ChemFactsheet

January 2002 Number 29

Answering Questions On Born-Haber Cycles

To succeed in this topic you need to thoroughly understand how to write Born-Haber cycles (covered in Factsheet No. 28)

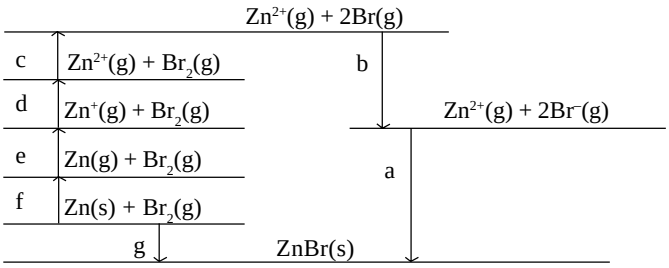
After working through this Factsheet you will know and understand:

- **how to convert Born-Haber cycles into numerical answers given the relevant data;**
- **how the data given is used to test the understanding of definitions by candidates;**
- **the relationship between the marks for a question and the balance between writing the cycle and calculating an answer;**
- **the use of enthalpy level diagrams to test the understanding of candidates of definitions and Born-Haber cycles.**

Questions on Enthalpy Level Diagrams

There are two types of questions on these diagrams:
1. Identifying enthalpy changes
2. Calculating a numerical answer from given values on a diagram

1. Identifying enthalpy changes



Example 1
Question: Identify the stages a – g

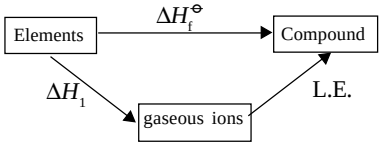
Method
For each arrow look to see **what has changed**. It is then a matter of deciding **which definition** it matches and **how many moles**.

Answer:

a	=	gaseous ions to ionic solid	= L.E.
b	=	$2Br(g) \rightarrow 2Br^-(g)$	= 2×1^{st} E.A.
c	=	$Br_2(g) \rightarrow 2Br(g)$	= $2 \times \triangle H^{\ominus}_{at}[\frac{1}{2}Br_2]$
d	=	$Zn^+(g) \rightarrow Zn^{2+}(g)$	= 2^{nd} I.E.
e	=	$Zn(g) \rightarrow Zn^+(g)$	= 1^{st} I.E.
f	=	$Zn(s) \rightarrow Zn(g)$	= $\triangle H^{\ominus}_{at}[Zn(s)]$
g	=	elements $\rightarrow$ compound	= $\triangle H^{\ominus}_{f}[ZnBr_2(s)]$

Example 2
Question: How are a – g linked by Hess's Law?

Method: Identify on the diagram: elements, compound and gaseous ions

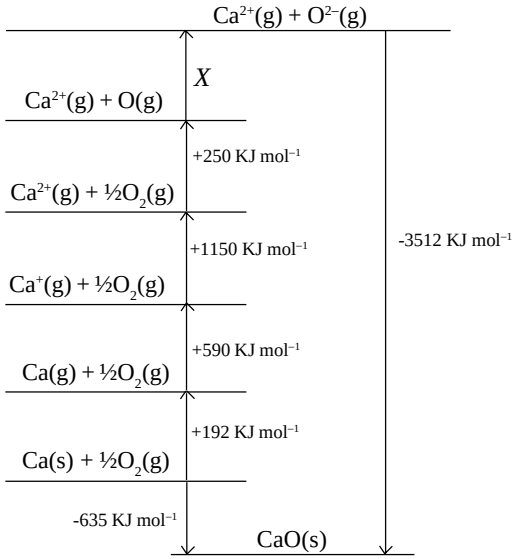


So: $\triangle H_1$ + L.E. = $\triangle H^{\ominus}_{f}$

Answer: f + e + d + c + b + a = g

Or alternatively, "follow the diagram round" - starting and finishing with the elements. If you go in the **same** direction as an arrow, you **add** the corresponding value; if in the **opposite** direction, **subtract** the value. Finally, equate to zero: f + e + d + c + a – g = 0

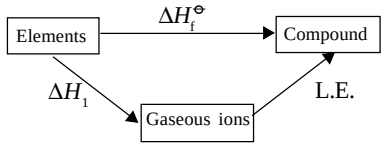
2. Calculating a numerical answer given all the other values and the diagram



Question What is the value of *X*?

