1.

Two half-equations are shown.

$$MnO_4^- + 2H_2O + 3e^- \rightarrow MnO_2 + 4OH^-$$

$$2OH^- + SO_3^{2-} \rightarrow SO_4^{2-} + H_2O + 2e^-$$

The equation for the reaction between manganate(VII) ions and sulfite ions is shown.

$$uMnO_4^- + vH_2O + wSO_3^{2-} \rightarrow xMnO_2 + ySO_4^{2-} + zOH^-$$

Which statements are correct?

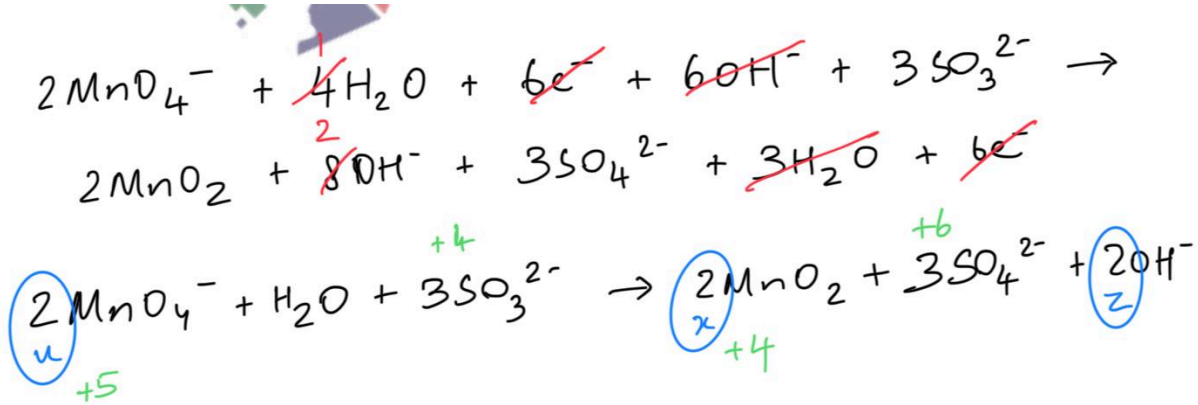
1 $u = x = z$

2 Manganese is reduced to oxidation state +4.

3 Sulfur is oxidised from oxidation state +4 to +6.

A 1, 2 and 3 **B** 1 and 2 only **C** 1 and 3 only **D** 2 and 3 only

Ans: A



2.

Cobalt can form the positive ion $Co(NH_3)_4Cl_2^+$.

What is the oxidation number of cobalt in this ion?

A +1 **B** +2 **C** +3 **D** +6

$(NH_3)_4 = 0$

$Cl_2 = -2$

Thus, Co = +3

3.

When solid $KClO_3$ is heated in the absence of air, a mixture of two chlorine compounds in the mole ratio of 3 : 1 is formed. Chlorine is the only element whose oxidation number changes in this reaction.

What could be the oxidation numbers of chlorine in the two compounds that are formed?

A +3 and –1 **B** +6 and +4 **C** +7 and –1 **D** +7 and +1

Ans: C

Oxidation number of chlorine in $KClO_3$ = +5
This will be equal to the average oxidation numbers of chlorine in the products.
Total number of moles = 4
Average oxidation number for (a) = ((3 x 3) + (1 x -1)) / 4 = +2
Average oxidation number for (b) = ((3 x 6) + (1 x 4)) / 4 = +5.5
Average oxidation number for (c) = ((3 x 7) + (1 x -1)) / 4 = +5
Average oxidation number for (d) = ((3 x 7) + (1 x 1)) / 4 = +5.5

Thus (c) is the correct option.

4.

In which reaction does an element undergo the largest change in oxidation number?

A $Cl_2 + 2OH^- \rightarrow OCl^- + Cl^- + H_2O$

B $3Cl_2 + 6OH^- \rightarrow ClO_3^- + 5Cl^- + 3H_2O$

C $Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \rightarrow 2Cr^{3+} + 6Fe^{3+} + 7H_2O$

D $3MnO_4^{2-} + 4H^+ \rightarrow MnO_2 + 2MnO_4^- + 2H_2O$

Ans: B

In this case, chlorine changes from 0 to +5 and from 0 to -1.
0 to +5 is the greatest change in oxidation number.
DO NOT ADD up the oxidation numbers of the products formed!! Consider as separate.

