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VCE Chemistry ¾
Fuels [1.5]
Homework Solutions

Homework Outline:

Section A: Compulsory Questions (61 Marks)

Sub-Section [1.5.1]: Explain the Production of Biofuels (Biogas, Bioethanol & Biodiesel)

Question 1 (4 marks)

a. State the two gases produced in biogas. (2 marks)

Methane (CH_4) and carbon dioxide (CO_2) are produced.

b. Write the balanced equation for the fermentation of glucose to produce bioethanol. (2 marks)

$$C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$$

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Question 2 (4 marks)

a. Explain the anaerobic process through which biogas is formed, identifying the role of bacteria. (2 marks)

Biogas is produced through the anaerobic breakdown of organic materials by bacteria (1). The bacteria consume the organic matter, digest it, and release methane (CH_4) and carbon dioxide (CO_2) as waste products (2).

b. Amber is interested in producing bioethanol.

i. State the conditions required for bioethanol production. (1 mark)

Bioethanol production requires glucose (from sugar sources), yeast, and anaerobic conditions.

ii. State the role that yeast plays in producing bioethanol. (1 mark)

Yeast acts as a catalyst, converting glucose into ethanol and carbon dioxide via fermentation.

Question 3 (6 marks)

a. Explain the transesterification process used to produce biodiesel, including the key reactants and byproducts. (3 marks)

Transesterification is the process where fats or oils (plant/animal triglycerides) react with methanol in the presence of a catalyst (1). This reaction produces biodiesel (Fatty Acid Methyl Esters) and glycerol as a byproduct (2).

b. Compare biogas, bioethanol, and biodiesel in terms of their production processes and main components. (3 marks)

Name of Fuel	**Fuel Comparison**
Biogas	Produced through anaerobic respiration of organic waste; main components are methane and carbon dioxide.
Bioethanol	Produced via fermentation of glucose by yeast; main component is ethanol (C_2H_5OH).
Biodiesel	Produced via transesterification of fats/oils with methanol; main component is Fatty Acid Methyl Esters.

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Sub-Section [1.5.2]: Identify & Explain Differences Between Fossil Fuels & Biofuels With Reference to Renewability

Question 4 (3 marks)

a. Define a renewable fuel and provide one example. (1 mark)

A renewable fuel can be replenished naturally within a relatively short time. Example: Bioethanol.

b. Provide two examples of fossil fuels and explain why these fuels are classified as non-renewable. (2 marks)

Two examples include natural gas and coal (1). These fuels take millions of years to form from the fossilisation of organic matter, making them non-replenishable in a human timeframe (2).

Question 5 (4 marks)

a. Provide and justify an example of a fuel which is considered carbon neutral. (2 marks)

Bioethanol is considered carbon neutral (1). This is because the CO_2 released during combustion is offset by the CO_2 absorbed during the photosynthesis process when growing the sugar crops used to produce it (2).

b. Compare the carbon emissions from burning coal and biofuels. (2 marks)

Burning coal releases large amounts of CO_2 and particulates, contributing to climate change (1). Whereas, biofuels release CO_2 as well but are considered more sustainable because their emissions are partially offset during production (e.g., photosynthesis) (2).

Question 6 (5 marks)

a. Bhuvi is comparing the heat of combustion of bioethanol and petrol. State and justify the difference in energy content between petrol and bioethanol. (3 marks)

Petrol has a higher heat of combustion than bioethanol (1). This is because it is a hydrocarbon and does not contain oxygen in its structure, allowing more energy to be released during combustion (2). Whereas, bioethanol is partially oxidised, reducing its energy content (3).

b. Provide two practices in farming which reduce the carbon neutrality of biofuels. (2 marks)

- Farming practices require machinery that burns fossil fuels, contributing additional CO_2 emissions (1).
- Fertilisers and transportation of crops also add to the carbon footprint of biofuels (2)

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Sub-Section [1.5.3]: Write Cellular Respiration & Photosynthesis Equations

Question 7 (3 marks)

a. Write the equation for cellular respiration. (1 mark)

$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

b. Write the equation for photosynthesis. (1 mark)

$6CO_2(g) + 6H_2O(l) \xrightarrow{sunlight} C_6H_{12}O_6(aq) + 6O_2(g)$

c. Identify the energy source required for photosynthesis. (1 mark)

Sunlight

Question 8 (4 marks)

a. Explain how photosynthesis and cellular respiration are interconnected. (2 marks)

Photosynthesis produces glucose and oxygen, which are reactants for cellular respiration (1). Cellular respiration, in turn, releases CO_2 and H_2O, which are used in photosynthesis (2).

b. Identify the products of photosynthesis and state how they are used in cellular respiration. (2 marks)

Products of photosynthesis are glucose and oxygen (1). Glucose is broken down to release energy, and oxygen is used as the final electron acceptor in cellular respiration (2).

