23. Chemical energetics

23.1 Lattice energy and Born-Haber cycles

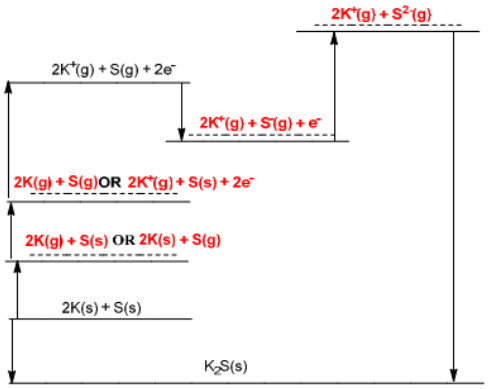
Paper 4

Marking Scheme

Q1.

(e)	**M1** $Mg(NO_3)_2(s)$, $NaNO_3(s)$, $RbNO_3(s)$ **M2** Mg^{2+} has a higher charge than Na^+ **OR** Rb^+ **AND** Na^+ has a smaller radius than Rb^+ **M3** correct statement relating magnitude of LE to attraction between ions **OR** strength of ionic bonds	**3**

Q2.

(b)	**M1** ΔH / energy change when 1 mole of an ionic solid / compound is formed **M2** from gaseous ions (under standard conditions)	**2**
(c)	**M1** as ionic radii increases **AND** ΔH_{latt} less exothermic **M2** as ionic charge increases **AND** ΔH_{latt} increases/more exothermic	**2**
(d)(i)	 any two [1] any three [2] all four [3]	**3**

(d)(ii)	**M1** selection of **ONLY** six correct values (–381, 89, 419, 279, –200, 640) **AND** use of × 2 as only multiplier with K **M2** correct evaluation of data used ecf $-381 = (89 \times 2) + (419 \times 2) + 279 + (-200) + 640 + \Delta H^{\ominus}_{latt}$ $\Delta H^{\ominus}_{latt} = -2116$ (kJ mol^{-1})	**2**

Q3.

(b)(i)	**M1** energy released when one mole of a ionic solid / compound is formed **M2** from gas (phase) ion(s) / gaseous ion(s) (under standard conditions)	**2**
(b)(ii)	• (ΔH_{decomp} / it) becomes **more positive/less negative** (down the group) • size /(ionic) radii of oxide ion is **smaller** (than carbonate ion) **ORA** • so ΔH_{latt} of oxides becomes **ORA** less exothermic **faster OR** less negative **faster** **OR** changes **more OR** changes **faster** Any two [1], all three [2]	**2**

Q4.

(a) **1**

energy change	always positive	always negative	can be either negative or positive
bond energy	✓		
enthalpy change of atomisation	✓		
enthalpy change of formation			✓

(b) **2**

M1 (enthalpy change) when one mole of gaseous atoms is produced **IGNORE** energy released
M2 from its element(s) in its standard state / standard conditions / 298 K **AND** 1 atm

(c) **3**

M1 use of correct six numbers only –31 / 285 / 731 / –141 / 798 / 496

M2 2 × used correctly with Ag (2 × 285 (570) and 2 × 731 (1462)) **AND** 0.5 with O=O (496 (248))

M3 correct signs and evaluation
$-31 = (2 \times 285) + (2 \times 731) + (-141) + (798) + x + (0.5 \times 496)$

$x = -2968$ kJ mol^{-1}

(d) **2**

- Ag_2Se Ag_2S Ag_2O **OWTTE**
  least exothermic *most exothermic*
- charge density of anion decreases down the group **ORA**
  / radius/size of anion increases down the group
  / Se^{2-} largest radius / O^{2-} smallest radius / O has smallest ionic radius
- less attraction between the ions / ionic bond gets weaker (with Ag_2Se) **ORA**

Any two [1], all three [2]

Q5.

(d)(i) **3**

$-1473 = 180 + 503 + 965 + \Delta H^{\ominus}_f - 2469$

$\Delta H^{\ominus}_f$ of $SO_4^{2-}(g) = -652$ kJ mol^{-1}

M1 correct five values used [1]
M2 only correct five values used [1]
M3 correct signs and evaluation [1]

(d)(ii) **2**

- $BaSO_4$ is more negative/bigger
- as Ba^{2+} is smaller **OR** Ba^{2+} has a larger charge
- stronger force of attraction between the ions

One mark for two correct
Two marks for all three correct

Q6.

