**IB Chemistry HL**

**Topic 5 Questions**

**1.** Which combination of ionic charge and ionic radius give the largest lattice enthalpy for an ionic compound?

|  |  |  |
| --- | --- | --- |
|  | **Ionic charge** | **Ionic radius** |
| A. | high | large |
| B. | high | small |
| C. | low | small |
| D. | low | large |

**2.** The lattice enthalpy values for lithium fluoride and calcium fluoride are shown below.

LiF(s) ∆*H*~~ο~~ = +1022 kJ mol–1   
CaF2(s) ∆*H*~~ο~~ = +2602 kJ mol–1

Which of the following statements help(s) to explain why the value for lithium fluoride is less than that for calcium fluoride?

I. The ionic radius of lithium is less than that of calcium.

II. The ionic charge of lithium is less than that of calcium.

A. I only

B. II only

C. I and II

D. Neither I nor II

**3.** Which reaction has the most negative ∆*H*~~ο~~ value?

A. LiF(s) → Li+(g) + F–(g)

B. Li+(g) + F–(g) → LiF(s)

C. NaCl(s) → Na+(g) + Cl–(g)

D. Na+(g) + Cl–(g) → NaCl(s)

**4.** Which type of reaction is referred to in the definition of *standard enthalpy change of formation*?

A. the formation of a compound from its elements

B. the formation of a crystal from its ions

C. the formation of a molecule from its atoms

D. the formation of a compound from other compounds

**5.** What is the correct order of decreasing entropy for a pure substance?

A. gas  liquid  solid

B. solid  liquid  gas

C. solid  gas  liquid

D. liquid  solid  gas

**6.** Which reaction has the largest positive value of *S*Ө?

A. CO2(g) + 3H2(g)  CH3OH(g) + H2O(g)

B. 2Al(s) + 3S(s)  Al2S3(s)

C. CH4(g) + H2O(g)  3H2(g) + CO(g)

D. 2S(s) + 3O2(g)  2SO3(g)

**7.** Which is a correct equation to represent the lattice enthalpy of magnesium sulfide?

A. MgS(s)  Mg(s) + S(s)

B. MgS(s)  Mg(g) + S(g)

C. MgS(s)  Mg+(g) + S–(g)

D. MgS(s)  Mg2+(g) + S2–(g)

**8.** Which equation represents a change with a negative value for *S*?

A. 2H2(g) + O2(g)  2H2O(g)

B. H2O(s)  H2O(g)

C. H2(g) + Cl2(g)  2HCl(g)

D. 2NH3(g)  N2(g) + 3H2(g)

**9.** The expression for the standard free energy change of a reaction is given by

*G*Ө = *H*Ө – T*S*Ө

What are the signs for *H*Ө and *S*Ө for a reaction that is spontaneous at all temperatures?

|  |  |  |
| --- | --- | --- |
|  | *H*Ө | *S*Ө |
| A. | + | – |
| B. | – | + |
| C. | + | + |
| D. | – | – |

**10.** Which are characteristics of ions in an ionic compound with a large lattice enthalpy value?

A. Large ionic radius and high ionic charge

B. Small ionic radius and low ionic charge

C. Large ionic radius and low ionic charge

D. Small ionic radius and high ionic charge

**11.** The following reaction is spontaneous only at temperatures above 850C.

CaCO3(s)  CaO(s) + CO2(g)

Which combination is correct for this reaction at 1000C?

|  |  |  |  |
| --- | --- | --- | --- |
|  | *G* | *H* | *S* |
| A. | – | – | – |
| B. | + | + | + |
| C. | – | + | + |
| D. | + | – | – |

**12.** Consider the following information.

|  |  |  |  |
| --- | --- | --- | --- |
| Compound | C6H6(l) | CO2(g) | H2O(l) |
| *H*fӨ / kJ mol–1 | +49 | -394 | –286 |

C6H6 (l) + O2 (g)  6 CO2 (g) + 3 H2O (l)

Which expression gives the correct value of the standard enthalpy change of combustion for benzene (l), in kJ mol–1?