Method: Either convert to an enthalpy cycle:

Identify each of: elements, compound and gaseous ions, then draw the diagram:



$\triangle H_1$ + L.E. = $\triangle H^{\ominus}_{f}$

Identify the components in the diagram and put in the values.

Answer -635 = + 192 + 590 + 1150 + 250 + X - 3512
-635 = X – 1330
X = + 1330 – 635 = +695 kJ mol^{-1}

Or follow the diagram round, starting and finishing with the elements:
192 + 590 + 1150 + 250 + X + (-3512) – (-635) = 0

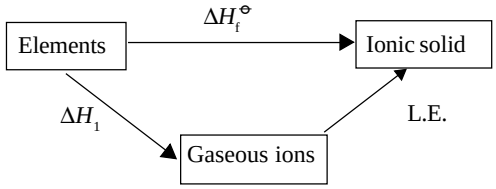
***Note**: The direction of the arrow tells us whether to add or subtract. We are going in the direction of the arrow for the -3512, so we add (-3512).*

X – 695 = 0 so X = +695 kJmol^{-1}

For practice on this type of calculation, go to question 1.

Further calculations using Borh-Haber Cycles

All of these use the enthalpy cycle below (or the enthalpy level diagrams - whichever you prefer). You may be required to find enthalpies of formation, electron affinities etc, but the approach in each case is identical.



$\triangle H_1$ + L.E. = $\triangle H_f^\ominus$

Method

1. Draw the Born-Haber Cycle – including all parts of $\triangle H_1$, which will include enthalpies of atomisation and appropriate ionisation energies and electron affinites
2. Substitute the values given
3. Calculate the 'missing' value and so the answer

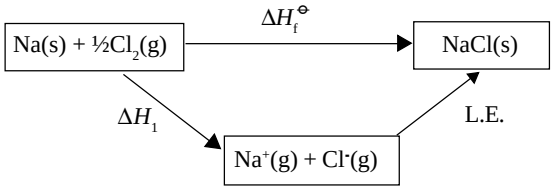
Exam Hint: - *Candidates should be aware that* ***all*** *the definitions for I.E, E.A, $\Delta H_{at,}^\ominus$ $\Delta H_{f,}^\ominus$ and L.E. are based on* ***1 mole****. Watch out for the following 'data traps' that are used to test whether you know the definitions are for 1 mole*

a) $Cl_2(g) \rightarrow 2Cl^-(g)$ ΔH = + 244 kJmol^{-2}
i.e. you have been given 2 x ΔH_{at} [½Cl_2]. The question means you have to use +244/2 if the cycle uses ½$Cl_2 \rightarrow Cl(g)$

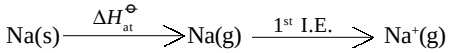
b) $Mg(g) \rightarrow Mg^{2+}(g)$ ΔH = + 2289 kJmol^{-1}
i.e. you have been given the ***total*** *of the 1st I.E. + 2nd I.E. for Mg*

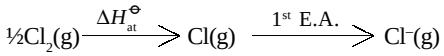
c) Suppose you are asked to find the E.A. of Cl from a cycle involving $MgCl_2(s)$.
When you put in all the values you find the answer for $2Cl(g) \rightarrow 2Cl^-(g)$. The answer needs ÷ 2 because E.A. is for 1 mole! This is a common way of catching out candidates.

Look out for these 'data traps' as you attempt Question 3. onwards – they are marked in the answers in order to help you out.



$\triangle H_1$





$\triangle H_f^\ominus$ = $\triangle H_1$ + L.E.

Question: What is the L.E. for NaCl(s)?

