)₂CCl
   D. (CH₂)₂CBr

38. Which would be the main product of the reaction between 1-bromobutane and concentrated sodium hydroxide in hot ethanol?
   A. CH₂CHCH₂CH₃
   B. CH₂CHCHCH₃
   C. CH₃CH₂CH₂CH₃
   D. CH₃CHOHCH₂CH₂

39. Which molecules can react to form a condensation polymer with a dicarboxylic acid such as hexanedioic acid?
   I. HOCH₂CH₂OH
   II. CH₃CH₂NH₂
   III. H₂N(CH₂)₂NH₂
   A. I and II only
   B. I and III only
   C. II and III only
   D. I, II and III
32. What is the name of \((\text{CH}_3)_2\text{CHCOCH}_3\) applying IUPAC rules?
   
   A. 3,3-dimethylpropan-2-one
   
   B. 3-methylbutan-2-one
   
   C. 2-methylbutan-3-one
   
   D. 3-methylbutanal

33. The drug methadone contains several different functional groups. Which functional groups are present in methadone?

\[
\begin{align*}
\text{CH}_3 & \quad \text{N} \quad \text{CH}_3 \\
\text{H}_3\text{C} & \quad \text{O} \\
\text{H} \quad \text{C} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\text{H} & \quad \text{C} \\
\end{align*}
\]

   A. ketone, benzene ring, amine
   
   B. ketone, benzene ring, amide
   
   C. aldehyde, alkene, amide
   
   D. aldehyde, alkene, amine

34. Which compound has the lowest boiling point?

   A. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}\)
   
   B. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}\)
   
   C. \(\text{CH}_3\text{CH}_2\text{COOH}\)
   
   D. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3\)
35. Which organic compounds, Q and P, are formed in the following two-stage reaction pathway?

\[ \text{Stage 1: } \text{CH}_3(\text{CH}_2)_2\text{Cl} \xrightarrow{\text{NaOH(aq), heat}} Q \]

\[ \text{Stage 2: } Q \xrightarrow{\text{Cr}_2\text{O}_7^{2-}(\text{aq})/\text{H}^+(\text{aq}), reflux}} P \]

<table>
<thead>
<tr>
<th></th>
<th><strong>Q</strong></th>
<th><strong>P</strong></th>
</tr>
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<tbody>
<tr>
<td>A</td>
<td>CH₃(CH₂)₃OH</td>
<td>CH₃(CH₂)₃COOH</td>
</tr>
<tr>
<td>B</td>
<td>CH₃(CH₂)₃OH</td>
<td>CH₃(CH₂)₃COOH</td>
</tr>
<tr>
<td>C</td>
<td>CH₂CH₂CH=CH₂</td>
<td>no reaction product formed</td>
</tr>
<tr>
<td>D</td>
<td>CH₃(CH₂)₃OH</td>
<td>CH₃(CH₂)₂CHO</td>
</tr>
</tbody>
</table>

36. What is the organic product, Y, formed in the following reaction?

\[ \text{CH₃(CH₂)₃CN} + 2\text{H}_2 \xrightarrow{\text{Ni}} \text{Y} \]

A. CH₃(CH₂)₂NH₂

B. CH₃(CH₂)₄NH₂

C. CH₃(CH₂)₂CH₃

D. CH₃(CH₂)₃COOH

37. What organic product is formed from the reaction of benzoic acid, C₆H₅COOH, with ethylamine, CH₃CH₂NH₂?

A. C₆H₅CONHCH₂CH₃

B. C₆H₅CONH₂

C. CH₂CH₂CONHC₆H₅

D. C₆H₅COOCH₂CH₃
38. Which compound has a chiral carbon?

A. Propan-2-ol
B. 1-bromo-2-methylbutane
C. 3-bromopentane
D. Ethane-1,2-diol

39. What effect of optical isomers on plane-polarized light can be measured using a polarimeter?

A. Reflection
B. Emission
C. Rotation
D. Absorption

34. Which statements about CH₃CH₂CHO are correct?

I. It can be oxidized to CH₃CH₂COOH.
II. It can be produced by oxidation of CH₃CH₂OH.
III. It can be reduced to CH₃CH₂CH₂OH.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

35. Which reaction of but-2-ene produces 2-chlorobutane?

A. Addition reaction with chlorine
B. Substitution reaction with hydrogen chloride
C. Substitution reaction with chlorine
D. Addition reaction with hydrogen chloride
36. What are the correct names of the reaction types shown?

\[
\begin{align*}
\text{CH}_3\text{CH}_2\text{CH}_3 & \xrightarrow{\text{I}} \text{ClCH}_2\text{CH}_2\text{Cl} & \xrightarrow{\text{II}} \text{HOCH}_2\text{CH}_2\text{CH}_3
\end{align*}
\]

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<tbody>
<tr>
<td>A</td>
<td>nucleophilic substitution</td>
<td>oxidation</td>
</tr>
<tr>
<td>B</td>
<td>free-radical substitution</td>
<td>oxidation</td>
</tr>
<tr>
<td>C</td>
<td>nucleophilic substitution</td>
<td>nucleophilic substitution</td>
</tr>
<tr>
<td>D</td>
<td>free-radical substitution</td>
<td>nucleophilic substitution</td>
</tr>
</tbody>
</table>

37. What is the name of the substance below?

\[
\begin{align*}
\text{H} & \quad \text{CH}_3 \\
\text{H} & \quad \text{C} - \text{C} - \text{CN} \\
\text{H} & \quad \text{CH}_3
\end{align*}
\]

A. Pentanenitrile
B. 2-methyl-2-propanenitrile
C. 2,2-dimethylpropanenitrile
D. 1,1-dimethylethanenitrile

38. What is the correct order of increasing rate of reaction between the following halogenoalkanes and a warm aqueous solution of sodium hydroxide?