A. 12 (394) + (286) 2 (+49)

B. 12 (394) + 6 (286) 2 (-49)

C. 6 (394) + 3 (286)  (+49)

D. 6 (394) + 3 (286)  (-49)

**13.** Which equation represents the lattice enthalpy of magnesium oxide?

A. MgO(s)  Mg(s) + O2(g)

B. MgO(g)  Mg2+(g) + O2–(g)

C. MgO(s)  Mg2+(g) + O2(g)

D. MgO(s)  Mg2+(g) + O2(g)

**14.** The *H*Ө and *S*Ө values for a reaction are both negative. What will happen to the spontaneity of this reaction as the temperature is increased?

A. The reaction will become more spontaneous as the temperature is increased.

B. The reaction will become less spontaneous as the temperature is increased.

C. The reaction will remain spontaneous at all temperatures.

D. The reaction will remain non-spontaneous at any temperature.

**15.** Which reaction has the most negative ∆*H*~~ο~~ value?

A. LiF(s) → Li+(g) + F–(g)

B. Li+(g) + F–(g) → LiF(s)

C. NaCl(s) → Na+(g) + Cl–(g)

D. Na+(g) + Cl–(g) → NaCl(s)

**16.** Which equation represents the electron affinity of calcium?

A. Ca(g) →Ca+(g) + e–

B. Ca(g) →Ca–(g) + e–

C. Ca(g) + e– → Ca–(g)

D. Ca+(g) + e– → Ca(g)

**17.** Which reaction causes a decrease in the entropy of the system?

A. CaCO3(s) → CaO(s) + CO2(g)

B. 2H2(g) + O2(g) → 2H2O(l)

C. 2C(s) + O2(g) → 2CO(g)

D. 2SO3(g) → 2SO2(g) + O2(g)

**18.** What are the signs of ∆*H*~~ο~~ and ∆*S*~~ο~~ for a reaction that is non-spontaneous at low temperature but spontaneous at high temperature?

|  |  |  |
| --- | --- | --- |
|  | ***H*~~ο~~** | ***S*~~ο~~** |
| A. | – | – |
| B. | + | – |
| C. | – | + |
| D. | + | + |

**19.** The equation for the decomposition of calcium carbonate is given below.

CaCO3(s) → CaO(s) + CO2(g)

At 500 K, ∆*H* for this reaction is +177 kJ mol–1 and ∆*S* is 161 J K–1 mol–1.

(a) Explain why ∆*H* for the reaction above cannot be described as ∆*H*f~~ο~~.

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(2)

(b) State the meaning of the term ∆*S*.

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(1)

(c) Calculate the value of ∆*G* at 500 K and determine, giving a reason, whether or not the reaction will be spontaneous.

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(3)

(Total 6 marks)

**20.** The standard enthalpy change for the combustion of phenol, C6H5OH(s), is –3050 kJ mol–1 at 298 K.

(a) Write an equation for the complete combustion of phenol.

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(1)

(b) The standard enthalpy changes of formation of carbon dioxide, CO2(g), and of water, H2O(l), are –394 kJ mol–1 and –286 kJ mol–1 respectively.

Calculate the standard enthalpy change of formation of phenol, C6H5OH(s).

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(3)

(c) The standard entropy change of formation, ∆*S*~~ο~~, of phenol, C6H5OH(s) at   
298 K is –385 J K–1 mol –1. Calculate the standard free energy change of formation,   
∆*G*~~ο~~, of phenol at 298 K.

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(3)

(d)Determine whether the reaction is spontaneous at 298 K, and give a reason.

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(2)

(e) Predict the effect, if any, of an increase in temperature on the spontaneity of this reaction.