(a)(i)	• enthalpy change / energy change • one mole of electrons • (gained by) **one mole** of **gaseous atoms** two for one mark, three for two marks	**2**
(a)(ii)	(energy required to overcome) the repulsion between the electron and anion / negative ion	**1**

(a)(iii)	• less negative / less exothermic down the group • greater the distance between the nucleus and (the shells of the) electrons **OR** atomic radii increases **OR** more shielding by inner shells • the less **attraction** between nucleus and incoming electron (and the less energy released) two for one mark, three for two marks	**2**
(b)	**M1** use of correct seven numbers only in calculation / energy cycle **M2** only 2 × used correctly **M3** correct signs and evaluation ecf –208 = 131 + 906 + 1733 + 62 + 151 + 2x – 2605 2x = –586 x = –293 kJ mol^{-1}	**3**
(c)	first box ticked **AND** Cd^{2+} larger / Cd^{2+} lower charge density **AND** less attraction between the ions / weaker ionic bonds	**1**

Q7.

(c)	• Mg^{2+} is **smaller** (than K^+) • Mg^{2+} is **greater charge** (than K^+) • greater **attraction** between Mg^{2+} and Cl^- /**between the ions** (in $MgCl_2$) **OR** stronger ionic bonds (in $MgCl_2$)	**2**
(d)(i)	enthalpy change when **one mole** of **gaseous atoms** formed from the **element** (in its standard state at 298 K)	**1**
(d)(ii)	enthalpy change when every atom in one mole of gaseous atoms gains one electron **OR** one mole of gaseous atoms gains one mole of electrons	**1**

Q8.

(c)	Fe^{2+} is smaller / has a smaller radius **OR** Fe^{2+} greater charge density [1] polarises/distorts the anion / $CO_3^{(2)-}$ more [1]	**2**

Q9.

(a)	(energy change) when one mole of ionic solid is formed from gaseous ions	**1**
(b)	(–2237 + 193 + 590 + 1150 + (2 × 121) – (2 × 364)) [1] = –790 [1]	**2**
(c)	–342 **and** Br atom has larger radius	**1**

Q10.

(a)(i)	**M1:** energy change when 1 mole of a ionic compound is formed **M2:** from its gaseous ions under standard conditions	**2**

Q11.

(a)	• enthalpy/energy change • one mole of electrons gained • by one mole of atoms • gaseous (atoms)	**2**

(d)(i)	**attraction** between nucleus / protons / nuclear charge **and** electron [1]	**1**
(d)(ii)	**repulsion** between 1– ion / electrons of O^- **and** electron [1]	**1**
(e)	M1: selecting correct data 951, 1933, 3517 only (ignore signs) M2: evaluation to give –633 (ΔH_f) ecf ΔH_f = 951 + 1933 – 3517 = **–633** (kJ mol^{-1}) [2]	**2**
(f)	ionic charge / charge density (of the ions) [1] greater (attractive) force between the ion**s** [1]	**2**

Q12.

(a)	moles of H_2 = 462 / 24 000 = 0.01925[1] molecules of H_2 = $0.019 \times 6.02 \times 10^{23}$ = **1.16×10^{22}** (1.1×10^{22} / 1.2×10^{22}) [1] **min 2sf** ecf M1	**2**
(b)	number of electrons = $1.16 \times 10^{22} \times 2$ = **2.32×10^{22}** [1] min 2sf ecf 1a	**1**
(c)	Q = 2.32×10^{22} $\times 1.6 \times 10^{-19}$ = **3.71×10^{3}** [1] min 2sf ecf 1b	**1**
(d)	x = $3.71 \times 10^{3} / (14 \times 60)$ = **4.4** (A) [1] min 2sf ecf 1c	**1**
(e)(i)	ΔS = 262 + 205 – 140 = (+) **327** (J K^{-1} mol^{-1})[1]	**1**
(e)(ii)	ΔG = $\Delta H - T\Delta S$ **OR** use of Gibbs equation [1] ΔG = 572 – (298 × 0.327) = (+)**474.6** (kJ mol^{-1}) [1] min 3sf ecf 1e(i)	**2**
(e)(iii)	becomes more feasible / spontaneous as TΔS is more positive / –TΔS becomes more negative • ✓	**1**

Q13.