Question 9 (7 marks)

a. Write the balanced chemical equations for both cellular respiration and photosynthesis, highlighting the relationship between each of the equations. (2 marks)

Cellular Respiration: $C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$
Photosynthesis: $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g)$
The reactants of one reaction are the products of the other (2).

b. If 2 moles of glucose undergo cellular respiration, calculate:

i. The moles of carbon dioxide produced. (1 mark)

From the equation, 1 mole of glucose produces 6 moles of CO_2.
For 2 moles of glucose: $2 \times 6 = 12$ moles of CO_2

ii. The moles of water produced. (1 mark)

From the equation, 1 mole of glucose produces 6 moles of H_2O.
For 2 moles of glucose: $2 \times 6 = 12$ moles of H_2O

c. Explain why photosynthesis is classified as an endothermic process, while cellular respiration is classified as an exothermic process. Provide one example of energy transformation in each. (3 marks)

Tutor's Note: "1 mark awarded if BOTH examples are correct."

Photosynthesis is endothermic because it absorbs light energy from the sun and converts it into chemical energy stored in glucose (1). For example, solar energy → chemical energy (glucose). Whereas cellular respiration is exothermic because it releases energy stored in glucose as heat and ATP (2). For example, chemical energy (glucose) → thermal energy and ATP (usable energy) (3).

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Sub-Section [1.5.4]: Calculate Energy Obtained From Foods

Question 10 (3 marks)

a. Calculate the energy obtained from 10 g of carbohydrates, given that carbohydrates release 16 kJ/g. (1 mark)

Energy = $10\ g \times 16\ kJ/g = 160\ kJ$

b. Arjun is comparing the energy content of fats and proteins. State and justify which macromolecule produces more energy. (2 marks)

Fats have a higher energy content than proteins (1). Fats provide more energy per gram because they are less oxidised and have a higher proportion of C-H bonds than proteins (2).

Question 11 (2 marks)

a. A food sample contains 5 g of fat and 8 g of carbohydrates. Calculate the total energy content. (1 mark)

Energy = $(5 \times 37) + (8 \times 16) = 185 + 128 = 313\ kJ$. (1)

b. Explain why fats provide more energy per gram than carbohydrates. (1 mark)

Fats are less partially oxidised compared to carbohydrates, meaning they release more energy when broken down (1).

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Question 12 (7 marks)

a. A sample of food contains 25 g of carbohydrates, 15 g of proteins, and 30 g of fats. Calculate the total energy released from this food. (2 marks)

Energy from carbohydrates $= 25\ g \times 16\ kJ/g = 400\ kJ$
Energy from proteins $= 15\ g \times 17\ kJ/g = 255\ kJ$
Energy from fats $= 30\ g \times 37\ kJ/g = 1110\ kJ$
Total Energy $= 400\ kJ + 255\ kJ + 1110\ kJ = 1765\ kJ$

b. Explain why cellulose cannot be used to provide energy by humans. (2 marks)

Cellulose is a complex carbohydrate made of long chains of glucose molecules connected by β-1,4-glycosidic bonds (1). Humans lack the enzyme cellulose required to break these bonds, making it indigestible. Therefore, cellulose cannot be metabolised to release energy (2).

c. A person consumes a salad meal that contains 30 g of carbohydrates, 10 g of protein, 15 g of fats, and 20 g of cellulose. Calculate the total energy content of the meal. (3 marks)

Energy from carbohydrates $= 30\ g \times 16\ kJ/g = 480\ kJ$
Energy from proteins $= 10\ g \times 17\ kJ/g = 170\ kJ$
Energy from fats $= 15\ g \times 37\ kJ/g = 555\ kJ$
Total Energy from the meal $= 480\ kJ + 170\ kJ + 555\ kJ = 1205\ kJ$

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Sub-Section: The 'Final Boss'

Question 13 (9 marks)

a. Describe the processes used to produce biogas, bioethanol, and biodiesel. Compare their main components and identify which of these biofuels is the most carbon neutral. (3 marks)

