

Topics in the June 2009 Exam Paper for CHEM1001

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2009-J-12:

- [Types of Intermolecular Forces](#)

- Complete the following table.

Formula	Systematic name
CaBr ₂	calcium bromide
KHCO₃	potassium hydrogencarbonate
KMnO ₄	potassium permanganate
Fe(NO ₃) ₃	iron(III) nitrate

Marks
4

- Consider the elements **W**, **X**, **Y** and **Z** from the same period, *n*, with the following valence electron configurations:



Which element will conduct electricity in the solid state?

X (alkaline earth)

Which element will be the most electronegative?

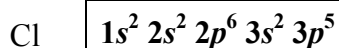
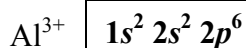
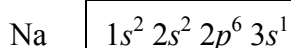
Y (halogen)

Which element will possess the largest atomic radius?

X (left hand side)

3

- Write the electronic configuration of lowest energy for the following species. Na is given as an example.



2

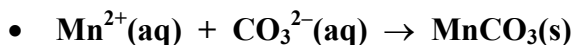
- Manganese(II) chloride and manganese(II) sulfate are both soluble in water. Manganese(II) carbonate, manganese(II) hydroxide and manganese(II) phosphate are all insoluble. Describe, using equations where appropriate, how to convert solid manganese(II) chloride into solid manganese(II) sulfate.

Marks
4

Dissolve the manganese chloride in water.



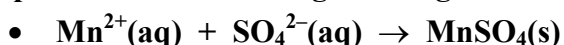
Add a solution of sodium carbonate. Manganese carbonate will precipitate.



Filter off and wash the precipitate and then dissolve it in dilute sulfuric acid.



Evaporate the solution to give manganese sulfate.



- Sodium chloride is soluble in water, magnesium oxide is not. Using your understanding of the intermolecular forces involved, explain why this is so.

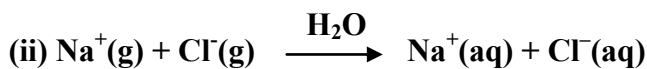
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Both sodium chloride and magnesium oxide are ionic compounds with strong electrostatic forces between the oppositely charged particles. The energy required to overcome these attractions is called the lattice enthalpy.

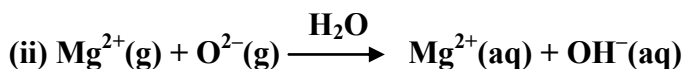
When the ions dissolve in water strong bonds are formed between the ions and the polar water molecules. The energy released in this process is called the solvation enthalpy.

If the solvation enthalpy exceeds the lattice enthalpy the compound will be soluble.

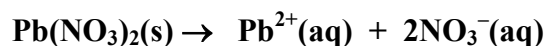
Sodium chloride is soluble because the magnitude of ΔH (i) is less than the magnitude of ΔH (ii):



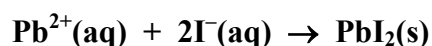
Magnesium oxide is insoluble because the magnitude of ΔH (i) is greater than the magnitude of ΔH (ii):



- A solution is prepared by dissolving lead(II) nitrate (33.12 g) in 1.00 L of water. Write the balanced ionic equation for this dissolution reaction.

Marks
5

When a 100.0 mL portion of this solution is mixed with a solution of potassium iodide (0.300 M, 150.0 mL), a bright yellow precipitate of lead(II) iodide forms. Write the balanced ionic equation for this precipitation reaction.



What mass of lead(II) iodide is formed?

The formula mass of $\text{Pb}(\text{NO}_3)_2$ is:

$$\begin{aligned}\text{formula mass} &= (207.2 \text{ (Pb)} + 2 \times 14.01 \text{ (N)} + 6 \times 16.00 \text{ (O)}) \text{ g mol}^{-1} \\ &= 331.22 \text{ g mol}^{-1}\end{aligned}$$

The number of moles in 33.12 g is therefore:

$$\text{number of moles} = \frac{\text{mass}}{\text{formula mass}} = \frac{33.12 \text{ g}}{331.22 \text{ g mol}^{-1}} = 0.1000 \text{ mol}$$

If this dissolved in 1.00 L and a 100.0 mL portion is taken, this will contain 0.01000 mol of $\text{Pb}^{2+}(\text{aq})$.

