SL HL Paper 3 Section A Data Response (8) with worked answers

Coal is an abundant fossil fuel. The different grades of coal can be classified according to the percentage of carbon they contain.

Grade of coal	% by mass carbon	% by mass hydrogen	% by mass oxygen	% by mass sulfur	Heat content / kJ kg-1
Lignite	60-75	6.0-5.8	34-17	0.5-3	< 28470
Flame coal	75-82	6.0-5.8	>9.8	~ 1	< 32870
Gas flame coal	82-85	5.8-5.6	9.8-7.3	~ 1	< 33910
Gas coal	85-87.5	5.6-5.0	7.3-4.5	~ 1	< 34960
Fat coal	87.5-89.5	5.0-4.5	4.5-3.2	~ 1	< 35380
Forge coal	89.5-90.5	4.5-4.0	3.2-2.8	~ 1	< 35380
Nonbaking coal	90.5-91.5	4.0-3.75	2.8-2.5	~ 1	< 35380
Anthracite	> 91.5	< 3.75	< 2.5	~ 1	< 35300

(a) Analysis of a sample of coal shows that it contains 90.5% carbon, 4.2% hydrogen and 0.8% sulfur by mass. Identify the name of the grade of coal this sample belongs to. *[1]*

Forge coal *[1]*

(b) (i) Assuming no other elements in the sample of coal combust, use Section 13 of the data booklet to determine the theoretical heat content of 1.00 kg of this particular sample of coal. *[2]*

Correct calculation of molar amounts *[1]*; 35708 kJ kg^{-1} *[1]*

(Underlying chemistry concepts can be found in 1.2 The mole & Avogadro's constant.)

(ii) Suggest one reason why the value obtained for **(b) (i)** is higher than the value given in the table above for this particular grade of coal. *[1]*

The calculation in **(b) (i)** is theoretical as it assumes standard conditions and that complete combustion of all three elements occurs which will not be the case when coal burns normally. *[1]*

(Underlying chemistry concepts can be found in 5.1 Measuring energy changes.)

(c) The combustion of coal is one of the main causes of carbon dioxide pollution in the atmosphere.
In 2011 it is estimated that the total amount of coal combusted worldwide was 7.695×10^9 tonnes, which added 1.442×10^{10} tonnes of carbon dioxide into the atmosphere.
Assuming that coal contains on average 87% by mass of carbon and that all the carbon burned to form carbon dioxide, calculate the percentage of coal that did not release carbon dioxide into the atmosphere when it was combusted in 2011. *[2]*

44.01 g of carbon dioxide formed when 12.01 g of carbon combust completely
Mass of coal required to produce 1.442×1010 tonnes of CO_2
$= 1.442 \times 1010 \times (12.01 \div 44.01) \times (100 \div 87.0) = 4.523 \times 10^9$ tonnes. *[1]*
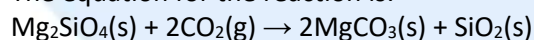Mass of coal not releasing CO_2 into the atmosphere $= 7.695 \times 109 – 4.523 \times 109 = 3.172 \times 10^9$ tonnes.
Percentage of coal not releasing CO_2 into the atmosphere $= ((3.172 \times 109) \div (7.695 \times 109)) \times 100 = 41.2\%$. *[1]*

(Underlying chemistry concepts can be found in 1.2 The mole & Avogadro's constant.)

(d) "Carbon capture" describes different methods in which carbon dioxide produced by coal combustion is prevented from entering the atmosphere. One such method is called "mineral sequestration" and involves reacting the carbon dioxide with naturally occurring metal silicates such as forsterite, Mg_2SiO_4.
The equation for the reaction is:
$Mg_2SiO_4(s) + 2CO_2(g) \rightarrow 2MgCO_3(s) + SiO_2(s)$
Explain why carbon dioxide is a gas at STP whereas silicon dioxide is a solid with a high melting point (1600 °C). *[2]*

Carbon dioxide consists of simple non-polar O=C=O molecules which have weak forces of attraction between them. *[1]*
Silicon dioxide consists of a giant covalent tetrahedral structure and it takes much energy to break down the lattice. *[1]*

(Underlying chemistry concepts can be found in 4.3 Covalent structures (1).)

(e) The products of coal combustion can also cause acid deposition.

(i) State one equation to show how the products from the combustion of coal can lead to acid rain. *[1]*

$SO_2(g) + H_2O(l) \rightarrow H_2SO_3(aq)$ or $SO_3(g) + H_2O(l) \rightarrow H_2SO_4(aq)$ *[1]*

(Underlying chemistry concepts can be found in 8.5 Acid deposition.)

(ii) Outline why rainwater needs to have a pH below 5.6 before it is classified as "acid rain". *[1]*

As rain falls through the air it dissolves carbon dioxide to form carbonic acid. Carbonic acid is a weak acid with a pH no lower than 5.65. For rain to be 'acidic rain" it must contain a greater concentration of hydrogen ions than are present in carbonic acid so the pH must be below 5.6. *[1]*

(Underlying chemistry concepts can be found in 8.5 Acid deposition.)