~ Biogas is produced through anaerobic digestion, where bacteria break down organic waste (e.g., food scraps, animal manure) without oxygen, producing methane (CH_4) and carbon dioxide (CO_2).
~ Bioethanol is made by fermenting sugars from crops like sugarcane or corn, using yeast, which converts the sugars into ethanol (C_2H_5OH) and CO_2.
~ Biodiesel is produced by transesterification, where oils or fats react with methanol to produce methyl esters (biodiesel) and glycerol.
~ Of the three, biogas is the most carbon neutral because the methane produced is part of a continuous natural cycle, and the CO_2 released during combustion is offset by the CO_2 absorbed during the growth of the organic material used to produce it.

b. A 50 g sample of salad contains 20% (m/m) fat, 10% (m/m) protein, 50% (m/m) carbohydrates, 20% (m/m) of which is cellulose. Calculate the total energy released from the salad. (3 marks)

Energy from fat:
$50\ g\ \times\ 20\%\ =\ 10\ g$ of fat.
Energy from fat $=\ 10\ g\ \times\ 37\ kJ/g\ =\ 370\ kJ$

Energy from protein:
$50\ g\ \times\ 10\%\ =\ 5\ g$ of protein.
Energy from protein $=\ 5\ g\ \times\ 17\ kJ/g\ =\ 85\ kJ$

Energy from carbohydrates:
$50\ g\ \times\ 30\%\ =\ 15\ g$ of carbohydrates.
Energy from carbohydrates $=\ 15\ g\ \times\ 16\ kJ/g\ =\ 240\ kJ$
Total energy $=\ 370\ kJ\ +\ 85\ kJ\ +\ 240\ kJ\ =\ 695\ kJ$

c. Write the balanced equations for photosynthesis and cellular respiration and explain how they are linked in the production and use of energy. (3 marks)

The process of photosynthesis is represented by the equation:

$$6CO_2(g) + 6H_2O(l) \xrightarrow{\text{light energy, chlorophyll}} C_6H_{12}O_6(aq) + 6O_2(g)$$

In photosynthesis, plants use light energy to convert carbon dioxide and water into glucose and oxygen. This glucose is then used in cellular respiration, which can be written as:

$$C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + \text{energy (ATP)}$$

Cellular respiration breaks down glucose in the presence of oxygen to release energy in the form of ATP, which is used by living organisms for various cellular processes. The byproducts of cellular respiration, carbon dioxide and water, are then used again in photosynthesis, creating a continuous cycle. Therefore, photosynthesis and cellular respiration are linked, as the products of one process are the reactants of the other, facilitating the flow of energy in ecosystems.

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Section B: Supplementary Questions (64 Marks)

Sub-Section [1.5.1]: Explain the Production of Biofuels (Biogas, Bioethanol & Biodiesel)

Question 14 (4 marks)

a. Describe one method through which biogas production helps reduce greenhouse gas emissions. (2 marks)

Biogas production captures methane (a potent greenhouse gas) released during organic waste decomposition. Instead of being emitted directly into the atmosphere, methane is combusted as a fuel, producing carbon dioxide which traps less heat.

b. State how the breakdown of glucose by yeast results in a usable fuel source. (2 marks)

Yeast ferments glucose under anaerobic conditions, converting it into ethanol and carbon dioxide via the reaction:

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

Ethanol is then distilled and used as a renewable biofuel.

Question 15 (4 marks)

a. Discuss why anaerobic digestion is more sustainable than landfill decomposition for waste management. (2 marks)

Anaerobic digestion prevents uncontrolled methane release from landfills by capturing the gas in a controlled environment, where it can be used as biogas. (1) It also reduces landfill volume and produces nutrient-rich digestate for use as fertiliser. (2)

b. Propose how agricultural residues could be converted into bioethanol and explain the advantage of this approach. (2 marks)

Agricultural residues (e.g., corn stalks, wheat straw) can be broken down into simple sugars using enzymes. (1) These sugars are then fermented by yeast to produce bioethanol. This approach reduces waste, adds value to residues, and does not compete directly with food crops. (2)

Question 16 (5 marks)

a. Explain why glycerol is produced during the synthesis of biodiesel, and suggest one industrial use for this byproduct. (2 marks)

Glycerol is produced as a byproduct during the transesterification of triglycerides (fats/oils) with methanol. (1) It can be used in the pharmaceutical industry for making soaps, cosmetics, and moisturisers. (2)

b. Compare the feedstocks for producing biogas, bioethanol, and biodiesel, and evaluate which feedstock has the least environmental impact. (3 marks)

- Biogas: Organic waste (e.g., food scraps, animal manure).
- Bioethanol: Sugar-rich crops (e.g., sugarcane, corn).
- Biodiesel: Vegetable oils or animal fats.