150.0 mL of a 0.300 M solution of KI contains:

$$\begin{aligned}\text{number of moles} &= \text{concentration} \times \text{volume} \\ &= 0.300 \text{ mol L}^{-1} \times 0.1500 \text{ L} = 0.0450 \text{ mol}\end{aligned}$$

The precipitation reaction requires 2 mol of $\text{I}^{-}(\text{aq})$ for every 1 mol of $\text{Pb}^{2+}(\text{aq})$. The 0.01000 mol of $\text{Pb}^{2+}(\text{aq})$ that is present requires 0.02000 mol of $\text{I}^{-}(\text{aq})$. As there is more $\text{I}^{-}(\text{aq})$ than this present, $\text{I}^{-}(\text{aq})$ is in excess and $\text{Pb}^{2+}(\text{aq})$ is the limiting reagent.

From the precipitation reaction, 1 mol of $\text{Pb}^{2+}(\text{aq})$ will produce 1 mol of $\text{PbI}_2(\text{s})$. Therefore 0.01000 mol of $\text{Pb}^{2+}(\text{aq})$ will produce 0.01000 mol of $\text{PbI}_2(\text{s})$.

The formula mass of PbI_2 is:

$$\begin{aligned}\text{formula mass} &= (207.2 \text{ (Pb)} + 2 \times 126.9 \text{ (I)}) \text{ g mol}^{-1} \\ &= 461.0 \text{ g mol}^{-1}\end{aligned}$$

The mass of 0.01000 mol is therefore:

$$\begin{aligned}\text{mass} &= \text{formula mass} \times \text{number of moles} = 461.0 \text{ g mol}^{-1} \times 0.01000 \text{ mol} \\ &= 4.61 \text{ g}\end{aligned}$$

Answer: **4.61 g**

ANSWER CONTINUES ON THE NEXT PAGE

What is the final concentration of $\Gamma(\text{aq})$ ions remaining in solution after the reaction is complete?

As described above reaction of 0.01000 mol of $\text{Pb}^{2+}(\text{aq})$ requires 0.02000 mol of $\Gamma(\text{aq})$. As 0.0450 mol are initially present, there are $(0.0450 - 0.02000) \text{ mol} = 0.0250 \text{ mol}$ of $\Gamma(\text{aq})$ after the precipitation reaction.

After mixing the two solutions, the total volume becomes $(100.0 + 150.0) \text{ mL} = 250.0 \text{ mL}$. The final concentration of $\Gamma(\text{aq})$ is therefore:

$$\text{concentration} = \frac{\text{number of moles}}{\text{volume}} = \frac{0.0250 \text{ mol}}{0.2500 \text{ L}} = 0.100 \text{ mol L}^{-1} = 0.100 \text{ M}$$

Answer: **0.100 M**

- Direct damage to the DNA of skin cells can be brought about by exposure to ultraviolet radiation of wavelength 300 nm. What are the frequency and energy (in kJ mol^{-1}) of this radiation?

Marks
4

The frequency, ν , and the wavelength, λ of the radiation are related by $c = \nu\lambda$. Hence:

$$\nu = \frac{c}{\lambda} = \frac{2.998 \times 10^8 \text{ m s}^{-1}}{300 \times 10^{-9} \text{ m}} = 1 \times 10^{15} \text{ s}^{-1} = 1 \times 10^{15} \text{ Hz}$$

The energy of the radiation is given by $E = h\nu = \frac{hc}{\lambda}$. Hence:

$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34} \text{ J s})(2.998 \times 10^8 \text{ m s}^{-1})}{(300 \times 10^{-9} \text{ nm})} = 6.62 \times 10^{-19} \text{ J}$$

This is the energy per photon. For a mole, the energy is:

$$E = (6.62 \times 10^{-19} \text{ J}) \times (6.022 \times 10^{23} \text{ mol}^{-1}) = 400000 \text{ J mol}^{-1} = 400 \text{ kJ mol}^{-1}$$

Frequency: $1 \times 10^{15} \text{ Hz}$

Energy: 400 kJ mol^{-1}

- Three different oxides of lead are known. The oxide that is red in colour is found to consist of 90.67 % lead. What is its empirical formula?