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(2)

(Total 11 marks)

**21.** Explain in terms of *G*~~ο~~, why a reaction for which both*H*~~ο~~ and *S*~~ο~~ are positive is sometimes spontaneous and sometimes not.

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(Total 4 marks)

**22.** Consider the following reaction.

N2(g) + 3H2(g) → 2NH3(g)

(i) Using the average bond enthalpy values in Table 10 of the Data Booklet, calculate the standard enthalpy change for this reaction.

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(4)

(ii) The absolute entropy values, *S*, at 300 K for N2(g), H3(g) and NH2(g) are 193, 131 and 192 JK–1 mol–1 respectively. Calculate *S*~~ο~~ for the reaction and explain the sign of *S*~~ο~~.

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(3)

(iii) Calculate *G*~~ο~~ for the reaction at 300 K.

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(1)

(iv) If the ammonia was produced as a **liquid** and not as a gas, state and explain the effect this would have on the value of *H*~~ο~~ for the reaction.

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(2)

(Total 10 marks)

**23.** Define the term *standard enthalpy of formation*, and write the equation for the standard enthalpy of formation of ethanol.

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(Total 5 marks)

**24.** Throughout this question, use relevant information from the Data Booklet.

(a) Define the term *standard enthalpy change of formation,* and illustrate your answer with an equation, including state symbols, for the formation of nitric acid.

(4)

(b) Propyne undergoes complete combustion as follows:

C3H4(g) + 4O2(g)  3CO2(g) + 2H2O(l)

Calculate the enthalpy change of this reaction, given the following additional values:

*H*fӨ of CO2(g) = –394 kJ mol–1

*H*fӨ of H2O(l) = –286 kJ mol–1

(4)

(c) Predict and explain whether the value of *S*Ө for the reaction in part (b) would be negative, close to zero, or positive.

(3)

(Total 11 marks)

`­**25.** (a) Propyne reacts with hydrogen as follows:

C3H4(g) + 2H2(g)  C3H8(g) *H*Ө = –287 kJ

Calculate the standard entropy change of this reaction, given the following additional information:

*S*Ө of H2(g) = 131 J K–1 mol–1

(3)

(b) Calculate the standard free energy change at 298 K, *G*Ө, for the reaction in part (a). Use your answer and relevant information from part (d). If you did not obtain an answer to part (a), use *S*Ө = –360 J K–1 (this is not the correct value).

(3)

(Total 6 marks)

**26.** (a) The lattice enthalpy of an ionic compound can be calculated using a Born-Haber cycle. Using lithium fluoride as the example, construct a Born-Haber cycle, labelling the cycle with the formulas and state symbols of the species present at each stage.

(6)

(b) Two values of the lattice enthalpies for each of the silver halides are quoted in the Data Booklet. Discuss the bonding in silver fluoride and in silver iodide, with reference to these values.

(2)

(Total 8 marks)

**27.** Hex-1-ene gas, C6H12, burns in oxygen to produce carbon dioxide and water vapour.

(a) Write an equation to represent this reaction.

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(1)

(b) Use the data below to calculate the values of *H*cӨ and *S*cӨ for the combustion of hex-1-ene.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Substance** | O2(g) | C6H12(g) | CO2(g) | H2O(g) |
| **Standard enthalpy of formation, *H*fӨ / kJ1 mol** | 0.0 | –43 | –394 | –242 |
| **Entropy, S**Ө **/ J K1 mol1** | 205 | 385 | 214 | 189 |

(i) Value of *H*cӨ

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(2)

(ii) Value of *S*cӨ

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(2)

(c) Calculate the standard free energy change for the combustion of hex-1-ene.

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(2)

(d) State and explain whether or not the combustion of hex-1-ene is spontaneous at 25C.

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(1)

(Total 8 marks)

**28.** Calculate the enthalpy change, *H*4 for the reaction

C + 2H2 + O2  CH3OH *H*4

using Hess’s Law, and the following information.

