Chemistry Olympiad Training for Secondary School Level – Part One

1. First ionization energy is the energy required to convert one mole of gaseous atoms into one mole of mono-positive gaseous ions. It is summarised by the equation below:

$$E \text{ (g)} \rightarrow E^+ \text{ (g)} + e^-$$
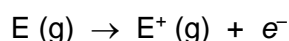
How does first ionization energy change across a Period (from left-to-right) and within a Group (from top-to-bottom) of the Periodic Table?

   **A**   Increases across a Period and increases down a Group.

   B   Decreases across a Period and increases down a Group.

   C   Increases across a Period and Decreases down a Group.

   D   Decreases across a Period and Decreases down a Group.

2. The shapes of some molecules are shown below.

Tetrahedral	Pyramidal	Angular	Linear

Phosphine is a compound of phosphorus and hydrogen. What shape is a phosphine molecule likely to have?

   A   Angular

   B   Linear

   C   Pyramidal

   D   Tetrahedral

3. Nitrogen and hydrogen react according to the equation:

$$N_2 \text{ (g)} + 3H_2 \text{ (g)} \rightleftharpoons 2NH_3 \text{ (g)} \qquad \Delta H = -78 \text{ kJ mol}^{-1}$$
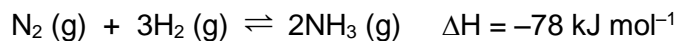
According to Le Chatelier's principle, which change in temperature and pressure will increase the yield of ammonia?

A Increase temperature and increase pressure.

B Increase temperature and decrease pressure.

C Decrease temperature and increase pressure.

D Decrease temperature and decrease pressure.

4. Which one of the following is a *disproportionation* reaction?

A $Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$

B $2CO \rightarrow C + CO_2$

C $4S + 5O_2 \rightarrow 2SO_2 + 2SO_3$
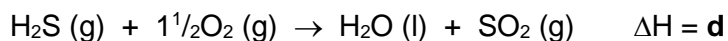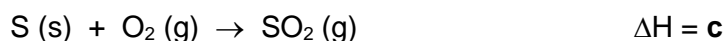
D $MnO_2 + 4HCl \rightarrow MnCl_2 + 2H_2O + Cl_2$

5. Which of the following compounds contains ions which are *isoelectric*?

A CaO

B $CaBr_2$

C Na_2O

D LiF

6. Which one of the following reactions has a value for $\Delta S° > 0$?

A $S_8 \text{ (l)} \rightarrow S_8 \text{ (s)}$

B $H_2 \text{ (g)} + O_2 \text{ (g)} \rightarrow H_2O_2 \text{ (l)}$

C $H_2 \text{ (g)} + 2Ag^+ \text{ (aq)} \rightarrow 2H^+ \text{ (aq)} + 2Ag \text{ (s)}$

D $PCl_5 \text{ (g)} \rightarrow PCl_3 \text{ (g)} + Cl_2 \text{ (g)}$

7. Study the following reactions:

$S (s) + H_2 (g) \rightarrow H_2S (g)$ $\Delta H = \mathbf{a}$

$H_2 (g) + \frac{1}{2}O_2 (g) \rightarrow H_2O (l)$ $\Delta H = \mathbf{b}$
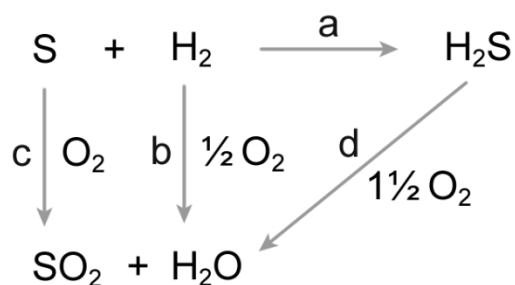
$S (s) + O_2 (g) \rightarrow SO_2 (g)$ $\Delta H = \mathbf{c}$

$H_2S (g) + 1\frac{1}{2}O_2 (g) \rightarrow H_2O (l) + SO_2 (g)$ $\Delta H = \mathbf{d}$
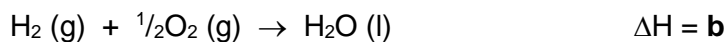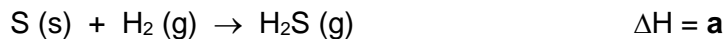
The relationships between the four reactions, and their enthalpy changes, are summarised in the diagram below:

What is the relationship between **a**, **b**, **c** and **d**?