5.

Acidified potassium manganate(VII) reacts with iron(II) ethanedioate, FeC_2O_4.

The reactions taking place are shown.

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

$$Fe^{2+} \rightarrow Fe^{3+} + e^-$$

$$C_2O_4^{2-} \rightarrow 2CO_2 + 2e^-$$

How many moles of iron(II) ethanedioate react with **one** mole of potassium manganate(VII)?

A 0.60 **B** 1.67 **C** 2.50 **D** 5.00

Ans: B

$5e^-$ in reactant side + $3e^-$ in product side

$3(MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O)$

$5(Fe^{2+} \rightarrow Fe^{3+} + e^-)$

$5(Cr_2O_4^{2-} \rightarrow 2CO_2 + 2e^-)$

$\frac{5}{3} = 1.67$

→ Fe^{2+} & $Cr_2O_4^{2-}$ have to be the same no. of moles
→ $15e^-$ in reactant side & $15e^-$ in product side

6.

Ethanedioic acid, HO_2CCO_2H, can be oxidised by $KMnO_4$ in dilute sulfuric acid. The products of this reaction are carbon dioxide, water, potassium sulfate and manganese(II) sulfate.

In this reaction each ethanedioic acid molecule loses two electrons as it is oxidised. A half-equation for this process is shown.

$$HO_2CCO_2H \rightarrow 2CO_2 + 2H^+ + 2e^-$$

How many water molecules are produced when five ethanedioic acid molecules are oxidised by $KMnO_4$ in dilute sulfuric acid?

A 5 **B** 8 **C** 10 **D** 16

Ans: B

Oxidation Half-Reaction:

Given in the problem:

$$HO_2CCO_2H \rightarrow 2CO_2 + 2H^+ + 2e^-$$

Reduction Half-Reaction:

The permanganate ion (MnO_4^-) is reduced in acidic solution:

$$MnO_4^- + 8H^+ + 5e^- \rightarrow Mn^{2+} + 4H_2O$$

Balancing the Half-Reactions:

To combine the half-reactions, we need to balance the number of electrons. The oxidation half-reaction loses 2 electrons per molecule of ethanedioic acid, and the reduction half-reaction gains 5 electrons per permanganate ion. To balance the electrons, we find the least common multiple of 2 and 5, which is 10.

1. **Oxidation Half-Reaction (multiplied by 5):**
   $$5HO_2CCO_2H \rightarrow 10CO_2 + 10H^+ + 10e^-$$

2. **Reduction Half-Reaction (multiplied by 2):**
   $$2MnO_4^- + 16H^+ + 10e^- \rightarrow 2Mn^{2+} + 8H_2O$$

Combine the Half-Reactions:

Adding the balanced half-reactions together:

$$5HO_2CCO_2H + 2MnO_4^- + 16H^+ \rightarrow 10CO_2 + 10H^+ + 2Mn^{2+} + 8H_2O$$

We can simplify by canceling out the $10H^+$ on both sides:

$$5HO_2CCO_2H + 2MnO_4^- + 6H^+ \rightarrow 10CO_2 + 2Mn^{2+} + 8H_2O$$

Water Molecules Produced:

According to the balanced equation, 8 water molecules are produced when 5 ethanedioic acid molecules are oxidized.

Therefore, when five ethanedioic acid molecules are oxidized by $KMnO_4$ in dilute sulfuric acid, **8 water molecules** are produced.

- Each ethanedioic acid molecule loses 2 electrons as it gets oxidised.
- For 5 molecules of ethanedioic acid, total number of electrons lost = 5×2=10
- The reduction of the permanganate ion in acidic solution produces water.
- Typically, 1 permanganate ion gains 5 e^- and produces 4 water molecules.
- The 10 electrons lost by the oxidation of 5 ethanedioic acid molecules must be matched by the electrons gained by the reduction of permanganate ions.
- Since each $MnO4^-$ ion gains 5 electrons, two $MnO4^-$ ions will gain the 10 electrons lost.
- Each $MnO4^-$ ion, when reduced, produces 4 water molecules. Therefore, 2 $MnO4^-$ ions will produce 8 water molecules.

7.

Oxidation numbers should be used to answer this question.