A. \( \text{CH}_3\text{F} < \text{CH}_2\text{Cl} < (\text{CH}_3)_2\text{CHCl} \)
B. \( \text{CH}_2\text{Cl} < \text{CH}_3\text{F} < (\text{CH}_3)_2\text{CHCl} \)
C. \( \text{CH}_3\text{Cl} < (\text{CH}_3)_2\text{CHCl} < \text{CH}_3\text{F} \)
D. \( (\text{CH}_3)_2\text{CHCl} < \text{CH}_3\text{Cl} < \text{CH}_3\text{F} \)
39. Which statements are correct for the nylon shown below?

\[ \{OC(CH_2)_4CONH(CH_3)_2NH\}_n \]

I. It is produced by condensation polymerization.
II. It is a polyamide.
III. One of its monomers is \( \text{H}_2\text{N(CH}_3)_2\text{NH}_2 \).

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

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33. Which molecule contains an ester group?

A. \( \text{CH}_2\text{CH}_2\text{COOH} \)
B. \( \text{CH}_3\text{COOCH}_3 \)
C. \( \text{CH}_3\text{COCH}_2\text{CH}_2\text{OH} \)
D. \( \text{OHCCH}_2\text{CHO} \)

34. Which compound is produced in the reaction between but-2-ene and steam?

A. \( \text{CH}_3\text{CHOHCHOHCH}_3 \)
B. \( \text{CH}_2\text{OHCH}_2\text{CH}_2\text{CH}_2\text{OH} \)
C. \( \text{CH}_3\text{CH}_2\text{CHOHCH}_3 \)
D. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \)
35. From which monomer is this polymer made?

\[
\text{H} \quad \text{H} \quad \text{H} \quad \text{Cl} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{Cl} \\
\text{H} \quad \text{Cl} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{Cl} \quad \text{H} \quad \text{H} \\
\text{H} \quad \text{Cl} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{Cl} \quad \text{H} \quad \text{H}
\]

A. \[ \text{H} \quad \text{C} = \text{C} \quad \text{Cl} \]

B. \[ \text{Cl} \quad \text{C} = \text{C} \quad \text{H} \]

C. \[ \text{Cl} \quad \text{H} \quad \text{C} = \text{C} \quad \text{H} \]

D. \[ \text{H} \quad \text{C} = \text{C} \quad \text{Cl} \]

36. Which compound is the major product of the reaction when 1-bromobutane is heated with concentrated sodium hydroxide in ethanol?

A. \( \text{CH}_3\text{CHOHCH}_2\text{CH}_3 \)

B. \( \text{CH}_3\text{CHCHCH}_3 \)

C. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH} \)

D. \( \text{CH}_2\text{CHCH}_2\text{CH}_3 \)

37. Which halogenoalkane reacts fastest with sodium hydroxide?

A. 1-iodobutane

B. 1-chlorobutane

C. 2-chloro-2-methylpropane

D. 2-iodo-2-methylpropane
38. Which molecule exhibits optical isomerism?
   A. 3-iodopentane
   B. 2-iodo-2-methylpropane
   C. 1,3-diodopropane
   D. 2-iodobutane

39. What is the most likely use for the organic product of the following reaction?

   \[
   \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} + \text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} \rightarrow
   \]
   A. Catalyst
   B. Pesticide
   C. Detergent
   D. Perfume

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34. Which of the structures below is an aldehyde?
   A. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \)
   B. \( \text{CH}_3\text{CH}_2\text{COCH}_3 \)
   C. \( \text{CH}_3\text{CH}_2\text{COOCH}_3 \)
   D. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CHO} \)

35. Which type of reaction occurs when 2-iodo-2-methylpropane, \( \text{C(\text{CH}_3)_2\text{I} } \), reacts with aqueous sodium hydroxide, \( \text{NaOH (aq)} \)?
   A. Addition
   B. Free-radical substitution
   C. \( S_N1 \)
   D. \( S_p2 \)
36. Halogenoalkanes can undergo $S_N^1$ and $S_N^2$ reactions with aqueous sodium hydroxide. Which halogenoalkane will react fastest with a 0.1 mol dm$^{-3}$ solution of aqueous sodium hydroxide?

A. 2-chloro-2-methylpropane
B. 2-iodo-2-methylpropane
C. 1-chlorobutane
D. 1-iodobutane

37. Propanitrile can be prepared by reacting bromoethane with potassium cyanide. Which statement is not correct about the reaction between bromoethane and potassium cyanide?

A. The reaction is bi-molecular.
B. The reaction follows the $S_N^2$ mechanism.
C. Homolytic fission occurs between the carbon-bromine bond in bromoethane.
D. The cyanide ion, :CN$^-$, acts as a nucleophile.

38. Which reactants could be used to form the compound below?

![Chemical structure image]

A. Butanoic acid and ethanol
B. Propanoic acid and ethanol
C. Ethanoic acid and propan-1-ol
D. Ethanoic acid and butan-1-ol
39. Which compound is optically active?

A. 1-chlorobutane

B. 2-chlorobutane

C. 2-aminoethanoic acid

D. 2,2-dimethylpropane

33. Which molecule has a chiral centre?

A. CH₃CH=CHCHO

B. (CH₃)₂C=CHCH₂OH

C. CH₃OCH₂CH₃

D. CH₃CHOHCH₂CH₃

34. The compounds H₂NCH₂CH₂NH₂ and HOOCCH₂COOH react to form a polymer. What is the structure of the repeating unit of the polymer?