A   a = b + c − d

B   a = d − b − c

C   a = b − c − d

D   a = d + c − b

8. A reaction takes place in two stages:

Stage 1:

$S_2O_8^{2-} (aq) + 2I^- (aq) + 2Fe^{2+} (aq) \rightarrow 2SO_4^{2-} (aq) + 2I^- (aq) + 2Fe^{3+} (aq)$

Stage 2:

$2SO_4^{2-} (aq) + 2I^- (aq) + 2Fe^{3+} (aq) \rightarrow 2SO_4^{2-} (aq) + I_2 (aq) + 2Fe^{2+} (aq)$
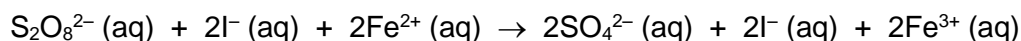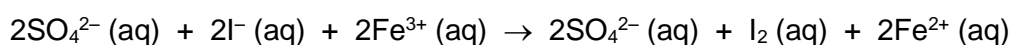
Which ion is the **catalyst** in this reaction?

A $S_2O_8^{2-} (aq)$ **B** $I^- (aq)$

C $Fe^{2+} (aq)$ **D** $SO_4^{2-} (aq)$

9. Some of the covalent bonds in an amino acid molecule are *polar*. A polar covalent bond arises when a bonding pair of electrons is not shared evenly between two atoms.

$$\begin{array}{c}
\text{H} \quad\;\; \text{H} \quad\;\; \text{O} \\
\diagdown \quad\; | \quad\;\; \diagup\diagup \\
\text{N}-\text{C}-\text{C} \\
\diagup \quad\; | \quad\;\; \diagdown \\
\text{H} \quad\;\; \text{H} \quad\;\; \text{O}-\text{H}
\end{array}$$

The table contains information about the attraction of some atoms for bonded pairs of electrons.

Atom	Relative Attraction for a Bonding Pair of Electrons
H	2.2
C	2.5
N	3.0
O	3.5

Based on this information, the most polar covalent bond in the amino acid will be:

A C – H   **B** N – H

C C – O   **D** O – H

10. The electronic configuration for an atom of nitrogen (atomic number = 7) is given below:

1s	2s	2p			3s
↑↓	↑↓	↑	↑	↑	

Which one of the following is the correct electronic configuration for a sodium ion?

A

1s	2s	2p			3s
↑↓	↑↓	↑↓	↑↓	↑	

B

1s	2s	2p			3s
↑↓	↑↓	↑↓	↑↓	↑↓	

C

1s	2s	2p			3s
↑↓	↑↓	↑↓	↑↓	↑↓	↑

D

1s	2s	2p			3s
↑↓	↑↓	↑↓	↑↓	↑↓	↑↓

11. A simple battery can be made by connecting two different half-cells together. When the two different half-cells are connected, a potential difference is produced between them.

Connecting a zinc half-cell [Zn(s) / Zn^{2+}(aq)] to a copper half-cell [(Cu(s) / Cu^{2+}(aq)] produces a potential difference of 1.10 volts.

The potential difference produced by two half-cells can be calculated from their *standard electrode potentials*.

| Half-cell	Standard Electrode Potential / V
[Mg(s) / Mg^{2+}(aq)]	–2.38
[Zn(s) / Zn^{2+}(aq)]	–0.76
[Cu(s) / Cu^{2+}(aq)]	+0.34
[Ag(s) / Ag^{+}(aq)]	+0.80

Which combination of half-cells will generate a potential difference of 1.56 V?

A   [Mg(s) / Mg^{2+}(aq)]   and   [Zn(s) / Zn^{2+}(aq)]

B   [Mg(s) / Mg^{2+}(aq)]   and   [Cu(s) / Cu^{2+}(aq)]

C   [Zn(s) / Zn^{2+}(aq)]   and   [Ag(s) / Ag^{+}(aq)]

D   [Cu(s) / Cu^{2+}(aq)]   and   [Ag(s) / Ag^{+}(aq)]

12. The rate of decomposition of hydrogen peroxide is first order for H_2O_2. At $[H_2O_2]$ = 0.150 mol dm^{-3}, the decomposition rate was measured to be 4.83×10^{-6} mol dm^{-3} s^{-1}. What is the rate constant for the reaction?