CH3OH + O2  CO2 + 2H2O *H*1 = 676 kJ mol1

C + O2  CO2 *H*2 = 394 kJ mol1

H2 + O2  H2O *H*3 = 242 kJ mol1

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(Total 4 marks)

**29.** Methylamine can be manufactured by the following reaction.

CH3OH(g) + NH3(g)  CH3NH2(g) + H2O(g)

(a) Define the term *standard enthalpy change of formation*.

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(2)

(b) The values of standard enthalpy changes of formation for some compounds are shown in the table.

|  |  |
| --- | --- |
| Compound | *H*fӨ / kJ mol–1 |
| NH3(g) | – 46 |
| H2O(g) | – 242 |

Predict, with a reason, whether the value of *H*fӨ for H2O(l) is less than, greater than, or equal to, the value of *H*fӨ for H2O(g).

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(2)

(c) Use information from the table in (b) and from Table 11 of the Data Booklet to calculate the enthalpy change for the reaction used to manufacture methylamine.

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(3)

(Total 7 marks)

**30.** (a) Define the term *standard enthalpy change of formation*, *H*fӨ.

(2)

(b) (i) Use the information in the following table to calculate the enthalpy change for the complete combustion of but-1-ene according to the following equation.

C4H8(g) + 6O2(g)  4CO2(g) + 4H2O(g)

|  |  |  |  |
| --- | --- | --- | --- |
| Compound | C4H8(g) | CO2(g) | H2O(g) |
| *H*fӨ / kJ mol–1 | + 1 | – 394 | – 242 |

(3)

(ii) Deduce, giving a reason, whether the reactants or the products are more stable.

(2)

(iii) Predict, giving a reason, how the enthalpy change for the complete combustion of but-2-ene would compare with that of but-1-ene based on average bond enthalpies.

(1)

(Total 8 marks)

**31.** (i) Define the term *standard enthalpy change of formation,* *H*fӨ.

(2)

(ii) Construct a simple enthalpy cycle and calculate the value of *H*fӨ (C2H5OH(l)) given the following data.

|  |  |  |
| --- | --- | --- |
| **Compound** | ***H***fӨ **/ kJ mol–1** | **ΔH**Өcomb**/ kJ mol–1** |
| H2O(l) | –286 |  |
| CO2(g) | –394 |  |
| C2H5OH(l) |  | –1371 |

(5)

(Total 7 marks)

**32.** Consider the following reaction:

N2(g) + 3H2(g)  2NH3(g)

(i) Suggest why this reaction is important for humanity.

(1)

(ii) Using the average bond enthalpy values in Table 10 of the Data Booklet, calculate the standard enthalpy change for this reaction.

(4)

(iii) The absolute entropy values, *S*, at 298 K for N2(g), H2(g) and NH3(g) are 192, 131 and 193 J K–1 mol–1 respectively. Calculate ∆*S*~~ο~~ for the reaction and explain the sign of ∆*S*~~ο~~.

(2)

(iv) Calculate ∆*G*~~ο~~ for the reaction at 238 K. State and explain whether the reaction is spontaneous.

(3)

(v) If ammonia was produced as a liquid and not as a gas, state and explain the effect this would have on the value of ∆*H*~~ο~~ for the reaction.

(2)

(Total 12 marks)

**33.** (i) Define the terms *lattice enthalpy* and *electron affinity*.

(2)

(ii) Use the data in the following table and from the data booklet to construct the Born-Haber cycle for sodium chloride, NaCl, and determine the lattice enthalpy of NaCl(s).

Na(s) + Cl2(g) → NaCl(g) ∆*H*~~ο~~= –411 kJ mol–1

Na(s) → Na(g) ∆*H*~~ο~~= +108 kJ mol–1

(4)

(iii) Describe the structure of sodium chloride.