A. →HNCH₂CONHCH₂CH₂NHCO→

B. →HNCH₂CH₂NHCOCH₂CO→

C. →OCCH₂CONHCH₂NHCO→

D. →HNCH₂CH₂NHCOCH₂NH→
35. Which two molecules are cis-trans isomers of each other?

\[
\begin{array}{c}
W & \text{H}_3\text{C} & \text{C} & \text{C} & \text{H} & \text{X} & \text{H} & \text{C} & \text{C} & \text{COOH} \\
& \text{HOOC} & \text{C} & \text{CH}_3 & & & \text{H}_3\text{C} & \text{C} & \text{CH}_3 & \\
Y & \text{H}_3\text{C} & \text{C} & \text{C} & \text{H} & \text{Z} & \text{H}_3\text{C} & \text{C} & \text{COOH} & \text{H} & \text{C} & \text{CH}_3
\end{array}
\]

A. X and Z
B. X and Y
C. W and Y
D. W and Z

36. What is the correct order of reaction types in the following sequence?

\[
\begin{array}{cccc}
\text{C}_3\text{H}_7\text{Br} & \xrightarrow{\text{I}} & \text{C}_3\text{H}_7\text{OH} & \xrightarrow{\text{II}} & \text{C}_2\text{H}_5\text{COOH} & \xrightarrow{\text{III}} & \text{C}_2\text{H}_5\text{COOC}_2\text{H}_5
\end{array}
\]

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>substitution</td>
<td>oxidation</td>
<td>condensation</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>addition</td>
<td>substitution</td>
</tr>
<tr>
<td>C</td>
<td>oxidation</td>
<td>substitution</td>
</tr>
<tr>
<td>D</td>
<td>substitution</td>
<td>oxidation</td>
</tr>
</tbody>
</table>
37. Which of the following pairs are members of the same homologous series?

A. CH₃CH₂CH₃OH and CH₃CH₂CHO
B. CH₂CH(OH)CH₃ and CH₂CH₂CH(OH)CH₃
C. CH₃COCH₂ and CH₃CH₂COOH
D. CH₃COCH₂CH₃ and CH₃CH₂CHO

38. Which of the following statements about alkenes is not correct?

A. They have reactive double bonds.
B. They can form addition polymers.
C. They react mainly by substitution.
D. They can react with water to form alcohols.

39. What is the type of mechanism and an important feature of the reaction between C(CH₃)₃Br and aqueous NaOH?

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.</td>
<td>Sₙ₁, a transition state</td>
</tr>
<tr>
<td>B.</td>
<td>Sₙ₁, an intermediate</td>
</tr>
<tr>
<td>C.</td>
<td>Sₙ₂, a transition state</td>
</tr>
<tr>
<td>D.</td>
<td>Sₙ₂, an intermediate</td>
</tr>
</tbody>
</table>
34. Which of the following substances are structural isomers of each other?

I. \( \text{CH}_3(\text{CH}_2)_2\text{CH}_3 \)
II. \( (\text{CH}_3)_2\text{CHCH}_3 \)
III. \( \text{CH}_3\text{CH}(\text{CH}_2)\text{CH}_2\text{CH}_3 \)

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

35. Which reaction pathway describes how ethanol can be formed?

A. ethene \( \xrightarrow{\text{addition}} \) chloroethane \( \xrightarrow{\text{elimination}} \) ethanol
B. ethane \( \xrightarrow{\text{substitution}} \) chloroethane \( \xrightarrow{\text{nucleophilic substitution}} \) ethanol
C. ethene \( \xrightarrow{\text{substitution}} \) ethanol
D. ethane \( \xrightarrow{\text{addition}} \) ethanol

36. By which reactants and type of reaction can ethylamine (aminoethane) be produced?

<table>
<thead>
<tr>
<th>Reactants</th>
<th>Type of reaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. ( \text{CH}_2\text{Br} + \text{NH}_3 )</td>
<td>Nucleophilic substitution</td>
</tr>
<tr>
<td>B. ( \text{CH}_3\text{CH}_2\text{Br} + \text{NH}_3 )</td>
<td>Reduction</td>
</tr>
<tr>
<td>C. ( \text{CH}_2\text{CN} + \text{H}_2 )</td>
<td>Nucleophilic substitution</td>
</tr>
<tr>
<td>D. ( \text{CH}_3\text{CN} + \text{H}_2 )</td>
<td>Reduction</td>
</tr>
</tbody>
</table>
37. Which compound is an amide?
   A. CH₃COOCH₃
   B. CH₃CONH₂
   C. CH₃NH₂
   D. CH₃(NH₂)COOH

38. Which process can produce a polyester?
   A. Addition polymerization of a dicarboxylic acid
   B. Condensation polymerization of a diol and a dicarboxylic acid
   C. Addition polymerization of a diol and dicarboxylic acid
   D. Condensation polymerization of a dicarboxylic acid

39. Which statement about stereoisomers is correct?
   A. 1,2-dichloroethane has two geometrical isomers.
   B. 1,2-dichloroethane has two optical isomers.
   C. 1,2-dichloroethene has two geometrical isomers.
   D. 1,2-dichloroethene has two optical isomers.

