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VCE Chemistry ¾
Thermochemistry & Energy Calculation [0.1]
Workshop

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Section A: Recap

Learning Objective: [1.1.1] – Identify ΔH & Ea in Endothermic/Exothermic Energy Profile Diagrams

Endothermic Reactions	Exothermic Reactions
[Absorb] / [Release] thermal energy.	[Absorb] / [Release] thermal energy.
Energy Conversion: _____	Energy Conversion: _____
Change in enthalpy (ΔH) sign is: [positive] / [negative]	Change in enthalpy (ΔH) sign is: [positive] / [negative]

➤ Energy profile diagram axis labels:

   ○ Vertical axis: _____

   ○ Horizontal axis: _____

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Learning Objective: [1.1.2] – Identify Differences Between Complete and Incomplete Combustion & Write Their Thermochemical Combustion Equations

Complete Combustion	Incomplete Combustion
Produces _____.	Produces _____.
[More] / [Less] oxygen used overall.	[More] / [Less] oxygen used overall.

➤ Method of balancing: _____

➤ State of fuels: _____.

➤ Thermochemical equations include _____.

➤ The state of water in thermochemical equations is _____ when using the databook.

Learning Objective: [1.1.3] – Apply Changing Equations to Thermochemical Equations & Energy Profile Diagrams

➤ When reversing the equation, the:

  ↩ ΔH: _____

  ↩ E_a: _____

➤ When multiplying the equation by some coefficient:

  ↩ ΔH value _____

  ↩ ΔH units _____

Learning Objective: [1.2.1] – Apply $q = \Delta H \times n$ to Energy Released

➤ To convert between mass and moles, _____.

➤ To find energy released by a fuel, use the Data Book, and the formula _____.

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Learning Objective: [1.2.2] – Apply ΔH in kJ/mol, kJ/g and kJ/mL to Energy Calculations

➤ The heat of combustion ΔH value can be calculated in the following ways:

ΔH (kJ/mol)	ΔH (kJ/g)	ΔH (kJ/mL)

➤ Density is used to convert between mass and volume: _____
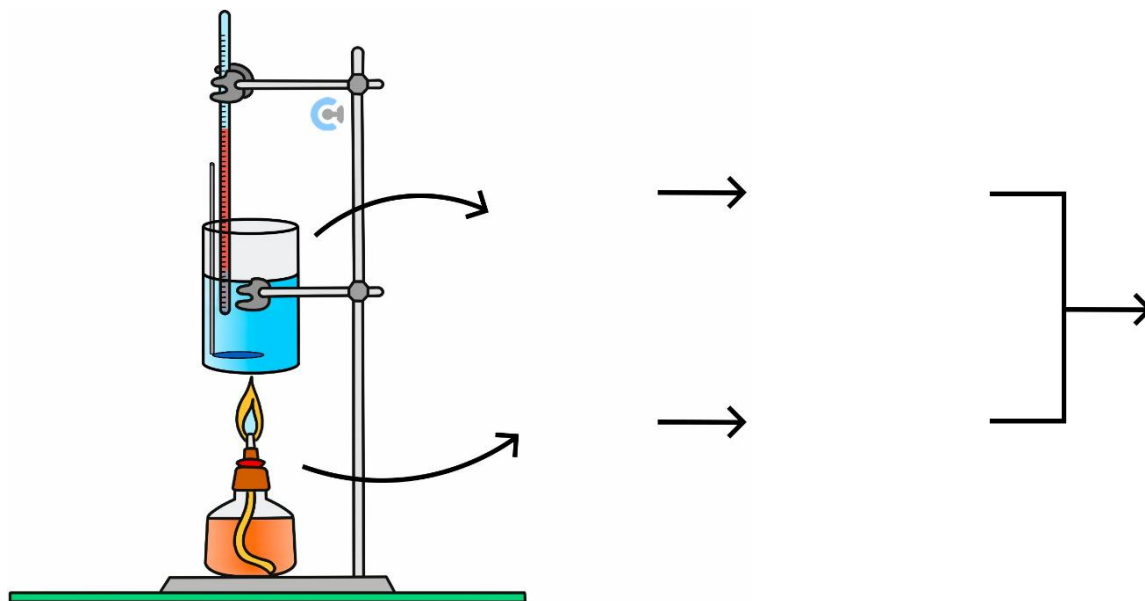
Question 1 Walkthrough.