A redox reaction takes place between hydroxylammonium ions, $[NH_3OH]^+$, and acidified iron(III) ions, Fe^{3+}. The products are iron(II) ions, Fe^{2+}, H^+ ions, water and a compound of nitrogen.

The mole ratio of reacting hydroxylammonium ions to reacting iron(III) ions is 1 : 2.

Which nitrogen-containing compound could be formed in the reaction?

A NH_3 **B** N_2O **C** NO **D** NO_2

Ans: B

$1NH_3OH^+ + 2Fe^{3+} + H^+ \longrightarrow 2Fe^{2+} + H^+ + H_2O + 1[N]$

$-1 \qquad +3 \qquad\qquad +2$

avg oxidation nos. of reactants $= \frac{-1+2\times3}{3} = \frac{5}{3}$

$\therefore \frac{1\times x + 2\times 2}{3} = \frac{5}{3} \Rightarrow x = 1 \quad \therefore$ Ox. no. of N in compound $= 1$

8.

A transition metal ion, M^{2+}, reacts with acidified dichromate(VI) ions to form M^{4+} ions, Cr^{3+} ions, and H_2O.

Which equation correctly represents this reaction?

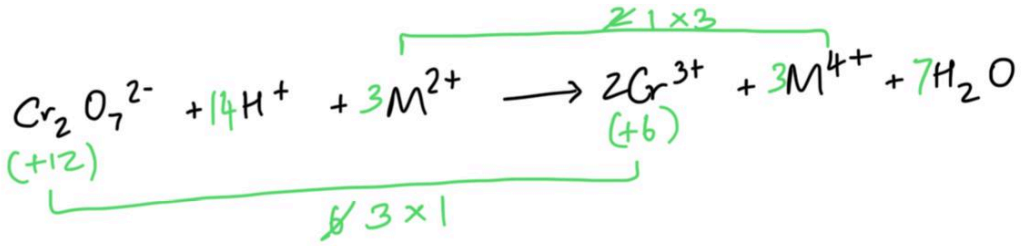
A $Cr_2O_7^{2-} + 14H^+ + M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + M^{4+}$

B $Cr_2O_7^{2-} + 14H^+ + 2M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 2M^{4+}$

C $Cr_2O_7^{2-} + 14H^+ + 3M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 3M^{4+}$

D $Cr_2O_7^{2-} + 14H^+ + 6M^{2+} \rightarrow 2Cr^{3+} + 7H_2O + 6M^{4+}$

Ans: C



When calculating the change in oxidation number of Cr, remember to use +12 instead of +6 and +6 instead of +3 (multiples should be taken).

9.

Vanadium reacts with dilute sulfuric acid to form $V_2(SO_4)_3$ and hydrogen gas.

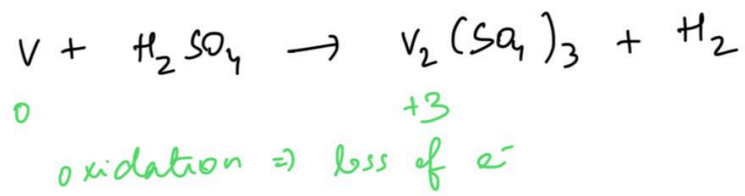
What happens to vanadium atoms in this reaction?

A They lose three electrons and are oxidised.

B They lose three electrons and are reduced.

C They lose two electrons and are oxidised.

D They lose two electrons and are reduced.



10.

$Na_2S_2O_3$ reacts with HCl as shown.

$$Na_2S_2O_3(aq) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l) + SO_2(g) + S(s)$$

When calculating the oxidation number of sulfur in $Na_2S_2O_3$, the **average** oxidation number of the two sulfur atoms should be found.

What is the oxidation number of sulfur in each of $Na_2S_2O_3$, SO_2, and S?

	$Na_2S_2O_3$	SO_2	S
A	+2	+2	+1
B	+2	+4	0
C	+4	+4	0
D	+5	+4	0

Ans: B

11.

In the treatment of domestic water supplies, chlorine is added to the water to form $HClO$.

$$Cl_2(aq) + H_2O(l) \rightarrow H^+(aq) + Cl^-(aq) + HClO(aq)$$

The $HClO$ reacts further to give ClO^- ions.

$$HClO(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + ClO^-(aq)$$

Both $HClO$ and ClO^- kill bacteria by oxidation.