33. What is the structural formula of 2,3-dibromo-3-methylhexane?
   A. CH₃CHBrCHBrCH(CH₃)CH₂CH₃
   B. CH₃CHBrCBr(CH₃)CH₂CH₂CH₃
   C. CH₃CH₂CHBrCBr(CH₂CH₃)₂
   D. CH₃CHBrCHBrCH(CH₂CH₃)₂
34. What organic product is formed in the following reaction?

\[(CH_2CH_3)CH=CH(CH_2CH_3) + H_2O \xrightarrow{H_2SO_4} \]

A. \(CH_3(CH_2)_2CH(OH)CH_2CH_3\)
B. \(CH_3(CH_2)_3CH_2\)
C. \(CH_3(CH_2)_2CH(OSO_3H)CH_2CH_3\)
D. \(CH_3(CH_2)_6OH\)

35. What happens when a few drops of bromine water are added to excess hex-1-ene and the mixture is shaken?

I. The colour of the bromine water disappears.
II. The organic product formed does not contain any carbon-carbon double bonds.
III. 2-bromohexane is formed.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

36. What is the IUPAC name for the following compound?

\(CH_3(CH_2)_2COOCH_3\)

A. Methyl butanoate
B. Butyl ethanoate
C. Butyl methanoate
D. Methyl propanoate
37. What is the product of the following reaction?

\[ \text{CH}_3\text{CH}_2\text{CH}_2\text{CN} + 2\text{H}_2 \xrightarrow{\text{Ni}} \]

A. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{NH}_2 \)
B. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_3 \)
C. \( \text{CH}_3\text{CH}_2\text{NH}_2 \)
D. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3 \)

38. How many chiral carbon atoms are present in a molecule of 2,3-dibromobutane?

A. 1
B. 2
C. 3
D. 4

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33. Which is the best definition of structural isomers?

A. Compounds which have atoms with the same atomic numbers but different mass numbers
B. Compounds which have the same general formula but differ by a \( \text{CH}_2 \) group
C. Compounds which have the same empirical formula but different molecular formulas
D. Compounds which have the same molecular formula but different arrangements of atoms
34. Which is the correct classification of these alcohols?

![Chemical structures](image)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>A.</td>
<td>tertiary</td>
<td>secondary</td>
</tr>
<tr>
<td>B.</td>
<td>tertiary</td>
<td>primary</td>
</tr>
<tr>
<td>C.</td>
<td>tertiary</td>
<td>tertiary</td>
</tr>
<tr>
<td>D.</td>
<td>secondary</td>
<td>primary</td>
</tr>
</tbody>
</table>

35. Which substances are possible products of the incomplete combustion of octane?

A. Carbon dioxide and hydrogen gas
B. Carbon monoxide and water vapour
C. Carbon monoxide and hydrogen gas
D. Methane and hydrogen gas
36. What is the IUPAC name of \( \text{CH}_3\text{CH}_2\text{CONH}_2 \)?

\[
\begin{array}{c}
H & H \\
\text{H} & \text{C} & \text{C} & \text{C} & \text{O} \\
\text{H} & \text{H} & \text{N} & \text{H} \\
\end{array}
\]

A. Aminopropanal  
B. Ethanamide  
C. Propylamine  
D. Propanamide

37. What is the main organic product formed from the reaction of \( \text{CH}_2\text{CH}_3\text{OH} \) with \( \text{CH}_3\text{CH}_2\text{CH}_2\text{COOH} \) in the presence of an acid catalyst?

A. Ethyl butanoate  
B. Butyl ethanoate  
C. Ethyl propanoate  
D. Propyl ethanoate

38. What are some uses of esters?

I. Flavouring agents  
II. Perfumes  
III. Solvents

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III
39. How many isomers can exist for a compound with the molecular formula $C_2H_2Cl_2$?

A. 1

B. 2

C. 3

D. 4

33. How many structural isomers exist with the formula $C_3H_6Cl_3$?

A. 3

B. 4

C. 5

D. 6

34. Which reaction occurs via a free-radical mechanism?

A. $C_2H_6 + Br_2 \rightarrow C_2H_4Br + HBr$

B. $C_2H_4 + Br_2 \rightarrow C_2H_4Br_3$

C. $C_4H_9I + OH^- \rightarrow C_4H_9OH + I^-$

D. $(CH_3)_3CI + H_2O \rightarrow (CH_3)_3COH + HI$

35. Which substance is produced by the reaction of hydrogen with a vegetable oil?

A. Margarine

B. Nylon

C. Polypropene

D. Soap
36. Propene is converted to propanone in a two stage process.

\[
\text{Propene} \rightarrow X \rightarrow \text{Propanone}
\]

What is the formula of compound X?

A. \(\text{CH}_3\text{CHBrCH}_3\)
B. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}\)
C. \(\text{CH}_3\text{CHOHCH}_3\)
D. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}\)

37. Which compound could rotate the plane of polarization of polarized light?

A. \((\text{CH}_3)_2\text{CHCH}_3\text{Cl}\)
B. \(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Cl}\)
C. \(\text{CH}_3\text{CH}_2\text{CHClCH}_3\)
D. \((\text{CH}_3)_2\text{CCl}\)

38. What is the name of the ester formed when \(\text{CH}_3\text{CH}_2\text{COOH}\) and \(\text{CH}_3\text{OH}\) react together?

A. Ethyl methanoate
B. Methyl ethanoate
C. Propyl methanoate
D. Methyl propanoate

39. Which formula represents a polyamide?

A. \(\text{CH}_2\text{CHCl}_2\)
B. \(\text{NH}-(\text{CH}_2)_4\text{NH-CO-(CH}_2)_4\text{CO})_n\)
C. \(\text{CF}_2\text{CF}_2\)
D. \(\text{O}-(\text{CH}_2)_2\text{O-CO-(CH}_2)_2\text{O})_n\)
33. What structural feature must a molecule have in order to undergo addition polymerization?