Biogas feedstocks have the least environmental impact as they use waste materials, avoiding the land-use and deforestation issues associated with crop-based biofuels.

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Question 17 (7 marks)

Evelyn is experimenting with methane.

a. She is interested in the methods to source methane. Her friend suggests using crude oil as a source of methane. State another 3 non-renewable methods of obtaining methane. (2 marks)

In gas deposits

Coal steam gas

Shale gas

b. Deciding on crude oil, Evelyn is unsure of how to obtain methane from crude oil. State the process used in this separation and how it works. (3 marks)

The process used to obtain methane from crude oil is fractional distillation. (1) Crude oil is heated, and its components separate based on their boiling points through a temperature gradient in a fractioning column. (2) Methane, being a lighter hydrocarbon with a very low boiling point, is collected in the fraction containing the gases at the top of the distillation column. (3)

c. State and explain an alternative renewable method of obtaining methane gas. (2 marks)

Through biogas in land fill deposits (1).

Biogas is produced via the anaerobic breakdown of waste/organic materials by bacteria. Bacteria feasts (yum) on the organic compounds within the waste, digesting it, and turning it into methane/. This methane is sucked up and forms our biogas.

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Sub-Section [1.5.2]: Identify & Explain Differences Between Fossil Fuels & Biofuels With Reference to Renewability

Question 18 (4 marks)

a. Define "renewable fuel" and explain why firewood from a sustainably managed forest fits this definition. (2 marks)

A renewable fuel can be replenished naturally within a short timeframe. (1) Firewood from a sustainably managed forest qualifies because trees are replanted at a rate equal to or faster than their harvest. (2)

b. Name two fossil fuels and explain why their rate of consumption exceeds their natural replenishment rate. (2 marks)

Examples: Coal and natural gas. (1) These fuels form over millions of years from organic matter under heat and pressure, far slower than their consumption rate. (2)

Question 19 (4 marks)

a. Justify why bioethanol derived from sugarcane is often labelled "carbon neutral," referencing photosynthesis and combustion. (2 marks)

Sugarcane absorbs CO_2 from the atmosphere during photosynthesis. (1) When bioethanol is combusted, the same amount of CO_2 is released back into the atmosphere, achieving a balance. (2)

b. Discuss how the heat of combustion differs between fossil fuels and biofuels, considering the molecular composition of each. (2 marks)

Fossil fuels (e.g., hydrocarbons like octane) are fully reduced, containing no oxygen in their structure, which allows for high energy release during combustion. (1) Biofuels (e.g., ethanol) are partially oxidised, containing oxygen, which reduces their energy density. (2)

Question 20 (4 marks)

a. Contrast the carbon emission profiles of burning natural gas versus biogas. (2 marks)

Burning natural gas releases carbon that has been sequestered for millions of years, increasing atmospheric CO_2 levels. (1) Biogas combustion, however, recycles contemporary carbon, maintaining a balance in the carbon cycle. (2)

b. List two factors during biofuel production that compromise its carbon neutrality and suggest solutions to mitigate these effects. (2 marks)

- Farming machinery emissions: Use electric or renewable-energy-powered equipment.
- Fertiliser production emissions: Adopt organic or low-emission fertilisers.

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Question 21 (6 marks)

a. Compare and justify the rate of replenishment of biofuels and fossil fuels. State the relationship between a renewable resource and its rate of replenishment. (4 marks)

The rate of replenishment for biofuels is much faster than for fossil fuels. (1) Biofuels are derived from recently living organisms, such as plants, which can grow and be harvested within a few months to years. (2) In contrast, fossil fuels form from the decomposition of ancient organic matter under high pressure and temperature over millions of years. (3)

This difference impacts their classification because biofuels can be replenished within a human timescale, making them renewable. Fossil fuels, on the other hand, cannot be replaced at the rate they are consumed, classifying them as non-renewable resources. (4)

b. Fossil fuels and biofuels both release CO_2 when burned. Despite this, why are biofuels considered more environmentally friendly in terms of CO_2 emissions? (2 marks)

Although both fossil fuels and biofuels release CO_2 when burned, biofuels are considered more environmentally friendly because the CO_2 released during combustion is offset by the CO_2 absorbed by plants during their growth. (1)
In contrast, fossil fuels release CO_2 that has been stored underground for millions of years, adding a significant amount of new CO_2 to the atmosphere (2).

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Sub-Section [1.5.3]: Write Cellular Respiration & Photosynthesis Equations

Question 22 (1 mark)

State how sunlight can be absorbed in photosynthesis.

Chlorophyll pigment (1).