2

The oxide contains 90.67 % Pb and so 9.33 % O.

	Pb	O
percentage	90.67	9.33
divide by atomic mass	$\frac{90.67}{207.2} = 0.438$	$\frac{9.33}{16.00} = 0.583$
divide by smallest value	1	1.33

The ratio of Pb : O is 1 : 1.33 or 3: 4. The empirical formula is thus Pb_3O_4 .

Answer: Pb_3O_4

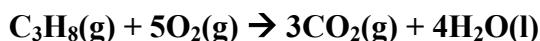
- Propane, C₃H₈, is commonly used in barbecue gas cylinders, its complete combustion yielding water and carbon dioxide as the only products. What volume of CO₂ is produced at 0 °C and 1.0 atm from the complete combustion of 15.0 L of propane at a pressure of 4.5 atm and a temperature of 25 °C?

Marks
3

Using the ideal gas law, $PV = nRT$, 15.0 L of propane at 25 °C (= 298 K) and 4.5 atm corresponds to:

$$n = \frac{PV}{RT} = \frac{(4.5 \text{ atm})(15.0 \text{ L})}{(0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1})(298 \text{ K})} = 2.76 \text{ mol}$$

The combustion reaction is:



Hence, combustion of 2.76 mol of C₃H₈(g) will give rise to (3 × 2.76) mol = 8.28 mol.

At 0 °C (= 273 K) and 1.0 atm, this amount will occupy:

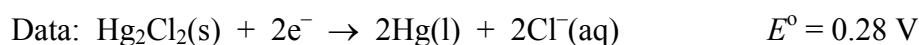
$$n = \frac{nRT}{P} = \frac{(8.28 \text{ mol})(0.08206 \text{ L atm K}^{-1} \text{ mol}^{-1})(273 \text{ K})}{(1.0 \text{ atm})} = 190 \text{ L}$$

Answer: 190 L

- The following cell has a potential of 0.55 V at 25 °C:

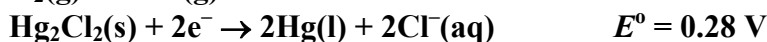


What is the concentration of H⁺ in the anode compartment?

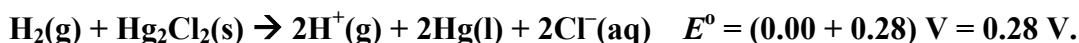


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The two half cells are:



Hence, the overall reaction and the standard cell potential are:



As [H⁺(aq)] is non-standard, the Nernst equation must be used to work out the cell potential:

$$E_{\text{cell}} = E^\circ - 2.303 \times \frac{RT}{nF} \log Q$$

ANSWER CONTINUES ON THE NEXT PAGE

The cell reaction is a $2 e^-$ process: $n = 2$. The reaction quotient only includes species that are gaseous or in solution:

$$Q = \frac{[\text{H}^+(\text{aq})]^2 [\text{Cl}^-(\text{aq})]^2}{[\text{H}_2(\text{g})]}$$

$$= [\text{H}^+(\text{aq})]^2 = x^2 \quad \text{since only } [\text{H}^+(\text{aq})] \text{ is non-standard.}$$

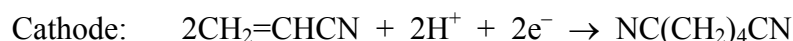
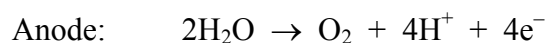
Hence, when $E_{\text{cell}} = 0.55 \text{ V}$:

$$0.55 \text{ V} = (0.28 \text{ V}) - 2.303 \times \frac{(8.314 \text{ J K}^{-1} \text{ mol}^{-1})(298 \text{ K})}{(2 \times 96485 \text{ C mol}^{-1})} \log x^2$$

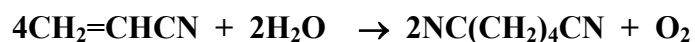
$$x = [\text{H}^+(\text{aq})] = 2.8 \times 10^{-5} \text{ M}$$

Answer: $2.8 \times 10^{-5} \text{ M}$

- Adiponitrile, a key intermediate in the manufacture of nylon, is prepared by the reduction of acrylonitrile.