The density of ethanol is given to be 0.790 g/mL. Calculate the energy released, in kilojoules, when 3.92 L of ethanol is combusted at SLC.

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Learning Objective: [1.2.3] – Apply $q = mc\Delta T$ to Find Energy Absorbed

➤ To measure the energy absorbed by water, it can be calculated by _____, whereby the specific heat capacity of water is _____.

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Learning Objective: [1.2.4] – Calculate ΔH Experimentally

Question 2 (4 marks) **Walkthrough.**

A sample of ethanol in a spirit burner which initially weighs 198.30 g undergoes complete combustion. After the combustion is complete, it is found that the spirit burner weighs 196.09 g. The heat energy released is used to heat 150 mL of water at SLC. The temperature of the water rises to 89.60℃.

Calculate the experimental molar heat of combustion of ethanol.

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Section B: Warm Up (13 Marks)

INSTRUCTION: 13 Marks. 8 Minutes Writing.

Question 3 (1 mark)

a. What happens to the ΔH value when the whole equation is reversed? (0.5 marks)

_____

b. What happens to the ΔH value which is currently in kJ/mol when the whole equation is doubled? (0.5 marks)

_____

Question 4 (2 marks)

Write the thermochemical equation for the combustion of octane.

_____

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Question 5 (1 mark)

Calculate the amount of energy released when 2.78 mol of ethanol is combusted, providing your answer in kJ.

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Question 6 (1 mark)

Calculate the amount of energy released when $1.62\ kg$ of diesel is combusted.

_____

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Question 7 (1 mark)

Calculate the volume of petrol, in mL, which must undergo complete combustion to release $1500\ kJ$ of energy.

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Question 8 Walkthrough.

The density of ethanol is given to be $0.790\ g/mL$. Calculate the energy released, in kilojoules, when $3.92\ L$ of ethanol is combusted at SLC.

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Question 9 (2 marks)

Calculate the amount of energy released when $5.00\ g$ of ethane is combusted at $120°C$, given that the molar heat of combustion of ethane at this temperature is $-1480\ kJ/mol$.

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The following information applies to the two questions that follow.

The diagram below represents the heat change for the reaction $A(g) + B(g) \rightarrow 2C(g)$.
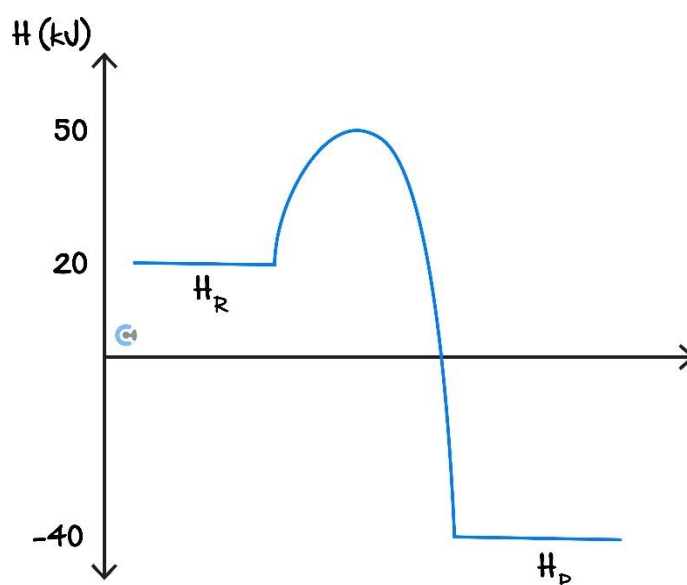
Question 10 (1 mark)

The enthalpy of reaction (ΔH) for $C(g) \rightarrow 0.5A(g) + 0.5B(g)$ is:

A. $-120\ kJ\ mol^{-1}$

B. $+60\ kJ\ mol^{-1}$
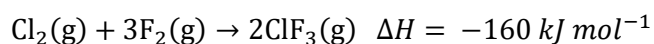
C. $-30\ kJ\ mol^{-1}$

D. $+30\ kJ\ mol^{-1}$

Question 11 (1 mark)

The activation energy for the reaction $2C(g) \rightarrow A(g) + B(g)$ is:

A. $30 \ kJ \ mol^{-1}$

B. $60 \ kJ \ mol^{-1}$

C. $90 \ kJ \ mol^{-1}$

D. $180 \ kJ \ mol^{-1}$

Question 12 (3 marks)

Chlorine trifluoride, ClF_3, is used in the electronics industry to clean electronic circuit boards during their manufacture. It is produced by reacting chlorine and fluorine gases according to the following equation:

$$Cl_2(g) + 3F_2(g) \rightarrow 2ClF_3(g) \quad \Delta H = -160 \ kJ \ mol^{-1}$$

The activation energy for the forward reaction is $50 \ kJ \ mol^{-1}$.

a. Sketch an energy profile for the reaction on the set of axes below. Clearly mark the enthalpy of the products (H_P), the change in enthalpy (ΔH) and the activation energy (E_A) of the reaction. (2 marks)
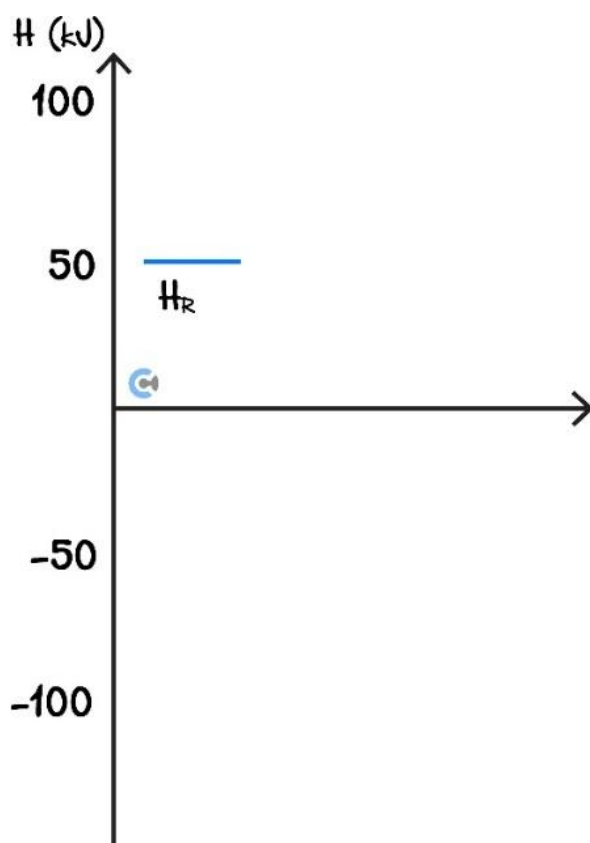
b. For the reaction $4ClF_3(g) \rightarrow 2Cl_2(g) + 6F_2(g)$, determine:

i. ΔH. (0.5 marks)

_____

ii. E_A. (0.5 marks)

_____

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Section C: Ramping Up (11 Marks)

INSTRUCTION: 11 Marks. 8 Minutes Writing.

Question 13 (3 marks)

The density of methanol is $0.791\ g/mL$. Find the volume of methanol required to release $67.3\ kJ$ of energy.

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Question 14 (4 marks)

A sample of butane in a spirit burner which initially weighs $250.40\ g$ undergoes complete combustion.
After the combustion is complete, it is found that the spirit burner weighs $248.25\ g$. The heat energy released is used to heat $200\ mL$ of water at SLC. The temperature of the water rises to $80.32°C$.

Calculate the experimental molar heat of combustion of butane.

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Question 15 (4 marks)

A sample of propane is combusted in excess oxygen at standard conditions.

a. Write a balanced thermochemical equation for this reaction. (2 marks)

_____

_____

b. Given that 5.70 *MJ* of energy is released, how much propane must have been used, in *g*? (2 marks)

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Section D: Getting Trickier I (9 Marks)

INSTRUCTION: 9 Marks. 7 Minutes Writing.