A. Two functional groups  
B. A carbon–carbon double bond  
C. Carbon atoms singly bonded together  
D. A polar covalent bond

34. What is the product of the oxidation of butan-2-ol?

A. But-2-ene  
B. Butanoic acid  
C. Butanal  
D. Butanone

35. What is the IUPAC name of the following compound?

A. 2-methylbutane  
B. Ethylpropane  
C. 3-methylbutane  
D. Pentane
36. Which equations represent the incomplete combustion of methane?

I. \( \text{CH}_4(g) + 2\text{O}_2(g) \rightarrow \text{CO}_2(g) + 2\text{H}_2\text{O}(g) \)

II. \( \text{CH}_4(g) + 1\frac{1}{2}\text{O}_2(g) \rightarrow \text{CO}(g) + 2\text{H}_2\text{O}(g) \)

III. \( \text{CH}_4(g) + \text{O}_2(g) \rightarrow \text{C}(s) + 2\text{H}_2\text{O}(g) \)

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

37. What is the organic product of the reaction between \( \text{CH}_3\text{CH}_2\text{NH}_2 \) and \( \text{CH}_2\text{CH}_2\text{COOH} \)?

A. \( \text{CH}_3\text{CH}_2\text{NCOCH}_2\text{CH}_3 \)

B. \( \text{CH}_3\text{CH}_2\text{CH}_2\text{NCOCH}_3 \)

C. \( \text{CH}_3\text{CH}_2\text{NCOCH}_3 \)

D. \( \text{CH}_2\text{NCOCH}_3 \)

38. What is the IUPAC name of the compound \( \text{CH}_3\text{CH}_2\text{COOCH}_2\text{CH}_3 \)?

A. Ethyl ethanoate

B. Propyl ethanoate

C. Ethyl propanoate

D. Pentyl propanoate

39. Which statement is correct about the enantiomers of a chiral compound?

A. Their physical properties are different.

B. All their chemical reactions are identical.

C. A racemic mixture will rotate the plane of polarized light

D. They will rotate the plane of polarized light in opposite directions.
33. Which three compounds can be considered to be a homologous series?

A. CH₃OH, CH₂CH₂OH, CH₃CH₂CH₂OH
B. CH₂CH₂OH, CH₂CHO, CH₂COOH
C. CH₃CH₂CH(OH)CH₃, CH₃CH₂CH₂CH₂OH, (CH₃)₂COH
D. CH₃CH₂CH₂CH₂OH, CH₃CH₂OCH₂CH₃, (CH₃)₂CH₂CHO

34. Identify the functional group present in HCOCH₂CH₃.

A. Ester
B. Ketone
C. Aldehyde
D. Alcohol

35. What is the IUPAC name for HCOOCH₂CH₂CH₃?

A. Butanoic acid
B. Butanal
C. Methyl propanoate
D. Propyl methanoate
36. Which conditions are required to obtain a good yield of a carboxylic acid when ethanol is oxidized using potassium dichromate(VI), K$_2$Cr$_2$O$_7$(aq)?

   I. Add sulfuric acid
   II. Heat the reaction mixture under reflux
   III. Distill the product as the oxidizing agent is added

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

37. Which statements about substitution reactions are correct?

   I. The reaction between sodium hydroxide and 1-chloropentane predominantly follows an S$_\text{N}$2 mechanism.
   II. The reaction between sodium hydroxide and 2-chloro-2-methylbutane predominantly follows an S$_\text{N}$2 mechanism.
   III. The reaction of sodium hydroxide with 1-chloropentane occurs at a slower rate than with 1-bromopentane.

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

38. What is the organic product of the reaction between methylamine and ethanoic acid?

A. CH$_3$COONH$_4$
B. CH$_3$NHCOCH$_3$
C. CH$_3$COCH$_2$NH$_2$
D. CH$_3$CH$_2$CONH$_2$
39. Which compound can exist as stereoisomers?

A. CH₃CH₂CHO
B. CH₂CH₃COCH₃
C. CH₃CH(CH₃)₂
D. CH₂CH₂CHOHCH₃

36. Which of the following can form an addition polymer?

A. Alanine (2-aminopropanoic acid)
B. Butane
C. But-2-ene
D. 1,2-dichlorobutane

37. Which compound, when hydrogenated, gives a product with a chiral centre?

A. CH₂=CH₂
B. CH₂CBr=CH₂
C. CH₃CH₂CBr=CH₃
D. CH₂CH₂C(CH₃)=CH₂

38. Which statement about the reactions between halogenoalkanes and aqueous sodium hydroxide is correct?

A. The reactions involve the homolytic fission of the carbon-halogen bond.
B. Chloroalkanes react faster than iodoalkanes.
C. The reactions of primary halogenoalkanes generally involve a two-step mechanism.
D. Tertiary halogenoalkanes generally react by an S_N1 mechanism.
40. Which products are formed by the dehydration of butan-2-ol?

   I. butane
   II. but-1-ene
   III. but-2-ene

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

34. What is the coefficient for $\text{II}^+(\text{aq})$, when this redox equation is balanced using whole numbers?

$$\text{Cr}_2\text{O}_7^{2-}(\text{aq}) + \text{Cl}^-(\text{aq}) + \text{H}^+(\text{aq}) \rightarrow \text{Cr}^{3+}(\text{aq}) + \text{Cl}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$$

A. 7
B. 2
C. 14
D. 1

35. Dilute sulfuric acid is electrolyzed using inert electrodes. What product, and in what relative amount, is produced at each electrode?