A 2.15×10^{-4} s^{-1} B 3.22×10^{-5} s^{-1}

C 4.83×10^{-6} s^{-1} D 7.25×10^{-7} s^{-1}

13. Which class of organic compound does not contain oxygen?

A   Alcohol   B   Amide

C   Amine   D   Ketone

14. Which of the following compounds could contain exactly one triple bond?

A C_5H_{10} B C_5H_{12}

C C_6H_{10} D C_6H_{12}

15. Which statement about bonding is correct?

A A σ bond has cylindrical symmetry about the bonding axis.

B A π bond is twice as strong as a σ bond.

C A double bond consists of two π bonds.

D A π bond results from the sideways overlap of hybridised orbitals.

**16.** Water spontaneously ionises according to the following chemical equation:

$$H_2O \text{ (l)} \rightleftharpoons H^+ \text{ (aq)} + OH^- \text{ (aq)}$$
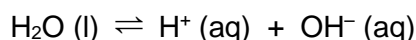
The pH of an aqueous solution can be calculated using the following equation:

$$pH = -\log_{10}[H^+]$$

What is the pH of an aqueous solution that contains 0.0100 mol dm^{-3} NaOH?

A 1×10^{-7} **B** 7

C 12   **D** 14

17. Consider the gas-phase reaction between nitrogen monoxide and oxygen showing the initial concentrations of the reactants at a constant temperature:

$$2NO \text{ (g)} + O_2 \text{ (g)} \rightarrow 2NO_2 \text{ (g)}$$
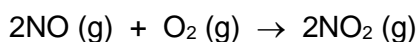
Experiment	[NO] / mol dm^{-3}	[O$_2$] / mol dm^{-3}	Initial Rate of NO$_2$ Formation / mol dm^{-3} s^{-1}
1	0.020	0.020	0.057
2	0.040	0.040	0.455
3	0.040	0.020	0.228

What is the order of the reaction with respect to NO (g) and O$_2$ (g)?

A NO (g) = zero order   O$_2$ (g) = third order

B NO (g) = first order   O$_2$ (g) = second order

C NO (g) = second order   O$_2$ (g) = first order

D NO (g) = third order   O$_2$ (g) = zero order

18. During the manufacture of sulfuric acid, sulfur(IV) oxide reacts with oxygen to form sulfur(VI) oxide. The balanced chemical equation for this reaction, known as the *Contact Process*, is shown below:

$$2SO_2 \text{ (g)} + O_2 \text{ (g)} \rightleftharpoons 2SO_3 \text{ (g)}$$
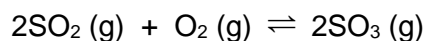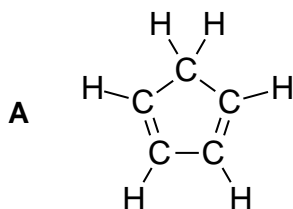
What is the equilibrium constant for this reaction?

A $\quad K_c = \dfrac{[SO_3]^2}{[SO_2]^2 \times [O_2]}$

B $\quad K_c = \dfrac{[SO_2]^2 \times [O_2]}{[SO_3]^2}$

C $\quad K_c = \dfrac{2[SO_3]}{2[SO_2] \times [O_2]}$

D $\quad K_c = \dfrac{2[SO_2] \times [O_2]}{2[SO_3]}$

19. Which one of the following organic compounds is *aromatic*?
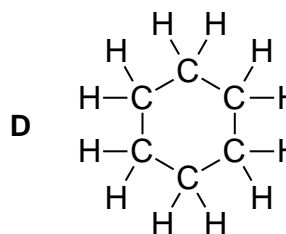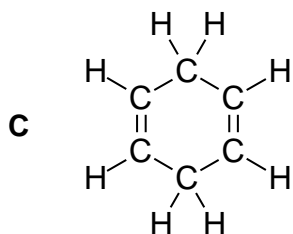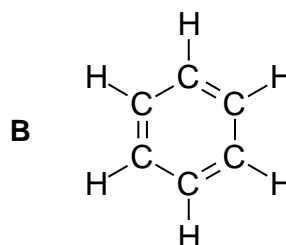
20. Given the enthalpy changes:

A + B → C	$\Delta H = -35 \text{ kJ mol}^{-1}$
A + D → E + F	$\Delta H = +20 \text{ kJ mol}^{-1}$
F → C + E	$\Delta H = +15 \text{ kJ mol}^{-1}$

What is ΔH for the reaction **2A + B + D → 2F** ?