Write a balanced equation for the overall electrochemical reaction.



What mass of adiponitrile (in kg) is produced in 10.0 hours in a cell that has a constant current of $3.00 \times 10^3 \text{ A}$?

A current of $3.00 \times 10^3 \text{ A}$ passed for 10.0 hours corresponds to:

$$\begin{aligned} \text{number of moles of electrons} &= \frac{It}{F} = \frac{(3.00 \times 10^3 \text{ A})(10.0 \times 60 \times 60 \text{ s})}{(96485 \text{ C mol}^{-1})} \\ &= 1120 \text{ mol} \end{aligned}$$

From the cathode half cell reaction, 2 mol of electrons are needed to produce 1 mol of adiponitrile. Therefore, 1120 mol of electrons will produce 560. mol of this product.

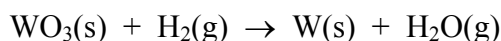
The molar mass of $\text{NC}(\text{CH}_2)_4\text{CN}$ is $(2 \times 14.01 \text{ (N)} + 6 \times 12.01 \text{ (C)} + 8 \times 1.008 \text{ (H)}) \text{ g mol}^{-1} = 108.44 \text{ g mol}^{-1}$.

560 mol therefore corresponds to $(560. \text{ mol}) \times (108.44 \text{ g mol}^{-1}) = 60500 \text{ g} = 60.5 \text{ kg}$.

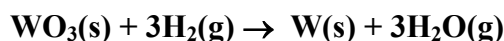
Answer: **60.5 kg**

Marks
3

- Write a balanced equation for the following reaction:



Marks
3



What is the equilibrium constant expression, K_p , for the above reaction?

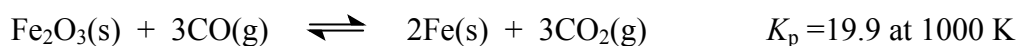
The equilibrium constant only involves the gaseous reactants and products. The equilibrium constant in terms of partial pressures, K_p , is therefore:

$$K_p = \frac{p^3(\text{H}_2\text{O})}{p^3(\text{H}_2)}$$

What is the equilibrium constant, K_c , for the above reaction, in terms of K_p ?

The reaction involves no change in the moles of gas during the reaction: $\Delta n = 0$. As $K_p = K_c(RT)^{\Delta n}$, for this reaction $K_p = K_c$.

- Fe_2O_3 can be reduced by carbon monoxide according to the following equation.



At 1000 K, what are the equilibrium partial pressures of CO and CO_2 if the only gas initially present is CO at a partial pressure of 0.978 atm?

3

The reaction table is:

	$\text{Fe}_2\text{O}_3(\text{s})$	$3\text{CO}(\text{g})$	\rightleftharpoons	$2\text{Fe}(\text{s})$	$3\text{CO}_2(\text{g})$
initial / atm	-	0.978		-	0
change / atm		-3x			+3x
equilibrium / atm		0.978 - 3x			3x

The solids do not appear in the equilibrium constant expression and do not need to be considered. The equilibrium constant in terms of partial pressures, K_p , is given by:

$$K_p = \frac{p(\text{CO}_2)^3}{p(\text{CO})^3} = \frac{(3x)^3}{(0.978 - 3x)^3} = 19.9$$

Hence,

$$\frac{(3x)}{(0.978 - 3x)} = (19.9)^{1/3} = 2.71$$

$$3x = (2.71)(0.978 - 3x) = 2.65 - 8.13x \text{ or } 11.1x = 2.65 \text{ or } x = 0.238$$

ANSWER CONTINUES ON THE NEXT PAGE

From the reaction table,

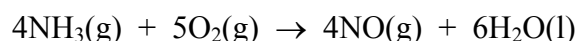
$$p(\text{CO}) = (0.978 - 3x) \text{ atm} = 0.264 \text{ atm}$$

$$p(\text{CO}_2) = 3x \text{ atm} = 0.714 \text{ atm}$$

$$p(\text{CO}) = 0.264 \text{ atm}$$

$$p(\text{CO}_2) = 0.714 \text{ atm}$$

- Calculate the standard-free energy change for the oxidation of ammonia to nitric oxide and water, according to the following equation.