<table>
<thead>
<tr>
<th>Positive electrode</th>
<th>Negative electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 1 mol H$_2$</td>
<td>2 mol O$_2$</td>
</tr>
<tr>
<td>B. 1 mol O$_2$</td>
<td>2 mol H$_2$</td>
</tr>
<tr>
<td>C. 2 mol H$_2$</td>
<td>1 mol O$_2$</td>
</tr>
<tr>
<td>D. 2 mol O$_2$</td>
<td>1 mol H$_2$</td>
</tr>
</tbody>
</table>

36. Which molecule has a chiral carbon atom?

A. $\text{CH}_2\text{CClCH}_2\text{CH}_3$
B. $\text{CH}_3\text{CHOHCH}_2\text{CH}_3$
C. $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_3$
D. $\text{H}_2\text{NCH}_2\text{COOH}$
37. Which organic product(s) could form when 2-aminoethanoic acid reacts with 2-aminopropanoic acid?

\[
\begin{align*}
\text{H}_2\text{N} & \text{C} - \text{C} \text{--COOH} + \text{H}_2\text{N} & \text{C} - \text{C} \text{--COOH} \\
\text{H} & \text{C} - \text{CH}_3 & \\
\end{align*}
\]

A. \( \text{H}_2\text{N} - \text{C} - \text{C} - \text{NH}_2 \) only

B. \( \text{H}_2\text{N} - \text{C} - \text{C} - \text{NH}_2 \) and \( \text{H}_2\text{N} - \text{C} - \text{C} - \text{COOH} \)

C. \( \text{H}_2\text{N} - \text{C} - \text{C} - \text{COOH} \) only

D. \( \text{H}_2\text{N} - \text{C} - \text{C} - \text{NH}_2 \) only

38. Which statement is correct about the determination of the structure of organic compounds?

A. Mass spectrometry is the best technique to provide information on the chemical environment of all the hydrogen atoms in a molecule.

B. \(^1\text{H NMR spectroscopy}\) provides the values of carbon-hydrogen bond distances present in a molecule.

C. Infrared spectroscopy is used to determine all the bond angles and bond distances in a molecule.

D. Mass spectrometry can provide information about the relative molecular mass of a compound.
39. Which statement best describes the reaction mechanism involved in the single step conversion of chloroethane to ethanol?

A. The reaction involves removal of HCl, followed by the addition of H₂O.
B. The reaction involves heterolytic fission of the C–Cl bond, followed by a reaction with H₂O.
C. The reaction involves nucleophilic attack of OH⁻ in a bimolecular mechanism.
D. The reaction mechanism involves a carbocation.

40. Which statement about alcohols is correct?

A. Primary alcohols can be obtained by the reduction of carboxylic acids or aldehydes.
B. Secondary alcohols can be obtained by the oxidation of ketones.
C. Tertiary alcohols can be obtained by the reduction of carboxylic acids and ketones.
D. Alcohols can be obtained by the addition of water to alkanes, using acid as a catalyst.

36. Which species cannot act as a nucleophile?

A. H₂O  
B. NH₃  
C. CN⁻  
D. CH₄

37. Which compounds show three main peaks in their ¹H NMR spectra?

I. CH₃CH₂CH₂CH₃  
II. CH₃CH₂COOH  
III. (CH₃)₃CCH₂CH₂Br

A. I and II only  
B. I and III only  
C. II and III only  
D. I, II and III
38. Which halogenoalkane reacts most rapidly with silver nitrate solution to form a precipitate?
   A. 1-bromobutane
   B. 1-iodobutane
   C. 2-bromo-2-methylpropane
   D. 2-iodo-2-methylpropane

39. Which is the correct formula of 2,3-dichloro-2-methylpentane?
   A. CH₃CCl(CH₃)CHClCH₂CH₃
   B. CH₃CH(CH₃)CCl₂CH₂CH₃
   C. CH₃CCl₂CH(CH₃)CH₂CH₃
   D. CH₃CH₂CH₂CHClCHClCH₃

40. What type of reaction occurs when hexanedioic acid and 1,6-diaminohexane react together to form nylon?
   A. Addition
   B. Condensation
   C. Esterification
   D. Substitution
<table>
<thead>
<tr>
<th>Q#</th>
<th>Question</th>
<th>Answer</th>
<th>Q#</th>
<th>Question</th>
<th>Answer</th>
<th>Q#</th>
<th>Question</th>
<th>Answer</th>
<th>Q#</th>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>255</td>
<td>IB/P1/2014/s/TZ 1/HL/</td>
<td>35. C</td>
<td>259</td>
<td>IB/P1/2012/w/TZ 0/HL/</td>
<td>34. C</td>
<td>263</td>
<td>IB/P1/2011/s/TZ 2/HL/</td>
<td>34. D</td>
<td>256</td>
<td>IB/P1/2013/w/TZ 0/HL/</td>
<td>35. B</td>
</tr>
</tbody>
</table>

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38. A student carried out a titration to determine the concentration of an acid and found that his value had good precision but poor accuracy. Which process explains this outcome?

A. Consistently overshooting the volume of solution from the burette into the flask.
B. Collection of insufficient titration data.
C. Reading the meniscus in the burette at a different angle each time.
D. Forgetting to rinse the flask after one of the titrations.

39. What is always correct about the molecular ion, M⁺, in a mass spectrum of a compound?

A. The M⁺ ion peak has the smallest m/z ratio in the mass spectrum.
B. The m/z ratio of the M⁺ ion peak gives the relative molecular mass of the molecule.
C. The M⁺ ion is the most stable fragment formed during electron bombardment.
D. The M⁺ ion peak has the greatest intensity in the mass spectrum.

40. Which property explains why tetramethylsilane, Si(CH₃)₄, can be used as a reference standard in ¹HNMR spectroscopy?

A. It has a high boiling point.
B. It is a reactive compound.
C. All its protons are in the same chemical environment.
D. It gives multiple signals.
38. Which combination in the table correctly states the value and units of the gradient?