Question 16 (4 marks)

Calculate the mass of ethanol that must be combusted to increase the temperature of 210 mL of water from 10℃ to 75℃, if exactly half of the heat released by this reaction is absorbed by the water.
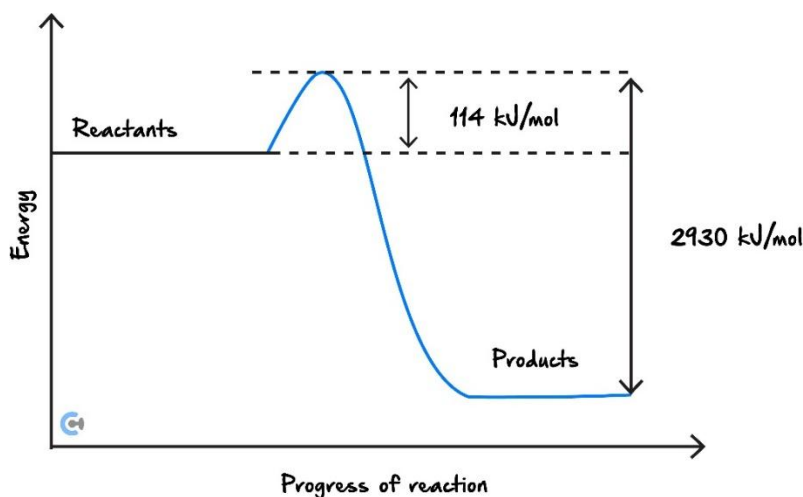
The heat of combustion of ethanol is 1367 $kJ\ mol^{-1}$ at this temperature.

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Question 17 (5 marks)

Glucose is a compound which is used in the body to store and obtain energy. Its molecular formula is $C_6H_{12}O_6$.

The following energy diagram shows the energy change associated with the combustion of glucose in $kJ\ mol^{-1}$ during cellular respiration.

a. Write a balanced thermochemical chemical equation for the combustion of glucose in an energy bar. (2 marks)

_____

_____

b. Calculate the energy released per gram of glucose. (1 mark)

_____

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c. An average cyclist uses $80\ kJ$ for every km travelled. If the glucose content of an energy bar is $34.7\ g$, how far can an average cyclist travel on only one energy bar? (2 marks)

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Section E: Getting Trickier II (8 Marks)

INSTRUCTION: 8 Marks. 8 Minutes Writing.

Question 18 (4 marks)

A spirit burner containing ethanol is used to heat an insulated beaker containing 568 g of water. The mass of ethanol that reacts is 1.80 g. A thermometer shows a temperature rise of the water from 17.4℃ to 25.6℃.

Calculate the percentage of the energy transferred from the combustion of the ethanol burner to the heating of the water.

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Question 19 (2 marks)

Find the mass of kerosene required to be completely combusted to release the same amount of energy as if 540 mL of petrol were to be completely combusted.

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Question 20 (2 marks)

Calculate the density of petrol, using Item 14 of the Data Book.

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Let's take a BREAK!

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Section F: VCAA-Level Questions I (12 Marks)

INSTRUCTION: 12 Marks. 0.5 Minutes Reading. 11 Minutes Writing.

**Question 21** (12 marks)

Inspired from VCAA Chemistry 3/4 Exam 2016
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2016/2016chem-amd-w.pdf#page=38

A senior Chemistry student bought a packet of Krispy Krackers from the local farmers' market. The label on the packet had no information on the energy content of the biscuits.

The student decided that he would measure the energy content of a Krispy Krackers biscuit by burning it under a can of water and measuring the temperature rise of the water.

Having performed a similar experiment in class, he knew that when the biscuit was burnt, heat energy would be lost to the environment. To increase the accuracy of the result, some butane gas from a butane canister was first burnt and the temperature rise of the water from that was measured. The heat energy released by burning butane was known, and the percentage energy loss using the equipment could be determined and adjusted to get the result for the biscuit.