Question 23 (2 marks)

Angela is talking with her classmates and overhears that "in cellular respiration, energy is absorbed." Evaluate this statement.

Angela's classmate is incorrect (1). In cellular respiration, energy is released for use in the body (2).

Question 24 (5 marks)

During photosynthesis, plants undergo the following reaction:

$$6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(aq) + 6O_2(g) \qquad \Delta H = +3000\ kJ$$

a. If **75.0 *L* of carbon dioxide** is absorbed, what is the mass of glucose produced during photosynthesis? (3 marks)

$n(CO_2) = \frac{V}{V_m} = \frac{75}{24.8} = 3.024$ mol

$\therefore n(CO_2) : n(C_6H_{12}O_6) = 6 : 1$

$\therefore n(C_6H_{12}O_6) = \frac{3.024}{6}$

$= 0.504$ mol

$\therefore m(C_6H_{12}O_6) = 180 \times 0.504$

$= 90.7$ g

b. How much energy is absorbed during this process? (2 marks)

$n(C_6H_{12}O_6) = 0.504$

$\therefore \quad E = \Delta H \times n$

$= 3000 \times$ 0.54 mol

$=$ 1512 kJ

$\approx 1.51 \times 10^3$ kJ

Question 25 (7 marks)

a. Write the balanced chemical equations for aerobic respiration and fermentation in yeast and explain the key differences between the two processes. (3 marks)

Aerobic Respiration: $C_6H_{12}O_6(aq) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$

Fermentation (in yeast): $C_6H_{12}O_6(aq) \rightarrow 2C_2H_5OH(aq) + 2CO_2(g)$

In aerobic respiration, oxygen is required, and more energy is produced. In fermentation, oxygen is not required, and the energy yield is lower.

b. If 4 moles of glucose undergo fermentation in yeast, calculate:

i. The moles of ethanol (C_2H_5OH) produced. (1 mark)

From the equation, 1 mole of glucose produces 2 moles of ethanol.
For 4 moles of glucose: $4 \times 2 = 8$ moles of ethanol.

ii. The moles of carbon dioxide produced. (1 mark)

From the equation, 1 mole of glucose produces 2 moles of CO_2.
For 4 moles of glucose: $4 \times 2 = 8$ moles of CO_2.

c. Compare and justify the energy output of aerobic respiration and fermentation. (2 marks)

- **Aerobic respiration** is more efficient because it produces more ATP per mole of glucose.
- **Fermentation** is less efficient because it does not fully break down glucose, releasing less energy.

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Sub-Section [1.5.4]: Calculate Energy Obtained From Foods

Question 26 (2 marks)

Fill in the table below.

Food	**Heat of combustion (kJg^{-1})**
Fats and oils	37
Protein	17
Carbohydrate	16

Question 27 (2 marks)

Julian is looking at food labels and notices that kJ/g rather than kJ/mol to describe the heat of combustion of foods. Justify this observation.

Food contains a mixture of macromolecules (1). Each macromolecule will have a different energy level, meaning that the overall energy content of the food cannot be expressed in mole. (2)

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Question 28 (3 marks)

Emma is investigating the effect of ingestion of fibres such as cellulose in the body. State and justify what happens to cellulose during digestion.

Cellulose will pass through the digestive system and be excreted (1). Cellulose is a complex carbohydrate made of long chains of glucose molecules connected by β-1,4-glycosidic bonds (2). Humans lack the enzyme cellulase required to break these bonds, making it indigestible (3).

Question 29 (4 marks)

The label on a packet of some biscuits, which has a serving size of $\mathbf{60.0}\ \boldsymbol{g}$, has the following composition:

- **Protein**: 8.25 g
- **Fats**: 2.10 g
- **Carbohydrates – sugars and starches**: 42.0 g
- **Carbohydrates – cellulose fibre**: 4.65 g

a. Calculate the total possible energy available to the body per gram of biscuit. (3 marks)

$q(\text{protein}) = 8.25 \times 17 =$ 140.25 kJ

$q(\text{fats}) = 37 \times 2.1 =$ 77.7 kJ

$q(\text{carbs}) = 16 \times 42 =$ 672 kJ

$q(\text{total}) = 140.25 + 77.7 + 672$

$= 889.95$

$\therefore$ 889.95 kJ

b. A sample of biscuit is combusted in a calorimeter to determine its energy value. The result obtained indicates that the energy content of the biscuit is $\mathbf{19}\ \boldsymbol{kJ/g}$. Explain why there is a difference between this answer and the value obtained in **part.a.** (1 mark)

Cellulose can be combusted producing additional energy (1).

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