3.4 Particles and thermochemical principles 2006 Answers

QUESTION ONE: PROPERTIES OF ATOMS AND IONS

a Ca^{2+} is smaller (or Cl^- is larger).
These ions both have 18 electrons in 3 shells, but the Ca^{2+} ion contains 20 protons in its nucleus, while the Cl^- ion only has 17 protons. The larger positive charge on the Ca^{2+} ion attracts the electrons more strongly than the Cl^- ion attracts electrons, so the Ca^{2+} is smaller.

A = Correct size.
M = Size and explanation correct.

b **i** The first ionisation energy of chlorine is the energy required to **remove** the **outermost electron** from **one mole** of **gaseous** chlorine **atoms** to form one mole of $Cl^+(g)$ ions.

OR $Cl(g) \longrightarrow Cl^+(g) + e^-$

A = Statement (with all bold words) or equation correct.

ii Ca < Mg < Cl

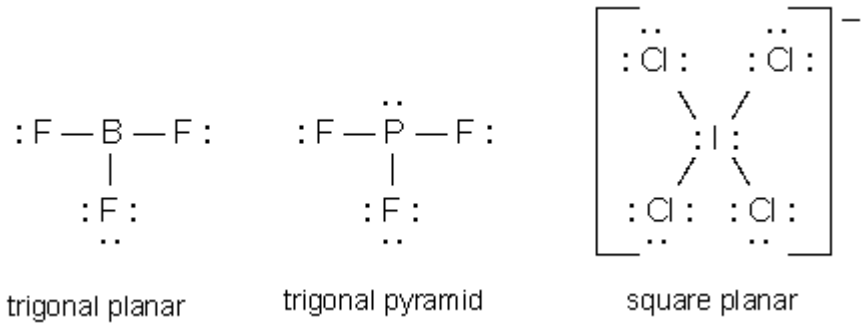
Ca and Mg are in the same group, but Ca has 4 electron shells while Mg has only 3. Ionisation energies decrease going down the group because the electrostatic attraction between the nucleus and the valence electrons decreases with distance from the nucleus. So Ca has a lower IE than Mg.

Mg and Cl are in the same period and both have three shells of electrons. Ionisation energy increases going across a period, because the effective nuclear charge on the valence electrons increases, attracting all electrons in the valence shell more strongly. So Cl has a higher IE than Mg.

A = Correct order OR correct statement of trends down a group and across a period without explanation OR one valid explanation of a trend.
M = Correct order AND one valid argument of a trend.
E = Correct order AND full explanation of the trends in a coherent, logical argument.

QUESTION TWO: SHAPES AND POLARITIES

a



A = valence electrons for both molecules correct OR one Lewis diagram correct.
M = Both Lewis diagrams correct.

A = 2 shapes correct.

b Both BF_3 and PF_3 contain polar bonds, because the electronegativities of B and P are both less than the electronegativity of F. This means that in each bond the electrons spend more time near the F atom and less time near the P or B atom, giving the F atoms slight negative charges and the P or B atoms slight positive charges. This each bond has a electrostatic dipole.

The BF_3 molecule is non-polar because the molecule contains no lone pairs of electrons and all three dipoles are balanced, so that the molecule itself has no net dipole.

The PF_3 molecule is polar because the molecule contains a lone pair of electrons. The four electron clouds (three bonds plus the lone pair) are arranged tetrahedrally, causing the three bonding clouds to appear on one side of the molecule. With the dipoles not balanced, the molecule is polar.

A = Correct polarities for both molecules stated OR One polarity correct with correct explanation.
M = Correct polarities for both molecules stated AND One polarity correct with correct explanation.
E = Correct polarities for both molecules AND explanation of bond polarity due to difference in electronegativites AND comprehensive justification of polarities for each molecule.