(2)

(Total 8 marks)

**IB Chemistry HL**

**Topic5 Answers**

**1.** B

**2.** B

**3.** B

**4.** A

**5.** A

**6.** C

**7.** D

**8.** A

**9.** B

**10.** D

**11.** C

**12.** C

**13.** D

**14.** B

**15.** B

**16.** C

**17.** B

**18.** D

**19.** (a) (cannot be ~~ο~~ as) conditions are not standard/at 500 K/*OWTTE*;   
(cannot be f as) not formation from elements/is decomposition/*OWTTE*; 2

(b) change in entropy/degree of (dis)order (of system); 1

(c) ∆*G* = 177000 – (500×161) = +96500;  
reaction is not spontaneous;  
∆*G* is positive; 3

Allow ECF from calculation for last two marks.

[6]

**20.** (a) C6H5OH + 7O2 → 6CO2 + 3H2O; 1

Ignore state symbols.

(b) ∆*Hr*~~ο~~ =Σ∆*Hf*~~ο~~products – Σ∆*Hf*~~ο~~ reactants;  
–3050 = (6(–394) +3 (–286) – (∆*Hf*~~ο~~ phenol + O));

∆*Hf*~~ο~~ phenol =–172 kJ mol–1; 3

Award **[3]** for correct final answer.

Apply –1 (U) if appropriate.

Award **[2 max]** for ∆Hf~~ο~~ phenol = +172 kJ mol –1.

(c) appropriate conversion of units;  
∆*G* = –172 – 298(– 0.385)   
 = –57.3 kJ mol–1/–57 300 J mol–1; 3

Award **[3]** for correct final answer.   
Accept answers in range –57.0 to –57.3 kJ mol–1.  
Accept 3 sig. fig. only.

Allow ECF from (b).  
Apply –1 (U) if appropriate.

(d) spontaneous;   
since ∆*G* is negative;

Allow ECF from (c). 2

(e) reaction becomes less spontaneous;   
∆G becomes less negative/more positive;

Accept a suitable calculation.   
Allow ECF from (c). 2

[11]

**21.** a reaction is spontaneous when ∆*G*~~ο~~ is negative;  
at high T, ∆*G*~~ο~~ is negative;  
–T∆S ~~ο~~ is larger/greater than ∆*H*~~ο~~;  
at low T, ∆*G*~~ο~~ is positive because –T∆*S*~~ο~~ is smaller than ∆H~~ο~~/*OWTTE*; 4

[4]

**22.** (i) ∆*H* = (sum of energies of bonds broken) – (sum of energies of bonds formed);

Can be implied by working.

Correct substitution of values and numbers of bonds broken;   
Correct substitution of values and numbers of bonds made;

(∆*H* = (N≡≡N) + 3(H—H) – 6(N—H) = 944 + 3(436) – 6(388) =) –76 (kJ);  
 4

Allow ECF.  
Do not penalize for SF or units.

(ii) ∆*S*~~ο~~ = (sum of entropies of products) – (sum of entropies of reactants); 3  
*Can be implied by working*.

(= 2×192 – (193 + 3×131) =) –202(J K–1 mol–1);  
four molecules make two molecules/fewer molecules of gas;

(iii) (∆*G*~~ο~~=∆*H*~~ο~~ – T∆*S*~~ο~~= –76.0 – 300(–0.202)) = – 15.4 (kJ mol –1); 1  
*Do not penalize for SF*.

(iv) ∆*H*~~ο~~ becomes more negative; 2  
heat released when gas → liquid;

[10]

**23.** enthalpy change associated with the formation of one mole of a   
compound/substance; from its elements;   
in their standard states/under standard conditions;

2C(s) + 3H2(g) + O2(g) → C2H5OH(l); 5

Award **[1]** for formulas and coefficients, **[1]** for state symbols.

[5]

**24.** (a) the enthalpy/energy/heat change for the formation of one mole of a  
compound/substance from its elements;

in their standard states/under standard conditions/at 298 K and 1 atm;

 4

Award **[1]** for correctly balanced equation, **[1]** for all state symbols correct.