$\triangle H_f^\ominus$ [NaCl(s)]= -411 kJmol^{-1} $\triangle H_{at}^\ominus$[Na(s)]= + 109 kJmol^{-1}

$\triangle H_{at}^\ominus$[½Cl_2(g)] = +121 kJmol^{-1} 1st E.A.Cl = -364 kJmol^{-1}

1st I.E. Na = +494 kJmol^{-1}

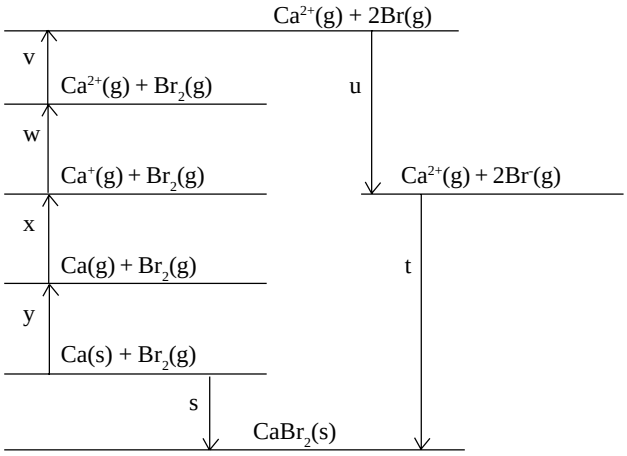
-411 = +109 +121 - 364 + 494 + L.E.

L.E. = -771 kJmol^{-1}

For more practice on Born-Haber cycles try questions 2 – 6

Questions

1. a) Identify s, t, u, v, w, x and y in the following cycle:

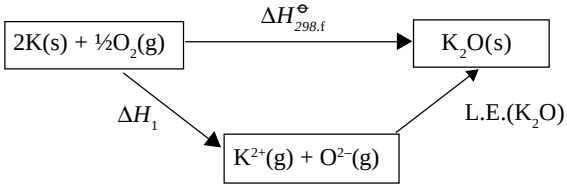


b) What is the relationship between s – x?

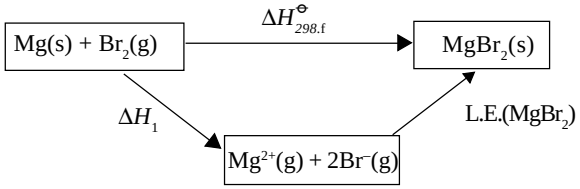
You will need the following data to answer questions 2 to 7 (all values in kJ mol^{-1}):

$Cl_2(g) \rightarrow 2Cl(g)$ = -242	$Cl(g) \rightarrow Cl^-(g)$ = -364
½$O_2(g) \rightarrow O(g)$ = +249	$O(g) \rightarrow O^-(g)$ = -141
$O^-(g) \rightarrow O^{2-}(g)$ = +798	$K(s) \rightarrow K(g)$ = +90
$K(g) \rightarrow K^+(g)$ = +418	$Mg(s) \rightarrow Mg(g)$ = +148
$Mg(g) \rightarrow Mg^+(g)$ = +738	$Mg^+(g) \rightarrow Mg^{2+}(g)$ = +1451
½$Br_2(g) \rightarrow Br(g)$ = +112	$Br(g) \rightarrow Br^-(g)$ = -325
$Zn(s) \rightarrow Zn(g)$ = +131	$Zn(g) \rightarrow Zn^{2+}(g)$ = +2639
$I_2(g) \rightarrow 2I(g)$ = +214	$I(g) \rightarrow I^-(g)$ = -314
$Sr(s) \rightarrow Sr(g)$ = +164	$Sr(g) \rightarrow Sr^+(g)$ = +550
$Sr^+(g) \rightarrow Sr^{2+}(g)$ = +1064	$Ca(s) \rightarrow Ca(g)$ = +178
$Ca(g) \rightarrow Ca^{2+}$ = +1735	$\triangle H_f^\ominus$ [$K_2O(s)$] = -361
$\triangle H_f^\ominus$ [$MgBr_2(s)$] = -524	L.E. (ZnI_2) (s) = -2605
L.E. (SrO) = -3223	$\triangle H_f^\ominus$[$CaCl_2$] = -796