Data: $\Delta_f G^\circ(\text{NO}(\text{g})) = 87.6 \text{ kJ mol}^{-1}$

$$\Delta_f G^\circ(\text{NH}_3(\text{g})) = -16.5 \text{ kJ mol}^{-1}$$

$$\Delta_f G^\circ(\text{H}_2\text{O}(\text{l})) = -237.2 \text{ kJ mol}^{-1}$$

Marks
3

Using $\Delta_{\text{rxn}} G^\circ = \sum m \Delta_f G^\circ(\text{products}) - \sum n \Delta_f G^\circ(\text{reactants})$,

$$\Delta_{\text{rxn}} G^\circ = ((4 \times 87.6 + 6 \times -237.2) - (4 \times -16.5)) \text{ kJ mol}^{-1} \text{ as } \Delta_f G^\circ(\text{O}_2(\text{g})) = 0.$$

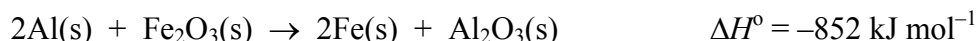
$$= -1007 \text{ kJ mol}^{-1}$$

Answer: **-1007 kJ mol⁻¹**

Is the reaction spontaneous under standard conditions? Give a reason for your answer.

The reaction is spontaneous as $\Delta_{\text{rxn}} G^\circ < 0$. This is the condition for a reaction to be spontaneous.

- How much heat is evolved, in kJ, when 5.00 g of Al reacts with a stoichiometric amount of Fe_2O_3 according to the following equation?



1

The atomic mass of Al is 26.98 g mol^{-1} so 5.00 g corresponds to:

$$\text{number of moles of Al} = \frac{\text{mass}}{\text{atomic mass}} = \frac{5.00 \text{ g}}{26.98 \text{ g mol}^{-1}} = 0.185 \text{ mol}$$

From the chemical equation, 852 kJ mol^{-1} is evolved when 2 mol of Al reacts so 426 kJ is evolved when 1 mol of Al reacts.

Therefore, when 0.185 mol of Al reacts, the heat evolved is $(0.185 \text{ mol} \times 426 \text{ kJ mol}^{-1}) = 78.9 \text{ kJ}$.

Answer: **78.9 kJ**

- The specific heat of Si is $0.71 \text{ J g}^{-1} \text{ K}^{-1}$. How much heat is required to heat a Si wafer weighing 0.45 g from $20.0 \text{ }^\circ\text{C}$ to $26.0 \text{ }^\circ\text{C}$?

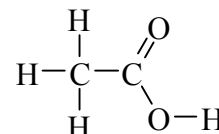
Marks
1

The heat, q , required to increase a solid of mass m by ΔT is given by $q = mC_v\Delta T$ where C_v is the specific heat capacity. Hence:

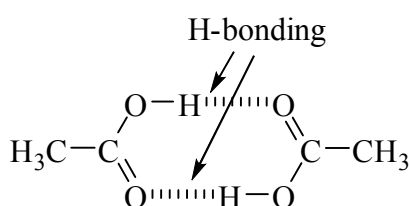
$$q = (0.45 \text{ g}) \times (0.71 \text{ J g}^{-1} \text{ K}^{-1}) \times ((26.0 - 20.0) \text{ K}) = 1.9 \text{ J}$$

Answer: **1.9 J**

- The structural formula of acetic acid is shown on the right. Acetic acid forms dimers (*i.e.* pairs of molecules) in the gas phase. Draw the dimer showing the H-bonding that occurs.