Do not award equation mark if 2HNO3 formed.

(b) *H*r = ∑*H*fӨ (products)  ∑*H*fӨ (reactants)/suitable cycle;

= 3(  394) + 2(  286)  185;

Award **[1]** for correct coefficients of CO2 and H2O values, **[1]** for correct value for C3H4 from Data Booklet.

= 1939 or 1940 kJ; 4

Ignore units.

Award **[4]** for correct final answer.

Award **[3]** for +1939 or  1569.

(c) negative;

decrease in disorder/increase in order;

5 mol of gas  3 mol of gas/reduction in number of gas moles; 3

Award **[1]** for answer of close to zero based on use of H2O(g).

[11]

**25.** (a) *S* = *S*Ө (products)  *S*Ө (reactants)/suitable cycle;

= 270  248  2131;

=  240 (J K1); 3

Units not needed for mark, but penalize incorrect units.

Award **[3]** for correct final answer.

(b) Δ*G*Ө =  287  (2980.240);

Award **[1]** for correct substitution of values and **[1]** for conversion of units.

= 215 kJ; 3

Units needed for mark.

Apply ECF from  360 kJ or incorrect answer from (a).

[6]

**26.** (a) 6



Award **[6]** for completely correct cycle, with endothermic processes in any order.

Deduct **[1]** for each line in which species symbol and/or state symbol is incorrect or missing.

Penalize missing electrons once only.

(b) bonding in AgF more ionic than in AgI/bonding in AgI more covalent than  
in AgF;

Accept AgF is ionic and AgI is covalent.

values closer/in better agreement in AgF/big(ger) difference in values for  
AgI/*OWTTE*; 2

[8]

**27.** (a) C6H12 + 9O2  6CO2 + 6H2O; 1

(b) (i) (*HӨ* = *∑H*f*Ө*products  *∑H*f*Ө*reactants)

*HӨ* = (6×394 + 6×242)  (43);

*HӨ*c = 3773/3.8×103 (kJ mol1); 2

Accept 2, 3 or 4 sig. fig..

Award **[1]** for + 3773/+ 3.8 ×103 (kJ mol1).

Allow ECF from (a) only if coefficients used.

(ii) *SӨ* = (Sp*Ө*  Sr*Ө*) = (6×189 + 6×214)  (385 + 9×205);

**S*Ө* =188 (J K1 mol1 ); 2

Accept only 3 sig. fig..

Award **[1]** for –188.

Allow ECF from (a) only if coefficients used.

(c) (**GӨc = **HӨc  T**SӨc) = 3800  (298×0.188);

=  3900 kJ mol1. 2

Accept  3800 to  3900.

Accept 2, 3 or 4 sig. fig.

Allow ECF from (b).

Units needed for second mark.

(d) spontaneous and *G*Ө negative; 1

Allow ECF from (c).

[8]

**28.**  1×*H*1/676;

1×*H*2/ 394;

2×*H*3/ 484;

H4 = 202 (kJ mol1); 4

Accept alternative methods.

Correct answers score **[4]**.

Award **[3]** for (+)202 or (+)40 (kJ/kJ mol1).

[4]

**29.** (a) enthalpy/energy change for the formation of 1 mol of a compound from  
its elements;

Do not accept **heat** needed to form 1 mol…

in their standard states/under standard conditions/at 298 K and 1 atm; 2

(b) greater value/more negative value;

energy given out when steam condenses/turns to water; 2

(c) *HӨ* = ∑*H*fӨ (products)  ∑*H*fӨ (reactants)/suitable cycle;

= (28242)(20146);

= 23 kJ/kJ mol1; 3

Units needed for 3rd mark.

Correct final answer scores **[3]**.

23 or +23 kJ/kJ mol1 scores **[2]**.

If 239 used instead of 201 for CH3OH, award **[2]** for +15 kJ.