The experimental setup and the results for Part 1 of the experiment are shown below:

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Part 1 – The heat content of butane

Part 1
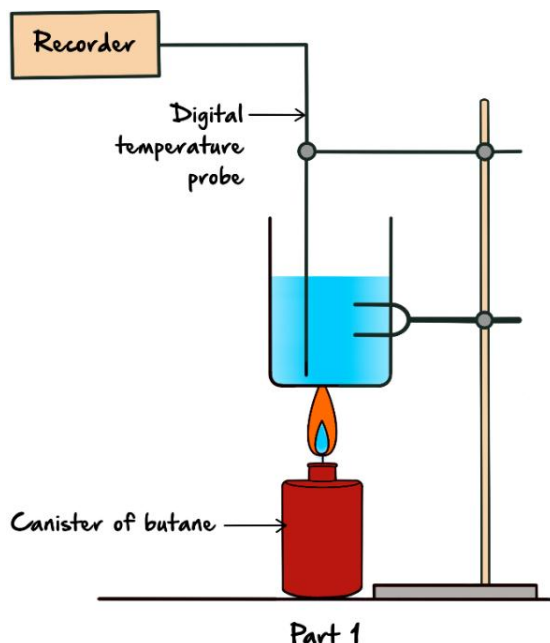
1. Measure the initial mass of a butane canister.

2. Measure the mass of a metal can, add $250\ mL$ of water and re-weigh.

3. Set up the apparatus as in the diagram and measure the initial temperature of the water.

4. Burn the butane gas for five minutes.

5. Immediately measure the final temperature of the water.

6. Measure the final mass of the butane canister when cool.

Results table for Part 1

Quantity	Measurement
Mass of empty can	52.14 g
Mass of can + water before combustion	303.37 g
Mass of butane canister before heating	260.15 g
Mass of butane canister after heating	259.79 g
Initial temperature of the water	22.1°C
Final temperature of the water	32.7°C

a.

   i. Write the balanced thermochemical equation for the complete combustion of butane. (2 marks)

_____

_____

   ii. Calculate the amount of heat energy absorbed by the water when it is heated by burning the butane. Give your answer in kilojoules. (2 marks)

_____

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   iii. Calculate the experimental value of the molar heat of combustion of butane. Give your answer in $kJ\ mol^{-1}$. (2 marks)

_____

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   iv. Use the known enthalpy change for butane to calculate the percentage energy loss to the environment using the following relationship. (1 mark)

$$percentage\ energy\ loss\ = \frac{(theoretical\ value\ of\ \Delta H - experimental\ value\ of\ \Delta H)}{theoretical\ value\ of\ \Delta H} \times \frac{100}{1}$$

_____

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The experimental setup and the results for Part 2 of the experiment are shown below:

Part 2 – The heat content of a Krispy Kracker
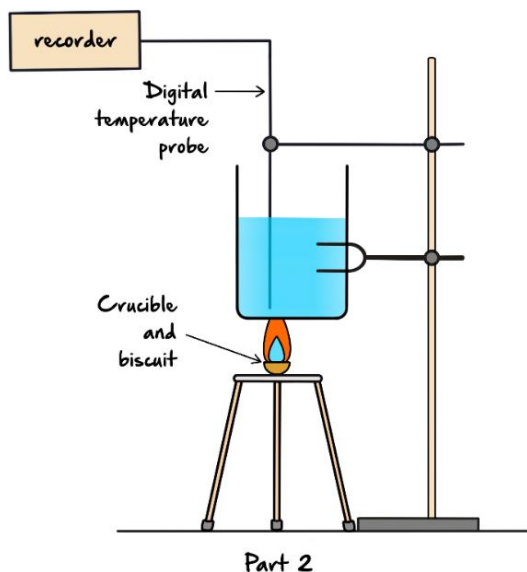
1. Measure the mass of a crucible, add a biscuit and re-weigh.

2. Set up the apparatus as in the diagram, using the same can of water as used in Part 1, and measure the initial temperature of the water.