QUESTION THREE: TRANSITION METALS

a Cr: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^1$ OR [Ar] $3d^5\ 4s^1$

Mn $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5\ 4s^2$ OR [Ar] $3d^5\ 4s^2$

Mn^{2+} $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^5$ OR [Ar] $3d^5$

A = Two correct.

b Both of these elements have incomplete ‘d’ shells of electrons and can form a number of different stable ions by losing different numbers of electrons – such as the 4s electrons only, or the 4s electrons plus one 3d electron, or 4s plus 2 3d electrons and so on.

c Manganese and chromium compounds are coloured because the energy required for electrons to move between the various ‘d’ orbitals is equal to the energy of the photons in visible (coloured) light. As this energy is absorbed it changes the colour of light we see from white to coloured.

A = Mn and Cr have partially filled d subshell or sublevel. OR They can form stable compounds by losing or sharing various numbers of 4s and 3d electrons. OR *d–d* transitions can occur. OR Absorbs light in the visible region of the spectrum.

M = Correct explanation for both, with link to partially filled subshell.

QUESTION FOUR: ENTHALPY OF VAPORISATION

The only difference between ethanal, propanal and butanal is the length of the hydrocarbon chain. We see an increase in vaporisation enthalpy as the chain increases.

Chain length influences the strength of the intermolecular force, because the longer the chain, the greater the number of electrons in the molecule and thus the greater the opportunity for temporary uneven distribution of electrons — which causes a temporary dipole in a molecule and induce temporary dipoles in nearby molecules.

Ethanoic acid has about the same molar mass as propanal, but has a much higher enthalpy of vaporisation because the –OH group gives the opportunity for hydrogen bonding. Whenever an H atom is bonded to the strongly electronegative elements O, F or N it is possible for the proton from the H to be shared between the lone pairs on the O, F or N atom of a nearby molecule. In the case of ethanoic acid, the proton is shared between the O of the –OH group and the slightly negatively-charged O of the C=O group. The hydrogen bond created by this shared proton is about 10% the strength of a normal covalent bond, and creates a strong intermolecular force between these molecules that increases the enthalpy of vaporisation of hydrogen-bonded compounds. It is much stronger than the intermolecular forces between polar compounds of similar molar mass.

A = Relating increase in molar mass to increase in $\Delta_{vap}H°$. OR Recognises that hydrogen bonding occurs in ethanoic acid and links this to the strength of the intermolecular forces in ethanoic acid OR explains when hydrogen bonding occurs.
M = Brief explanation of BOTH the trend in aldehydes and the hydrogen bonding in ethanoic acid.
E = Comprehensive analysis including explanation of temporary dipoles and the effect of increasing mass AND an explanation of how hydrogen bonding occurs and why, including its relative strength and mechanism in ethanoic acid.

QUESTION FIVE: ENTHALPY OF FORMATION AND COMBUSTION

a $H_2(g) + ½O_2(g) \longrightarrow H_2O(l)$

A = Correct (states must be included).

b When one mole of H_2 gas is burnt with its products returned to their standard states, one mole of H_2O liquid is formed. The $\Delta_fH°(H_2O, l)$ is the energy change when one mole of liquid H_2O is formed from gaseous H_2 and O_2.. Since the reactions for $\Delta_fH°(H_2O, l)$ and $\Delta_cH°(H_2, g)$ are the same, their values are equal.

A = identifies reactions or equations as the same.
M = Answer clearly shows that reactions or equations are the same AND that the species are in the same state for both reactions.

c i **$H_2(g) + ½O_2(g) \longrightarrow H_2O(g)$** $\Delta_fH°(H_2O, g) = ?$

$H—H + ½O=O \longrightarrow H—O—O$

Bonds broken (kJ mol^{-1})	Bonds formed (kJ mol^{-1})
$436 + ½(498)$	$2 \times (–463)$

$\Delta_fH°(H_2O, g) = 436 + (½ \times 498) – (2 \times 463) =$ **$–241$ kJ mol^{-1}**

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ii $H_2O(l) \longrightarrow H_2O(g)$

$\Delta_{vap}H°(H_2O) = \Delta_fH°(H_2O, g) - \Delta_fH°(H_2O, l)$
$= (-241 \text{ kJ mol}^{-1}) - (-286 \text{ kJ mol}^{-1})$
$= \mathbf{+ 45 \text{ kJ mol}^{-1}}$