What is the change in oxidation number of chlorine when forming the ClO^- ion from aqueous chlorine?

A –1 **B** 0 **C** +1 **D** +2

Ans: C

12.

Photochromic glass, used for sunglasses, darkens when exposed to bright light and becomes more transparent again when the light is less bright. The darkness of the glass is related to the concentration of silver atoms.

The following reactions are involved.

reaction 1 $Ag^+ + Cl^- \rightleftharpoons Ag + Cl$

reaction 2 $Cu^+ + Cl \rightarrow Cu^{2+} + Cl^-$

reaction 3 $Cu^{2+} + Ag \rightarrow Cu^+ + Ag^+$

Which statement about these reactions is correct?

A Cu^+ and Cu^{2+} ions act as catalysts.

B Cu^+ ions act as an oxidising agent in reaction 2.

C Reaction 3 increases the darkness of the glass.

D Silver atoms are reduced in reaction 3.

Ans: A

The statements about oxidation and reduction are wrong.

Darkness of glass depends on concentration of <u>silver atoms</u>; in reaction 3 silver atoms are converted to silver ions.

Thus A is the correct option.

13.

Element X forms a pollutant oxide Y. Y can be further oxidised to Z. Two students made the following statements.

Student P 'The molecule of Y contains lone pairs of electrons.'

Student Q 'The oxidation number of X increases by 1 from Y to Z.'

X could be carbon or nitrogen or sulfur.

Which student(s) made a correct statement?

A P only

B Q only

C both P and Q

D neither P nor Q

Ans: A

Possible Oxides of Carbon, Nitrogen, and Sulfur

1. **Carbon:**
   - Oxide Y: CO (carbon monoxide)
   - Oxide Z: $\mathrm{CO_2}$ (carbon dioxide)
2. **Nitrogen:**
   - Oxide Y: NO (nitric oxide)
   - Oxide Z: $\mathrm{NO_2}$ (nitrogen dioxide)
3. **Sulfur:**
   - Oxide Y: $\mathrm{SO_2}$ (sulfur dioxide)
   - Oxide Z: $\mathrm{SO_3}$ (sulfur trioxide)

Evaluate the Statements for Each Element

1. **Carbon:**
   - CO: Carbon in CO has an oxidation state of +2.
   - $\mathrm{CO_2}$: Carbon in $\mathrm{CO_2}$ has an oxidation state of +4.
   - The oxidation number increases by 2 (not 1) from CO to $\mathrm{CO_2}$.
2. **Nitrogen:**
   - NO: Nitrogen in NO has an oxidation state of +2.
   - $\mathrm{NO_2}$: Nitrogen in $\mathrm{NO_2}$ has an oxidation state of +4.
   - The oxidation number increases by 2 (not 1) from NO to $\mathrm{NO_2}$.
3. **Sulfur:**
   - $\mathrm{SO_2}$: Sulfur in $\mathrm{SO_2}$ has an oxidation state of +4.
   - $\mathrm{SO_3}$: Sulfur in $\mathrm{SO_3}$ has an oxidation state of +6.
   - The oxidation number increases by 2 (not 1) from $\mathrm{SO_2}$ to $\mathrm{SO_3}$.

Lone Pairs of Electrons in Molecule Y

1. **Carbon:**
   - CO: Carbon monoxide has a lone pair of electrons on the carbon atom.
2. **Nitrogen:**
   - NO: Nitric oxide does not have lone pairs on the nitrogen atom in a way that affects its bonding, but it does have an odd electron making it a radical.
3. **Sulfur:**
   - SO_2: Sulfur dioxide has lone pairs of electrons on the sulfur atom.

Therefore, Student P made a correct statement, while student Q did not.

14.

Calcium forms an ionic compound with carbon, called calcium carbide. The oxidation number of carbon in calcium carbide is –1.

Calcium carbide is readily hydrolysed by water giving two products only.

What could be the formulae of calcium carbide and the two products of hydrolysis?

	calcium carbide	products
A	Ca_2C	CaO and C_2H_4
B	Ca_2C	$Ca(OH)_2$ and C_2H_2
C	CaC_2	CaO and C_2H_4
D	CaC_2	$Ca(OH)_2$ and C_2H_2

Ans: D

15.

