MEGA LECTURE · A LEVEL CHEMISTRY

Chapter 14: Alkanes

OCR A Level Chemistry A (H432) — Structured Practice Worksheet

SPECIFICATION	TOTAL MARKS	SUGGESTED TIME
3.2.2 Alkanes: bonding, combustion, free-radical substitution, cracking	78	1 hour 34 minutes

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Instructions to candidates

- Answer **all** questions in the spaces provided. Show all working in calculations.
- Marks are shown in brackets [ ] at the end of each part.

Question 1 — Bonding in alkanes

3.2.2

a. State the general formula of the alkanes. **[1]**

b. State the hybridisation of the carbon atoms in an alkane and the bond angle around each carbon. **[2]**

c. Explain why alkanes are described as *saturated* hydrocarbons. **[1]**

d. Explain, in terms of sp^3 hybrid orbitals, why the shape around each carbon atom in an alkane is tetrahedral. **[3]**

e. State the type of bond formed between adjacent carbon atoms in an alkane and describe how it forms. **[2]**

Question 1 total: 9 marks

Question 2 — Boiling points of alkanes

3.2.2

a. Describe the trend in boiling point of the straight-chain (unbranched) alkanes as the number of carbon atoms in the chain increases. **[2]**

b. Explain this trend in terms of intermolecular forces. **[3]**

c. Explain why 2,2-dimethylpropane has a lower boiling point than pentane, even though both have the molecular formula C_5H_{12}. **[3]**

d. Explain why alkanes are generally insoluble in water. **[2]**

Question 2 total: 10 marks

Question 3 — Combustion of alkanes 3.2.2

a. Write an equation, including state symbols, for the complete combustion of propane, C_3H_8. **[2]**

b. Write an equation for the incomplete combustion of propane, forming carbon monoxide and water. **[2]**

c. Explain why incomplete combustion occurs when a hydrocarbon is burned in a limited supply of oxygen. **[2]**

d. Explain why carbon monoxide is toxic to humans. **[2]**

e.

State how solid carbon (soot) particulates are formed during the combustion of hydrocarbon fuels. **[1]**

f. Explain how oxides of nitrogen (NO_x) form in a car engine, and explain why high engine temperatures are responsible for their formation. **[3]**

Question 3 total: 12 marks

Question 4 — Environmental impact and catalytic converters 3.2.2

a. State one environmental or health problem associated with carbon monoxide emissions. **[1]**

b. State one environmental problem associated with emissions of oxides of nitrogen (NO_x). **[1]**

c. State one problem associated with unburnt hydrocarbons or soot particulates in vehicle exhaust emissions. **[1]**

d. Explain how a catalytic converter reduces emissions of carbon monoxide and nitrogen monoxide from a car exhaust, including an equation for the reaction that occurs. **[4]**

e. Explain why sulfur dioxide is also present in the exhaust emissions of some fuels, and state one problem this causes. **[2]**

Question 4 total: 9 marks

Question 5 — Free-radical substitution: chlorination of methane 3.2.2

Methane reacts with chlorine in the presence of ultraviolet light by a free-radical substitution mechanism.

a. Name this type of mechanism. **[1]**

b. Write an equation for the initiation step of this reaction, and state the type of bond fission involved. **[2]**

c. Write equations for the two propagation steps of this reaction. **[3]**

d. In the box below, use curly arrow notation to show the homolytic fission of Cl_2 that occurs in the initiation step. **[2]**

Curly arrows — initiation step

e. Write an equation for a possible termination step of this reaction. **[2]**

f. Explain why termination steps occur relatively rarely compared with propagation steps during the reaction. **[2]**

g. Explain why this reaction typically produces a mixture of chlorinated products rather than pure chloromethane. **[2]**

Question 5 total: 14 marks

Question 6 — The problem of further substitution 3.2.2

a. State the names of two further chlorinated products (other than chloromethane) that could form when methane reacts with an excess of chlorine. **[2]**

b.

Explain why the formation of a mixture of products is a practical disadvantage of this reaction industrially. **[2]**

c. Suggest one way the proportion of chloromethane (CH_3Cl) in the product mixture could be increased. **[1]**

d. State one other limitation of free-radical substitution as a method of introducing a functional group into an organic molecule. **[1]**

Question 6 total: 6 marks

Question 7 — Cracking

3.2.2

a. Define *cracking*. **[2]**

b. State the two main types of cracking used industrially and, for each, state the typical conditions used. **[4]**

Type of cracking	Conditions
Thermal	
Catalytic	

c. State two reasons why cracking is carried out industrially. **[2]**

d. Dodecane, $C_{12}H_{26}$, is cracked to form octane, C_8H_{18}, and one other product. Write a balanced equation for this reaction, and name the other product formed. **[2]**

e. Write a balanced equation for the cracking of C_8H_{18} to form ethene and one other alkane product. **[2]**

Question 7 total: 12 marks

Question 8 — Extended response

Synoptic

Crude oil, as obtained by fractional distillation, contains a much higher proportion of long-chain hydrocarbons than is needed by consumers, while demand for shorter-chain fuels and for alkenes (as feedstock for the polymer industry) is high. Explain how cracking addresses this mismatch between supply and demand, including reference to the types of cracking used and the products formed. **[6]**

This question is marked using a level of response.