1



- Heating SbCl_5 causes it to decompose according to the following equation.



A sample of 0.50 mol of SbCl_5 is placed in a 1.0 L flask and heated to $450 \text{ }^\circ\text{C}$. When the system reaches equilibrium there is 0.10 mol of Cl_2 present. Calculate the value of the equilibrium constant, K_c , at $450 \text{ }^\circ\text{C}$.

4

From the chemical equation, 1 mol of $\text{Cl}_2(\text{g})$ is produced from every 1 mol of $\text{SbCl}_5(\text{g})$ that reacts. As 0.10 mol of $\text{Cl}_2(\text{g})$ is present at equilibrium, 0.10 mol of $\text{SbCl}_5(\text{g})$ has reacted. Initially, 0.50 mol of $\text{SbCl}_5(\text{g})$ was present so the amount left at equilibrium is $(0.50 - 0.10) \text{ mol} = 0.40 \text{ mol}$.

From the chemical equation, 1 mol of $\text{SbCl}_3(\text{g})$ is produced from every 1 mol of $\text{SbCl}_5(\text{g})$ that reacts. As 0.10 mol of $\text{SbCl}_5(\text{g})$ has reacted, 0.10 mol of $\text{SbCl}_3(\text{g})$ is present at equilibrium.

$$[\text{SbCl}_5(\text{g})]_{\text{eq}} = \frac{\text{number of moles}}{\text{volume}} = \frac{0.40 \text{ mol}}{1.0 \text{ L}} = 0.40 \text{ mol L}^{-1} = 0.40 \text{ M}$$

$$[\text{SbCl}_3(\text{g})]_{\text{eq}} = [\text{Cl}_2(\text{g})]_{\text{eq}} = \frac{0.10 \text{ mol}}{1.0 \text{ L}} = 0.10 \text{ mol L}^{-1} = 0.10 \text{ M}$$

The equilibrium constant in terms of concentrations, K_c is given by:

$$K_c = \frac{[\text{SbCl}_3(\text{g})][\text{Cl}_2(\text{g})]}{[\text{SbCl}_5(\text{g})]} = \frac{(0.1)(0.1)}{(0.40)} = 0.025$$

Answer: **$K_c = 0.025$**

<ul style="list-style-type: none">• Which of acetone, $(\text{CH}_3)_2\text{CO}$, and water will have the greater surface tension. Why?	Marks 2
<p>Water will have the greater surface tension. It has much stronger intermolecular forces (H-bonds and dispersion) than acetone (dispersion and dipole-dipole forces).</p>	
<ul style="list-style-type: none">• Melting points of the hydrogen halides increase in the order $\text{HCl} < \text{HBr} < \text{HF} < \text{HI}$. Explain this trend.	2
<p>The major intermolecular forces in HCl, HBr and HI are dispersion forces. The heavier the halogen is, the larger is its electron cloud and the more polarisable it is. Higher polarisability leads to stronger dispersion forces therefore leading to melting points which increase in the order $\text{HCl} < \text{HBr} < \text{HI}$.</p> <p>F is a very small and very electronegative atom. The H–F bond is therefore highly polarised and H-bonds form. These are much stronger than dispersion forces and so HF has an anomalously high melting point. As seen by the experimental order given, this is enough to raise its melting point above that of HBr, but not above that of HI.</p>	
<ul style="list-style-type: none">• Why is the solubility of chloroform (CHCl_3) in water 10 times greater than that of carbon tetrachloride (CCl_4) in water?	2
<p>The C–H bond in CHCl_3 is quite polarised due to the electron-withdrawing effect of the Cl atoms. CHCl_3 has a fairly large dipole moment with δ^+ H and δ^- Cl.</p> <p>CCl_4 has no dipole moment. Although each C-Cl bond is fairly polar, the tetrahedral shape of the molecule leads to overall cancellation of these bond dipoles.</p> <p>The polar water molecules interact better with the polar CHCl_3 molecules than with the non-polar CCl_4 molecules so CHCl_3 is more soluble.</p>	