2. Using the cycle for K_2O below calculate the L.E.



3. Using the cycle for $MgBr_2$ below calculate the L.E.



4. Write the Born-Haber cycle for ZnI_2 and use it to find $\triangle H_f$ [ZnI_2]

5. Write the Born-Haber cycle for SrO and use it to find the $\triangle H_f$ [SrO]

6. What value for the E.A. of chlorine does the Born-Haber cycle for $CaCl_2$ produce?

Answers

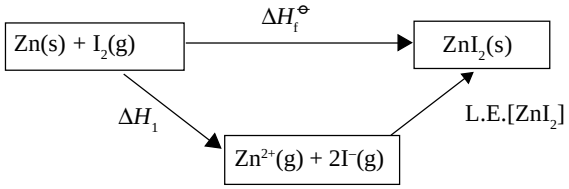
1. a) s = $\triangle H_f^{\ominus}[CaBr_2]$ t = L.E. ($CaBr_2$)
u = 2 × E.A. (Br) v = 2 × $\triangle H_{at}^{\ominus}[\frac{1}{2}Br_2]$
w = 2nd I.E. (Ca^+) x = 1st I.E. (Ca)
y = $\triangle H_{at}^{\ominus}$[Ca]

b) s = y + x + w + v + u + t

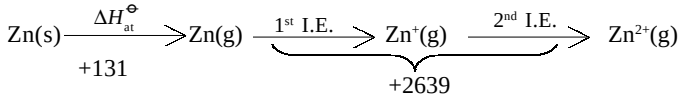
2. L.E. = - 1485 kJmol^{-1}

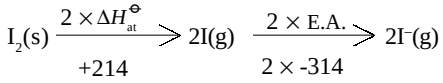
3. L.E. = - 2435 kJmol^{-1}

4.



$\triangle H_1$



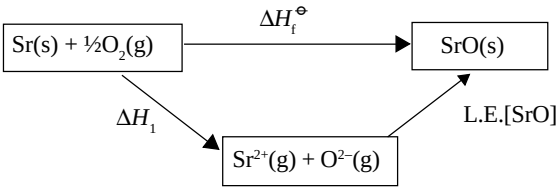


N.B. Notice data changes for I_2 and Zn/Zn^{2+}

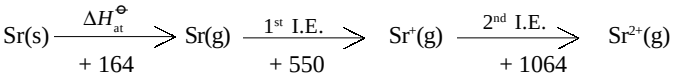
$\triangle H_1$ = + 2356

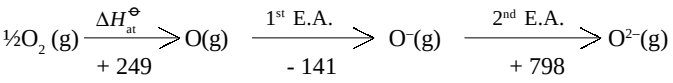
$\triangle H_f^{\ominus}$ = + 2356 = 2605
= - 249 kJmol^{-1}

5.



$\triangle H_1$

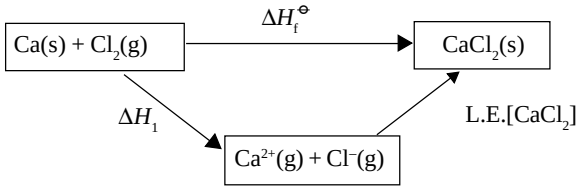




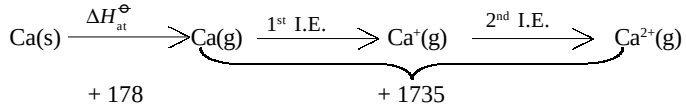
$\triangle H_1$ = + 2684

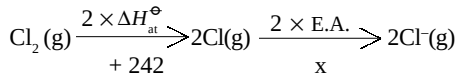
$\triangle H_f^{\ominus}$ = + 2356 - 3223 = -539 kJmol^{-1}

6.



$\triangle H_1$





N.B. Ca → Ca^{2+} is **total value**, and Cl_2 → is given for 2 × $\triangle H_{at}^{\ominus}$ already.

$\triangle H_1$ = + 1671 + x

- 796 = + 1671 + x - 2258

$\therefore$ x = - 796 – 1671 + 2258 = -209

but this is 2 × E.A, so –209/2 = - 104.5 kJmol^{-1}

Acknowledgements: *This Factsheet was researched and written by Kieron Heath.* ***Curriculum Press, Unit 305B, The Big Peg, 120 Vyse Street, Birmingham, B18 6NF. ChemistryFactsheets*** *may be copied free of charge by teaching staff or students, provided that their school is a registered subscriber. No part of these Factsheets may be reproduced, stored in a retrieval system, or transmitted, in any other form or by any other means, without the prior permission of the publisher.* ***ISSN 1351-5136***