<table>
<thead>
<tr>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\frac{3.0 \times 10^{-3} - 0.6 \times 10^{-3}}{0.050 - 0.010})</td>
<td>(s^{-1})</td>
</tr>
<tr>
<td>(\frac{3.0 \times 10^{-3} - 0.6 \times 10^{-3}}{0.050 - 0.010})</td>
<td>(s)</td>
</tr>
<tr>
<td>(\frac{0.050 - 0.010}{3.0 \times 10^{-3} - 0.6 \times 10^{-3}})</td>
<td>(s^{-1})</td>
</tr>
<tr>
<td>(\frac{0.050 - 0.010}{3.0 \times 10^{-3} - 0.6 \times 10^{-3}})</td>
<td>(s)</td>
</tr>
</tbody>
</table>
39. Which technique involves the absorption of radiation by bonds between atoms?

A. $^1$H NMR

B. Infrared spectroscopy

C. X-ray crystallography

D. Mass spectrometry

40. The graph shows the concentration of some pollutants in a city over a 24-hour period.

Which of the following could not be inferred from the graph?

A. Hydrocarbons cause less harm to health than PAN.

B. An increase in hydrocarbons is caused by the morning rush hour.

C. PAN concentration increases as the intensity of sunlight increases.

D. NO$_2$ production follows the production of NO.
40. Which is the best-fit line or best-fit curve for the points plotted on the graph?

A.  

B.  

C.  

D.  

40. What is the best way to minimize the random uncertainty when titrating an acid of unknown strength against a standard solution of sodium hydroxide (ie one of known concentration)?

A. First standardize the sodium hydroxide solution against a standard solution of a different acid.

B. Use a pH meter rather than an indicator to determine the equivalence point.

C. Keep your eye at the same height as the meniscus when reading the burette.

D. Repeat the titration several times.

40. A student weighs a standard 70.00g mass five times using the same balance. Each time she obtains a reading of 71.20 g. Which statement is correct about the precision and accuracy of the measurements?

A. Precise and accurate

B. Precise but inaccurate

C. Accurate but not precise

D. Neither accurate nor precise
40. In an experiment to determine a specific quantity, a student calculated that her experimental uncertainty was 0.9% and her experimental error was 3.5%. Which statement is correct?

A. Only random uncertainties are present in this experiment.
B. Both random uncertainties and systematic errors are present in this experiment.
C. Repeats of this experiment would reduce the systematic errors.
D. Repeats of this experiment would reduce both systematic errors and random uncertainties.

40. Which statement about errors is correct?

A. A random error is always expressed as a percentage.
B. A systematic error can be reduced by taking more readings.
C. A systematic error is always expressed as a percentage.
D. A random error can be reduced by taking more readings.

40. A student carries out a titration three times and obtains the following volumes: $3.0 \pm 0.1 \text{ cm}^3$, $3.2 \pm 0.1 \text{ cm}^3$ and $3.2 \pm 0.1 \text{ cm}^3$. What is the average volume?

A. $3.1 \pm 0.1 \text{ cm}^3$
B. $3.13 \pm 0.1 \text{ cm}^3$
C. $3.1 \pm 0.3 \text{ cm}^3$
D. $3.13 \pm 0.3 \text{ cm}^3$

40. A student measured the mass and volume of a piece of silver and recorded the following values.

<table>
<thead>
<tr>
<th>Mass of empty weighing bottle</th>
<th>1.0800 g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass of weighing bottle with piece of silver</td>
<td>11.5700 g</td>
</tr>
<tr>
<td>Volume of silver</td>
<td>1.00 cm$^3$</td>
</tr>
</tbody>
</table>

Which value, in g cm$^{-3}$, for the density of silver should the student report in her laboratory notebook?

A. 10.49
B. 10.4900
C. 10.5
D. 10.500
40. Using an accurate pH meter, the pH of lemonade was found to be 2.30. Some students deduced the pH of the lemonade after titration with a 0.10 mol dm$^{-3}$ sodium hydroxide solution. Their determined values of pH were 2.4, 2.5, 2.4 and 2.4. What is the best description of the precision and accuracy of these measurements?

<table>
<thead>
<tr>
<th>Precision</th>
<th>Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. precise</td>
<td>inaccurate</td>
</tr>
<tr>
<td>B. not precise</td>
<td>inaccurate</td>
</tr>
<tr>
<td>C. precise</td>
<td>accurate</td>
</tr>
<tr>
<td>D. not precise</td>
<td>accurate</td>
</tr>
</tbody>
</table>

40. Which would be the best method to decrease the random uncertainty of a measurement in an acid–base titration?

A. Ensure your eye is at the same height as the meniscus when reading the burette.

B. Use a different indicator for the titration.

C. Use a different burette.

D. Repeat the titration.

50 cm$^3$ of copper(II) sulfate solution is measured into a plastic cup using a 100 cm$^3$ measuring cylinder. Excess zinc powder is added and the temperature rise that occurs is measured with a $-10^\circ$C to $+110^\circ$C thermometer. The enthalpy change for the reaction is then calculated. Which statement is correct?

A. Systematic error will be reduced by repeating the experiment several times and averaging the results.

B. Random error will be reduced by insulating the plastic cup.

C. Random error will be reduced by using a 50 cm$^3$ graduated pipette instead of a measuring cylinder.

D. Systematic error will be increased by using a larger volume of copper(II) sulfate solution.
40. The relationship between the pressure, $P$, and the volume, $V$, of a fixed amount of gas at a constant temperature is investigated experimentally. Which statements are correct?