A 0 kJ mol^{-1}

B −30 kJ mol^{-1}

C −40 kJ mol^{-1}

D −70 kJ mol^{-1}

The Periodic Table of the Elements

Group

I	II		III	IV	V	VI	VII	0
								4 He helium 2
7 Li lithium 3	9 Be beryllium 4		11 B boron 5	12 C carbon 6	14 N nitrogen 7	16 O oxygen 8	19 F fluorine 9	20 Ne neon 10
23 Na sodium 11	24 Mg magnesium 12		27 A*l* aluminium 13	28 Si silicon 14	31 P phosphorus 15	32 S sulfur 16	35.5 C*l* chlorine 17	40 Ar argon 18

Transition elements:

1 H hydrogen 1												

39 K potassium 19	40 Ca calcium 20	45 Sc scandium 21	48 Ti titanium 22	51 V vanadium 23	52 Cr chromium 24	55 Mn manganese 25	56 Fe iron 26	59 Co cobalt 27	59 Ni nickel 28	64 Cu copper 29	65 Zn zinc 30	70 Ga gallium 31	73 Ge germanium 32	75 As arsenic 33	79 Se selenium 34	80 Br bromine 35	84 Kr krypton 36
85 Rb rubidium 37	88 Sr strontium 38	89 Y yttrium 39	91 Zr zirconium 40	93 Nb niobium 41	96 Mo molybdenum 42	– Tc technetium 43	101 Ru ruthenium 44	103 Rh rhodium 45	106 Pd palladium 46	108 Ag silver 47	112 Cd cadmium 48	115 In indium 49	119 Sn tin 50	122 Sb antimony 51	128 Te tellurium 52	127 I iodine 53	131 Xe xenon 54
133 Cs caesium 55	137 Ba barium 56	139 La lanthanum 57 *	178 Hf hafnium 72	181 Ta tantalum 73	184 W tungsten 74	186 Re rhenium 75	190 Os osmium 76	192 Ir iridium 77	195 Pt platinum 78	197 Au gold 79	201 Hg mercury 80	204 T*l* thallium 81	207 Pb lead 82	209 Bi bismuth 83	– Po polonium 84	– At astatine 85	– Rn radon 86
– Fr francium 87	– Ra radium 88	– Ac actinium 89 †															

*58-71 Lanthanoid series
†90-103 Actinoid series

140 Ce cerium 58	141 Pr praseodymium 59	144 Nd neodymium 60	– Pm promethium 61	150 Sm samarium 62	152 Eu europium 63	157 Gd gadolinium 64	159 Tb terbium 65	162 Dy dysprosium 66	165 Ho holmium 67	167 Er erbium 68	169 Tm thulium 69	173 Yb ytterbium 70	175 Lu lutetium 71
232 Th thorium 90	– Pa protactinium 91	238 U uranium 92	– Np neptunium 93	– Pu plutonium 94	– Am americium 95	– Cm curium 96	– Bk berkelium 97	– Cf californium 98	– Es einsteinium 99	– Fm fermium 100	– Md mendelevium 101	– No nobelium 102	– Lr lawrencium 103

Key

a	
X	a = relative atomic mass X = atomic symbol b = proton (atomic) number
b	

Answers

1. **C**
2. **C**
3. **C**
4. **B**
5. **C**
6. **D**
7. **A**
8. **C**
9. **D**
10. **B**
11. **C**
12. **B**
13. **C**
14. **C**
15. **A**
16. **C**
17. **C**
18. **A**
19. **B**
20. **B**

if…

A + B → C

and…

A + D → E + F

then…

2A + B + D → C + E + F
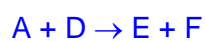
ΔH = (−35 *for A + B*) + (+20 *for A + D*) = <u>−15 kJ</u>

C + E can react to form the second molecule of F

forward reaction:　　F → C + E ΔH = +15 kJ

reverse reaction:　　C + E → F ΔH = <u>−15 kJ</u>

overall enthalpy change = (−15) + (−15) = <u>−30 kJ</u>