OR $H_2O(l) \longrightarrow H_2O(g)$ $\Delta_{vap}H°(H_2O) = ?$

$H_2(g) + ½O_2(g) \longrightarrow H_2O(g)$ $\Delta_fH°(H_2O, g) = -241 \text{ kJ mol}^{-1}$ (1)

$H_2(g) + ½O_2(g) \longrightarrow H_2O(l)$ $\Delta_fH°(H_2O, l) = -286 \text{ kJ mol}^{-1}$ (2)

$H_2O(l) \longrightarrow H_2(g) + ½O_2(g)$ $\Delta H = + 286 \text{ kJ mol}^{-1}$ (3)

Adding (1) and (3)

~~$H_2(g) + ½O_2(g)$~~ $\longrightarrow H_2O(g)$ $\Delta_fH°(H_2O, g) = -241 \text{ kJ mol}^{-1}$ (1)

$H_2O(l) \longrightarrow$ ~~$H_2(g) + ½O_2(g)$~~ $\Delta H = + 286 \text{ kJ mol}^{-1}$ (3)

$H_2O(l) \longrightarrow H_2O(g)$ $\Delta_{vap}H°(H_2O) = \mathbf{+ 45 \text{ kJ mol}^{-1}}$

$$n(H_2O) = \frac{m}{M}$$
$$= \frac{100 \text{ g}}{18.0 \text{ g mol}^{-1}}$$
$$= 5.556 \text{ mol}$$

Energy required to vaporise 100g of water

$$Energy = n(H_2O) \times 45 \text{ kJ mol}^{-1}$$
$$= 5.556 \text{ mol} \times 45 \text{ kJ mol}^{-1}$$
$$= \mathbf{250 \text{ kJ}}$$

A = One of the three values calculated correctly OR correct equation for $\Delta_fH°(H_2O, g)$.
M = Two processes correct OR one correct answer and two correct processes with minor error.
E = All processes and values correct including correct units.

d $2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \longrightarrow C_2H_5OH(l)$ $\quad \Delta_f H°(C_2H_5OH, l) = ?$

$C_2H_5OH(l) + 3O_2(g)$	$\longrightarrow$	$2CO_2(g) + 3H_2O(l)$	$\Delta_c H° = -1367$ kJ mol^{-1}
$C(s) + O_2(g)$	$\longrightarrow$	$CO_2(g)$	$\Delta_f H° = -394$ kJ mol^{-1}
$H_2(g) + \frac{1}{2}O_2(g)$	$\longrightarrow$	$H_2O(l)$	$\Delta_f H° = -286$ kJ mol^{-1}

~~$2CO_2(g)$~~ + ~~$3H_2O(l)$~~	$\longrightarrow$	$C_2H_5OH(l)$ + ~~$3O_2(g)$~~	$\Delta_c H° = +1367$ kJ mol^{-1}
$2C(s)$ + ~~$2O_2(g)$~~	$\longrightarrow$	~~$2CO_2(g)$~~	$\Delta_f H° = 2 \times -394$ kJ mol^{-1}
$3H_2(g)$ + ~~$1\frac{1}{2}O_2(g)$~~	$\longrightarrow$	~~$3H_2O(l)$~~	$\Delta_f H° = 3 \times -286$ kJ mol^{-1}

$2C(s) + 3H_2(g) + \frac{1}{2}O_2(g) \longrightarrow C_2H_5OH(l)$ $\quad \Delta_f H°(C_2H_5OH, l) =$ **-279 kJ mol^{-1}**

A = Correct equation for $\Delta_f H°(C_2H_5OH, l)$ OR calculation process correct but wrong equation used and no units in answer.
M = Clear method and correct equation but one mathematical error and/or no units.
E = Clear method with equation and calculation correct and including units.

Judgement Statement

Chemistry: Describe properties of particles and thermochemical principles (90780)

Achievement

SEVEN questions answered correctly.

Minimum of $7 \times$ A

Achievement with Merit

EIGHT questions answered correctly, including at least FIVE at Merit level.

Minimum of $5 \times$ M + $3 \times$ A

Achievement with Excellence

TEN questions answered correctly, including at least FOUR at Merit level and at least THREE at Excellence level.

Minimum of $3 \times$ E + $4 \times$ M + $3 \times$ A