(a)(i)	• energy change • when one electron is added • to each atom /ion in one mole of • gaseous atoms /ions Award one mark for two correct statements. Award two marks for four correct statements	**2**
(a)(ii)	**M1** energy change when 1 mole of an ionic compound is formed **M2** from gas phase ions/ gaseous ions	**2**

(b)	**M1** use of data (with no multipliers) 31, 131, -2678 **M2** extraction of data 908, 1730, 193 **M3** use of (2 x-325) **M4** evaluation of <u>their</u> expression correctly, as shown $\Delta H_f(ZnBr_2)$ = 131 + (908 +1730) + 193 + 31 + (2 x-325) + (-2678) = **-335** kJ mol^{-1} [4]	**4**
(c)(i)	Br^- is a largest ion/larger ion than Cl^- so attraction between Br^- and Zn^{2+} is smaller	**1**
(c)(ii)	O^{2-} is a smallest ion/smaller ion than Cl^- **AND** O^{2-} has the highest charge/ higher charge than Cl^- (so attraction between O^{2-} and Zn^{2+} is larger)	**1**

Q14.

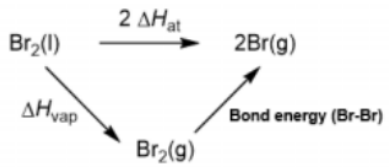
(a)(i)	**M1** energy released when 1 mole of an ionic compound is formed [1] **M2** from gaseous ions (under standard conditions) [1]	**2**
(a)(ii)	Ca^{2+} & O^{2-} have a higher charge / charge density (than Li^+ and F^-) [1]	**1**
(a)(iii)	MgO –3600 or more negative **AND** BaO –3200 or less negative **BOTH** [1]	**1**

(c)	**M1:** Use of 2 × –348 (EA F) and +158 (bond energy of F_2) [1] **M2:** Use of +147 (at Mg) and +736 and +1450 (IEs of Mg) [1] **M3:** evaluation and calculation of their answer (–1102 – (147 + 158 + 736 + 1450 – 696)) = **–2897** (kJ mol^{-1}) [1] ecf	**3**
(d)(i)	• (energy change) when an / one electron is added to • each atom / ion in one mole of • gaseous atoms / ions mark as • ✓ ✓ [2]	**2**
(d)(ii)	F has greater nuclear charge / more protons **AND** greater attraction between F atom / nucleus and the electrons • ✓ **BOTH** [1]	**1**

Q15.

(a)(i)	(+193 + 242 + 590 + 1150 + (2 × –349)) [1] answer (+)1477 [1]	**2**
(a)(ii)	(–795 – 83 – 1477) [1] –2355 [1]	**2**
(a)(iii)	(–2355 –(2 × –364)) [1] –1627 [1]	**2**
(a)(iv)	Z–Y or X–W [1]	**1**
(a)(v)	less (exothermic) and both ions (in $CaCl_2$) are larger [1]	1

Q16.

(b)	(energy change) when **1 mole** of **gaseous atoms** are formed (from an element in its standard state)	**1**
(c)	 **M1**: correct cycle: formulae and state symbols **M2**: use of 1 × 193 **and** 2 × (112) **M3**: for the correct sum and answer ecf from M2 $\Delta H^{\ominus}_{vap}$ (= (2 × 112) – (193)) = **+31** kJ mol^{-1} [scores M2 and M3]	**3**

Q17.

(a)	<table><tr><th>energy change</th><th>always positive</th><th>always negative</th><th>either negative or positive</th></tr><tr><td>lattice energy</td><td></td><td>✓</td><td></td></tr><tr><td>enthalpy of neutralisation</td><td></td><td>✓</td><td></td></tr></table> **both** [1]	1

(d)	Ca^{2+} have a higher charge / greater charge density [1] **ora** **stronger** electrostatic forces between Br^- and Ca^{2+} [1]	2

Q18.

(d)	use of (2 × 109) or 218 and (2 × 494) or 988	1
	use of (0.5 × 496) or 248	1
	use of 416, 142, 844	1
	evaluation of expression correctly ΔH_{lat} = –416 – (2 × 109) – (0.5 × 496) – (2 × 494) – (–142 + 844) = –2572	1
(e)	the lattice energy of Na_2S is less exothermic	1
	the sulfide ion is larger than the oxide ion / S^{2-} larger than O^2 / ionic radii quoted 0.184 nm and 0.140 nm **AND** less attraction (between the ions)/bonds are weaker	1