1. Butane

(a)

$2\ C_4H_{10}(g) + 13\ O_2(g) \rightarrow 8\ CO_2(g) + 10\ H_2O(\ell)$	1 point for balanced equation *[4.2-TRA-1.B]**

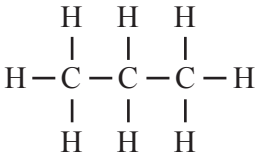
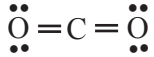
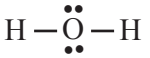
(b)

Moles of O_2: $n_{O_2} = 2.00\text{ g } C_4H_{10}\left(\frac{\text{mol}}{58.14\text{ g}}\right)\left(\frac{13\text{ mol } O_2}{2\text{ mol } C_4H_{10}}\right)$ $= 0.224\text{ mol } O_2$ Volume of O_2: $V_{O_2} = \frac{n_{O_2}RT}{P} = \frac{(0.224)(62.35)(301)}{750.} = 5.60\text{ L } O_2$ Volume of air: $V_{air} = 5.60\text{ L } O_2\left(\frac{100\text{ L air}}{20.9\text{ L } O_2}\right) = 26.8\text{ L air}$	1 point for correct moles of O_2 (may be implicit) *[4.5-SPQ-4.A]** 1 point for correct volume of O_2 (may be implicit) *[3.4-SAP-7.A]** 1 point for correct volume of air *[3.4-SAP-7.A]**

(c)

$\Delta H^\circ_{rxn} = \sum_{products} \Delta H^\circ_f - \sum_{reactants} \Delta H^\circ_f$ The enthalpy of reaction is for 2 moles of butane. $2 \times (-2877.5) = \{8 \times (-393.5) + 10 \times (-285.8)\}$ $- \{2 \times \Delta H^\circ_{f,\,C_4H_{10}} + 13 \times (0.0)\}$ $\Delta H^\circ_{f,\,C_4H_{10}} = \frac{2 \times 2877.5 + 8 \times (-393.5) + 10 \times (-285.8)}{2}$ $\Delta H^\circ_{f,\,C_4H_{10}} = -125.5\text{ kJ mol}^{-1}$	1 point for correct set-up *[6.8-ENE-3.B]** 1 point for a correct value for $\Delta H^\circ_{f,\,C_4H_{10}}$ *[6.8-ENE-3.B]**

(d)

 Butane  Oxygen  Carbon Dioxide  Water	1 point for any two correct structures *[2.5-SAP-4.A]** 1 additional point for all four correct structures *[2.5-SAP-4.A]**

(e)

$\Delta H^\circ_{rxn} \cong \sum_{broken} BEs - \sum_{formed} BEs$ $\Delta H^\circ_{rxn} \cong \{20 \times (C - H) + 6 \times (C - C) + 13 \times (0 = 0)\}$ $- \{16 \times (C = O) + 20 \times (O - H)\}$ $\Delta H^\circ_{rxn} \cong \{20 \times 413 + 6 \times 347 + 13 \times 498\}$ $- \{16 \times 799 + 20 \times 467\}$ $\Delta H^\circ_{rxn} \cong 16816 - 22124 = -5308$ kJ mol^{-1} Note: The enthalpy of combustion of 2 moles of butane with gaseous water as the product is –5314 kJ mol^{-1}.	1 point for the correct set-up *[6.7-ENE-3.A]** 1 point for the correct value for ΔH°_{rxn} *[6.7-ENE-3.A]**

2. Photoelectron spectroscopy

(a)

The peaks in the PES spectrum should be labelled from left to right: $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^4$	1 point for the correct labelling of the PES peaks *[1.6-SAP-1.B]**

(b)

$E = \frac{258.5 \times 10^6}{\text{mol}}\left(\frac{\text{mol}}{6.022 \times 10^{23}}\right)\left(\frac{\text{eV}}{1.602 \times 10^{-19}\ \text{J}}\right)$ $E = 2680.\ \text{eV}$	1 point for a correct calculation of the binding energy (BE) of one $1s^2$ electron *[1.6-SAP-1.B]**

(c)

Two ways the PES of the sulfide ion (S^{2-}) will differ from that for atomic sulfur (S) are: 1. The rightmost peak in the PES will have a higher amplitude due to the $3p^6$ configuration of S^{2-} vs. $3p^4$ for S. 2. All the peaks in the PES for S^{2-} will be shifted slightly to the right (to lower BE values) because of increased e-e repulsions in S^{2-} vs. S.	1 point for the higher amplitude of the $3p^6$ peak due to the higher electron occupancy *[1.6-SAP-1.B]** 1 point for a mention of lower binding energies due to increased e-e repulsions *[1.6-SAP-1.B]**

*The authors have combined the newly re-articulated AP Chemistry Unit, Topic, as well as the Learning Objective designations into one "UTLO code" shown below. It is important to note that the organizational structure and the designations themselves belong to the College Board, but the combined "UTLO codes" are the creation of the authors for the purpose of providing a short-hand way of identifying the learning objectives for each of our test questions.

How to identify the Unit, Topic, Big Idea, and Learning Objective from the assigned "UTLO codes":