3. Burn the biscuit until the flame runs out.

4. Immediately measure the final temperature of the water.

5. Measure the final mass of the crucible when cool.

Results table for Part 2

Quantity	Measurement
Mass of crucible	44.33 g
Mass of biscuit + crucible before combustion	46.75 g
Mass of crucible after combustion	44.34 g
Mass of water (from Part 1)	251.23 g
Initial temperature of the water	28.5°C
Final temperature of the water	34.9°C

b.

    i. Calculate the energy content of Krispy Krackers using the data in the results table for Part 2. Give your answer in $kJ/100\ g$. (2 marks)

_____

_____

_____

_____

    ii. Explain why the energy content of a biscuit cannot be given in $kJ\ mol^{-1}$. (1 mark)

_____

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c. Assume that the same percentage of heat energy loss occurred when burning the Krispy Kracker, as when the butane was burnt in Part 1. Calculate a more accurate value of the energy content of Krispy Krackers in $kJ/100\ g$. (2 marks)

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Section G: Multiple Choice Questions (9 Marks)

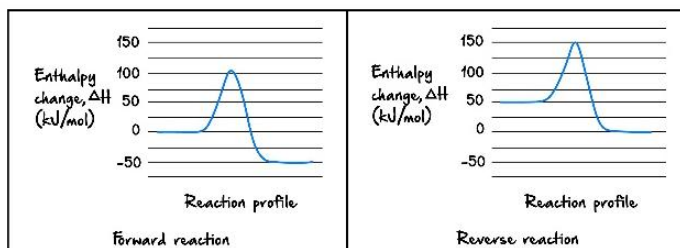INSTRUCTION: 9 Marks. 9 Minutes Writing.

Question 22 (1 mark)

Inspired from VCAA Chemistry NHT Exam 2019
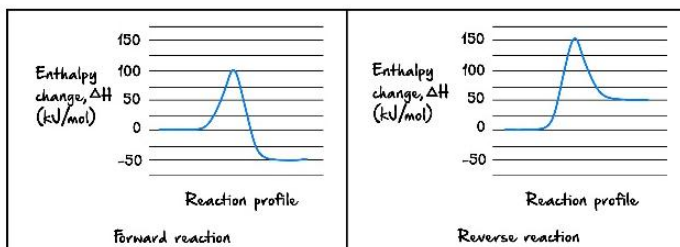https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2019/NHT/2019chem-nht-w.pdf#page=14

A reversible reaction has an enthalpy change, ΔH, of $+50 \ kJ \ mol^{-1}$ for the forward reaction.

Which one of the following pairs of energy profile diagrams, one for the forward reaction and one for the reverse reaction, represents this reaction?
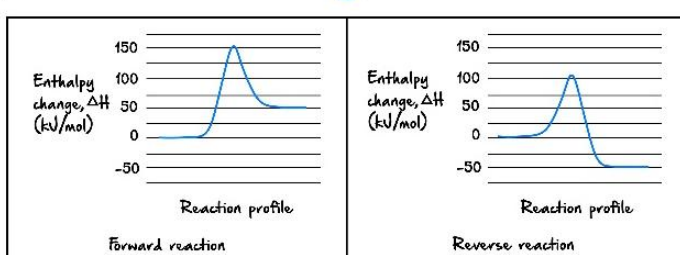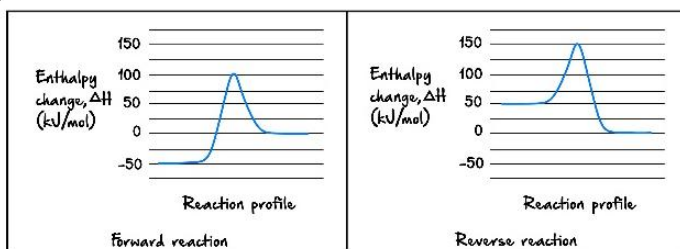
A

B

C

D

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Question 23 (1 mark)

Inspired from VCAA Chemistry NHT Exam 2019
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2019/NHT/2019chem-nht-w.pdf#page=10

0.50 g of ethane, C_2H_6, undergoes complete combustion in a bomb calorimeter containing 200 mL of water. The water temperature rises from 22.0°C to 48.5°C.