[7]

**30.** (a) the enthalpy change when one mole of compound is formed from its elements  
in their (standard state);

at (standard conditions of) 298 K/25C and 101 325 Pa/1 atm; 2

(b) (i) *H*P = (4×242 + 4×394) kJ mol1;

*HR* = 1 kJ mol1;

*HӨ* = (∑*HӨ* p∑*HӨ*R) = 2545 /2.55×103/ 2550 (kJ mol1); 3

Allow ECF.

(ii) products more stable than reactants;

bonds are stronger in products than reactants/*Hp* < *HR*/enthalpy/stored  
energy of products less than reactants; 2

(iii) same/equal, because the same bonds are being broken and formed; 1

[8]

**31.** (i) change in energy for the formation of (1 mol) of a substance from its  
elements; under standard conditions/1 atm pressure or 101 kPa and  
298 K/25C; 2

(ii)



*States not required.*

*Correct cycle showing:*

*HcombӨ*

*H*f*Ө* (C2H5OH(l));

2*H*f*Ө* (CO2(g)) and 3*H*f*Ө* (H2O(l));

(*H*f*Ө* (C2H5OH(l)) = (2*H*f*Ө* (CO2(g)) + 3*H*f*Ө* (H2O(l))  *HcombӨ*

= 2(394) + 3(286) + 1371;

= 275 kJ mol1; 5

If values are substituted for symbols in the enthalpy cycle diagram to give correct answer, award last **[2]** marks.

If no enthalpy cycle drawn but equation written and Hess’s  
Law applied or calculated as follows, then **[3 max]**

(*H*r = ∑*H*f (products)  ∑*H*f (reactants))

1371 = (394×2) + (286×3) *H*f (ethanol);

*H*f (ethanol) = 788  858 + 1371;

=  275(kJ mol1);

Award **[2]** for correct answer without enthalpy cycle and without working and **[1]** for 275 or + 275.

[7]

**32.** (i) fertilizers/increasing crop yields;  
production of explosives for mining; 1 max

(ii) *H* = (sum of energies of bonds broken) – (sum of energies of bonds formed);

Can be implied by working.

correct substitution of values and numbers of bonds broken;  
correct substitution of values and numbers of bonds made;  
(*H* = (NN) + 3(H–H) – 6(N–H) = 944 + 3(436) – 6(388) =) –76.0 (kJ); 4

Allow ECF.  
Do not penalize for sig. fig. or units.  
Award **[4]** for correct final answer.

(iii) (*S*~~ο~~[2×193] – [192 + 3×131]) = –199 (J K–1 mol–1); 2

Allow ECF.  
four gaseous molecules generating two gaseous molecules/fewer molecules of gas;

(iv) (*G*~~ο~~ = *H*~~ο~~ – *T**S*~~ο~~ = –76.0 – 298(–0.199)) = –16.7 (kJ);  
Spontaneous;  
*G* is negative; 3

Do not penalize for SF.

(v) heat released when gas → liquid;  
*H*~~ο~~ becomes more negative; 2

[12]

**33.** (i) lattice enthalpy for a particular ionic compound is defined as Δ*H* for the  
process, MX(s) → M+(g) + X–(g);

Accept definition for exothermic process

electron affinity is the energy change that occurs when an electron is added  
to a gaseous atom or ion; 2

(ii)  
  
lattice enthalpy = –[(–411) – (+108) – (+494) – (+121) – (–364)]  
= 770 (kJ mol–1)

Award **[2]** for all correct formulas in correct positions on cycle diagram.  
1 incorrect or missing label award **[1]**.  
Award **[1]** for all correct values in correct positions on cycle diagram.

calculation of lattice enthalpy of NaCl(s) = 770 (kJ mol–1); 4

Allow ECF.  
Accept alternative method e.g. energy level diagram.

(iii) lattice/network/regular structure;  
each chloride ion is surrounded by six sodium ions and each sodium ion is  
surrounded by six chloride ions/6:6 coordination; 2

[8]