Bromine reacts with aqueous sodium hydroxide at 25 °C.

reaction 1 $Br_2(aq) + 2NaOH(aq) \rightarrow NaBr(aq) + NaOBr(aq) + H_2O(l)$

The NaOBr formed is unstable at 25 °C and reacts further.

reaction 2 $3NaOBr(aq) \rightarrow 2NaBr(aq) + NaBrO_3(aq)$

Which reactions are disproportionations?

A both reaction 1 and reaction 2

B neither reaction 1 nor reaction 2

C reaction 1 only

D reaction 2 only

Ans: A

16.

In reactions 1 and 2, X represents an element in Period 3.

In each reaction, X is forming a product where X is in its highest oxidation state.

reaction 1 chlorine + element X $\rightarrow X_yCl_z$

reaction 2 oxygen + element X $\rightarrow X_pO_q$

Which ratios show a steady increase from sodium to phosphorus?

A neither z : y nor q : p

B z : y only

C q : p only

D both z : y and q : p

Ans: D

17.

The ionic equation shows iodide ions reacting with manganate(VII) ions in acidic solution.

$$u\mathrm{MnO_4^-} + v\mathrm{H^+} + w\mathrm{I^-} \rightarrow x\mathrm{Mn^{2+}} + y\mathrm{H_2O} + z\mathrm{I_2}$$

The letters *u*, *v*, *w*, *x*, *y* and *z* all represent whole numbers. Two or more of *u*, *v*, *w*, *x*, *y* and *z* are the same as each other.

What is the lowest possible value of *v*?

A 2 **B** 8 **C** 10 **D** 16

Ans: D

18.

Two half-equations are shown.

$$\mathrm{MnO_4^-} + 2\mathrm{H_2O} + 3\mathrm{e^-} \rightarrow \mathrm{MnO_2} + 4\mathrm{OH^-}$$

$$2\mathrm{OH^-} + \mathrm{SO_3^{2-}} \rightarrow \mathrm{SO_4^{2-}} + \mathrm{H_2O} + 2\mathrm{e^-}$$

The equation for the reaction between manganate(VII) ions and sulfite ions is shown.

$$u\mathrm{MnO_4^-} + v\mathrm{H_2O} + w\mathrm{SO_3^{2-}} \rightarrow x\mathrm{MnO_2} + y\mathrm{SO_4^{2-}} + z\mathrm{OH^-}$$

Which statements are correct?

1 $u = x = z$

2 Manganese is reduced to oxidation state +4.

3 Sulfur is oxidised from oxidation state +4 to +6.

A 1, 2 and 3 **B** 1 and 2 only **C** 1 and 3 only **D** 2 and 3 only

Ans: A

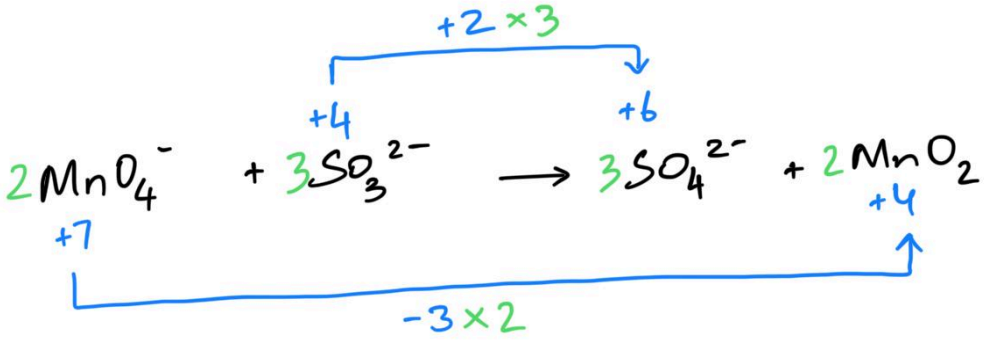
19.

In alkaline solution, $\mathrm{MnO_4^-}$ ions oxidise $\mathrm{SO_3^{2-}}$ ions to $\mathrm{SO_4^{2-}}$ ions. The $\mathrm{MnO_4^-}$ ions are reduced to $\mathrm{MnO_2}$.

What is the ratio of the two ions in the balanced chemical equation for this reaction?

	$\mathrm{MnO_4^-}$	$\mathrm{SO_3^{2-}}$
A	2	3
B	3	2
C	4	7
D	7	4

Ans: A



20.