The thermochemical equation for the combustion of C_2H_6 using this information is:

A. $C_2H_6 + 5O_2 \rightarrow 2CO_2 + 3H_2O$ $\Delta H = -1330 \ kJ \ mol^{-1}$

B. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$ $\Delta H = -3120 \ kJ$

C. $C_2H_6 + 5O_2 \rightarrow 2CO_2 + 3H_2O$ $\Delta H = -1560 \ kJ \ mol^{-1}$

D. $2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$ $\Delta H = -2660 \ kJ$

Question 24 (1 mark)

Inspired from VCAA Chemistry Exam 2020
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2020/2020chem-w.pdf#page=13

The combustion of which fuel provides the most energy per unit of mass?

A. Butane ($M = 58 \ g \ mol^{-1}$), which releases $49097 \ MJ \ tonne^{-1}$.

B. Nitromethane ($M = 61 \ g \ mol^{-1}$), which releases $11.63 \ kJ \ g^{-1}$.

C. Butanol ($M = 74 \ g \ mol^{-1}$), which releases $2670 \ kJ \ mol^{-1}$.

D. Ethyne ($M = 26 \ g \ mol^{-1}$), which releases $1300 \ kJ \ mol^{-1}$.

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Question 25 (1 mark)

Inspired from VCAA Chemistry Exam 2020
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2020/2020chem-w.pdf#page=11

An experiment was carried out to determine the enthalpy of combustion of propan-1-ol. Combustion of $723\ mg$ of propan-1-ol increased the temperature of $150\ g$ of water from $22.1℃$ to $43.8℃$.

The enthalpy of combustion is closest to:

A. $-17.8\ kJ/g$.

B. $-13.6\ kJ\ mol^{-1}$.

C. $-1129\ kJ\ mol^{-1}$.

D. $-1540\ kJ\ mol^{-1}$.

Question 26 (1 mark)

The complete combustion of $0.12\ mol$ of a particular fuel is found to require $0.42\ mol$ of oxygen gas.

The fuel is likely to be:

A. Methane.

B. Ethane.

C. Ethanol.

D. Butane.

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Question 27 (1 mark)

Inspired from VCAA Chemistry Exam 2021
https://www.vcaa.vic.edu.au/Documents/exams/chemistry/2021/2021chem-w.pdf#page=6

Butane, C_4H_{10}, undergoes complete combustion according to the following equation:

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$$
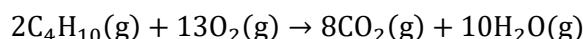
67.0 g of C_4H_{10} released 3330 kJ of energy during complete combustion at standard laboratory conditions (SLC). The mass of carbon dioxide, CO_2, produced was:

A. 0.105 g

B. 3.18 g

C. 50.9 g

D. 204 g

Question 28 (1 mark)

Four fuels undergo complete combustion in excess oxygen, O_2, and the energy released is used to heat 500 g of water.

Assuming that there is no energy lost to the environment, which one of the following fuels is likely to have increased the temperature of water from 32.0℃ to 92.0℃?

A. 0.444 g of hydrogen, H_2.

B. 1.96 g of propane, C_3H_8.

C. 0.140 mol of methane, CH_4.

D. 0.150 mol of methanol, CH_3OH.

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Question 29 (1 mark)

A student set up the equipment shown in the following diagram.
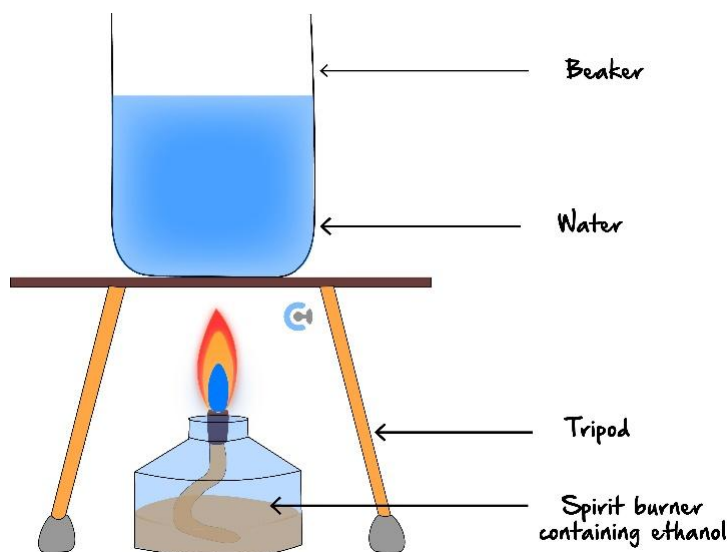
The thermochemical equation for the combustion of ethanol is:

A. $C_2H_5OH(l) + 3.5O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$ $\Delta H = -726 \ kJ \ mol^{-1}$

B. $2C_2H_5OH(l) + 6O_2(g) \rightarrow 4CO_2(g) + 6H_2O(l)$ $\Delta H = -2720 \ kJ \ mol^{-1}$

C. $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$ $\Delta H = -1360 \ kJ \ mol^{-1}$

D. $2C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(l)$ $\Delta H = -1452 \ kJ \ mol^{-1}$

Question 30 (1 mark)

The student made the following experimental measurements:
Mass of water in beaker $= 100.0 \ g$
Increase in temperature $= 10.00°C$

What mass of ethanol $(M = 46 \ g \ mol^{-1})$ must have undergone complete combustion to raise the temperature of the water? Assume that there is no heat loss.

A. $3.07 \times 10^{-3} g$

B. $1.41 \times 10^{-1} g$

C. $4.18 \ g$

D. $29.5 \ g$

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Section H: VCAA-Level Questions II (12 Marks)

INSTRUCTION: 12 Marks. 0.5 Minutes Reading. 11 Minutes Writing.

Question 29 (12 marks)

Two fuels, ethanol and methane are being investigated.

a. It is found that when methane undergoes incomplete combustion to produce carbon monoxide, it releases 82.5% of the energy it would release per mole if complete combustion were to occur.

   i. Explain why the heat of combustion for the incomplete combustion of methane is lower than the heat of combustion for the complete combustion of methane. (1 mark)

   _____

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   ii. Write the thermochemical equations representing the incomplete combustion of methane to produce carbon monoxide as the only carbon-containing product. (2 marks)

   _____

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b. Ethanol is then investigated, which is known to have a density of $0.790\ g/mL$. Some volume of ethanol is completely combusted and is used to heat $150\ mL$ of water from $20.0°C$ to $36.2°C$.

   Find the volume of ethanol which must have undergone complete combustion. (4 marks)

   _____

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c. On a separate occasion, both ethanol and methane undergo complete combustion. Find the mass of methane required to release the same amount of energy as completely combusting 5.00 L of ethanol does. (5 marks)

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<u>Section I:</u> Summary

What have we learnt today?

TIPS

<u>Pitfalls</u>

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Section J: Extension Questions (10 Marks)

Question 31 (4 marks)

$E10$ fuel is a blend of unleaded petrol and ethanol, where the percentage volume/volume (% v/v) of ethanol is 10%. Assume that the petrol component is entirely octane.

Fuel	Density ($g\ mL^{-1}$)
Ethanol	0.790
Octane	0.700

Consider a 3.00 L sample of $E10$.

a. Calculate the volume and mass of each fuel in the sample. (2 marks)

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Octane volume: _____   Octane mass: _____

Ethanol volume: _____   Ethanol mass: _____

b. Calculate the energy released from the complete combustion of the 3.00 L sample. (2 marks)

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Question 32 (6 marks)

Some students in a lab at standard conditions, are trying to experimentally determine the enthalpy of ethanol. Of course, the results they obtained differ from those expected from the literature.

a. Given the density of ethanol is 0.789 g/mL, and 8.00 mL of ethanol raised the temperature of 250 g of water by 22.7°C, calculate the percentage of heat lost to the environment. (4 marks)

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b. Give a possible reason as to why not all of the heat was transferred to the water, and suggest a possible modification to the experiment to minimise this heat loss. (2 marks)

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