   I. A graph of $V$ against $P$ will be a curve (non-linear).
   II. A graph of $V$ against $\frac{1}{P}$ will be linear.
   III. $V = \text{constant} \times \frac{1}{P}$

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

40. A student measured the mass of a solid on an analytical balance during an internally assessed IB practical experiment and recorded the mass in his raw data. The accuracy of the balance, as stated by the manufacturers, was ± 0.01 g. Which of the following choices would be the best record of his mass?

A. 10.2 g
B. 10 g
C. 10.20 g
D. 10.200 g

40. A student heated a solid in a crucible. The student measured the mass of the solid and crucible before and after heating and recorded the results.

   Mass of crucible and solid before heating = 101.692 g
   Mass of crucible and solid after heating = 89.312 g

What value should the student record for the mass lost in grams?

A. 12.4
B. 12.38
C. 12.380
D. 12.3800
40. A piece of metallic aluminium with a mass of 10.044 g was found to have a volume of 3.70 cm³. A student carried out the following calculation to determine the density.

\[ \text{Density (g cm}^{-3}\text{)} = \frac{10.044}{3.70} \]

What is the best value the student could report for the density of aluminium?

A. 2.715 g cm\(^{-3}\)
B. 2.7 g cm\(^{-3}\)
C. 2.71 g cm\(^{-3}\)
D. 2.7146 g cm\(^{-3}\)

40. A burette reading is recorded as 27.70 ± 0.05 cm³. Which of the following could be the actual value?

I. 27.68 cm³
II. 27.78 cm³
III. 27.74 cm³

A. I and II only
B. I and III only
C. II and III only
D. I, II and III

40. Density can be calculated by dividing mass by volume. 0.20 ± 0.02 g of a metal has a volume of 0.050 ± 0.005 cm³. How should its density be recorded using this data?

A. 4.0 ± 0.025 g cm\(^{-3}\)
B. 4.0 ± 0.8 g cm\(^{-3}\)
C. 4.00 ± 0.025 g cm\(^{-3}\)
D. 4.00 ± 0.8 g cm\(^{-3}\)

39. How many significant figures are there in 0.00370?

A. 2
B. 3
C. 5
D. 6
40. The following diagram shows a set of experimental data points, X, determined when one experimental measurement was repeated three times. The centre of the diagram represents the ideal value calculated from theory. What statement is correct about these measurements?

A. The measurements involve low accuracy and low precision.
B. The measurements involve low accuracy and high precision.
C. The measurements involve high accuracy and low precision.
D. The measurements involve high accuracy and high precision.

40. Which experimental procedure is most likely to lead to a large systematic error?

A. Determining the concentration of an alkali by titration with a burette
B. Measuring the volume of a solution using a volumetric pipette
C. Determining the enthalpy change of neutralization in a beaker
D. Measuring the volume of a gas produced with a gas syringe

40. Which are likely to be reduced when an experiment is repeated a number of times?

A. Random errors
B. Systematic errors
C. Both random and systematic errors
D. Neither random nor systematic errors

40. Which would be the best method to decrease the random uncertainty of a measurement in an acid-base titration?

A. Repeat the titration
B. Ensure your eye is at the same height as the meniscus when reading from the burette
C. Use a different burette
D. Use a different indicator for the titration
40. A student recorded the volume of a gas as 0.01450 dm$^3$. How many significant figures are there in this value?

A. 3

B. 4

C. 5

D. 6

39. An unknown organic compound gives the $^1$H low resolution nuclear magnetic spectrum below. The peak at 0 ppm is due to the TMS reference.

![Chemical shift spectrum](image)

Identify the organic compound.

A. CH$_3$CH$_2$CH$_3$

B. CH$_2$OHCH$_2$OH

C. CH$_3$CH$_2$OH

D. CH$_3$CH$_2$Cl
Topic 11 Mark Scheme

Q# 273/ IB/P1/2016/w/TZ 2/HL/ 38. A
39. B
40. C
Q# 274/ IB/P1/2016/s/TZ 0/HL/ 40. D
Q# 275/ IB/P1/2016/s/SpcmP/HL/ 38. A
39. B
40. A
Q# 276/ IB/P1/2015/w/TZ 2/HL/ 40. C
Q# 277/ IB/P1/2015/s/TZ 2/HL/ 40. D
Q# 278/ IB/P1/2015/s/TZ 1/HL/ 40. C
Q# 279/ IB/P1/2014/w/TZ 0/HL/ 40. B
Q# 280/ IB/P1/2014/s/TZ 2/HL/ 40. D
Q# 281/ IB/P1/2014/s/TZ 1/HL/ 40. A
Q# 282/ IB/P1/2013/w/TZ 0/HL/ 40. C
Q# 283/ IB/P1/2013/s/TZ 2/HL/ 40. B
Q# 284/ IB/P1/2013/s/TZ 1/HL/ 40. D
Q# 285/ IB/P1/2012/w/TZ 0/HL/ 40. C
Q# 286/ IB/P1/2012/s/TZ 2/HL/ 40. D
Q# 287/ IB/P1/2012/s/TZ 1/HL/ 40. C
Q# 288/ IB/P1/2011/w/TZ 0/HL/ 40.
Q# 290/ IB/P1/2011/s/TZ 1/HL/ 40.
Q# 291/ IB/P1/2010/w/TZ 0/HL/ 40.
Q# 293/ IB/P1/2010/s/TZ 1/HL/ 40.
Q# 294/ IB/P1/2009/w/TZ 0/HL/ 40.
Q# 298/ IB/P1/2008/w/TZ 0/HL/ 39.
Q# 299/ IB/P1/2008/s/TZ 1/HL/