Question 8 total: 6 marks

PAPER TOTAL: 78 MARKS

MARK SCHEME — Chapter 14: Alkanes

Award marks independently unless stated. ECF applies to calculations.

Q1 (a) [1]

- C_nH_{2n+2}. (1)

Q1 (b) [2]

- sp^3 hybridised. (1)
- Bond angle of 109.5°. (1)

Q1 (c) [1]

- Alkanes contain only single C–C and C–H bonds (no C=C double bonds or rings), so no more atoms could be added to the molecule. (1)

Q1 (d) [3]

- Each carbon atom forms four sp^3 hybrid orbitals from mixing one s and three p orbitals. (1)
- These four orbitals arrange as far apart as possible to minimise electron pair repulsion. (1)
- This gives a tetrahedral arrangement with bond angles of 109.5° around each carbon. (1)

Q1 (e) [2]

- A sigma (σ) bond. (1)
- Formed by the direct/end-on overlap of two orbitals (one from each atom) along the axis joining the two nuclei. (1)

Q2 (a) [2]

- Boiling point increases as the number of carbon atoms in the chain increases. (1)
- The increase in boiling point becomes smaller for each additional CH_2 added. (1)

Q2 (b) [3]

- Alkanes are non-polar molecules held together between molecules only by van der Waals (induced dipole–induced dipole/London) forces. (1)
- As chain length increases, there are more electrons and a greater surface area of contact between neighbouring molecules. (1)
- This increases the strength of the van der Waals forces, so more energy is needed to separate molecules, raising the boiling point. (1)

Q2 (c) [3]

- 2,2-dimethylpropane is a more highly branched, more compact/spherical molecule than straight-chain pentane. (1)
- This reduces the surface area of contact between neighbouring molecules. (1)
- This weakens the van der Waals forces between molecules, so less energy is required to separate them, giving a lower boiling point. (1)

Q2 (d) [2]

- Alkanes are non-polar and cannot form hydrogen bonds (or strong dipole interactions) with water molecules. (1)
- The energy released forming weak alkane–water interactions is not enough to compensate for the hydrogen bonds broken within water, so alkanes do not dissolve. (1)

Q3 (a) [2]

- $C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$ (2; 1 for correct formulae/balancing, 1 for correct state symbols)

Q3 (b) [2]

- $2C_3H_8 + 7O_2 \rightarrow 6CO + 8H_2O$ (2; 1 for correct products, 1 for balancing; accept fractional O_2 form)

Q3 (c) [2]

- With a limited oxygen supply there is insufficient oxygen to oxidise all the carbon fully to CO_2. (1)
- Carbon is instead oxidised only partially, forming carbon monoxide (or elemental carbon) instead of carbon dioxide. (1)

Q3 (d) [2]

- Carbon monoxide binds to haemoglobin in red blood cells (forming carboxyhaemoglobin) more readily than oxygen does. (1)
- This reduces the oxygen-carrying capacity of the blood, depriving the body's cells/tissues of oxygen. (1)

Q3 (e) [1]

- Soot (carbon) forms when there is insufficient oxygen to oxidise the carbon at all, leaving unburnt carbon particles. (1)

Q3 (f) [3]

- At the high temperatures reached inside a car engine/cylinder... (1)
- ...nitrogen and oxygen from the air are able to react together (a reaction that does not occur significantly at lower/ambient temperature). (1)
- ...forming oxides of nitrogen, e.g. $N_2(g) + O_2(g) \rightarrow 2NO(g)$, which may be further oxidised to NO_2. (1)

Q4 (a) [1]

- Carbon monoxide is toxic/poisonous (binds to haemoglobin, reducing oxygen transport in blood). (1)

Q4 (b) [1]

- NO_x contributes to acid rain / photochemical smog / respiratory problems (any one). (1)

Q4 (c) [1]

- Unburnt hydrocarbons/soot contribute to photochemical smog / are carcinogenic / cause respiratory problems / global dimming (any one). (1)

Q4 (d) [4]

- The catalytic converter contains a catalyst (e.g. platinum/rhodium/palladium) on a honeycomb support with a large surface area. (1)
- Exhaust gases pass over the catalyst, which provides a surface for CO and NO to adsorb onto and react. (1)
- Carbon monoxide is oxidised and nitrogen monoxide is reduced, converting them into less harmful gases. (1)
- $2CO(g) + 2NO(g) \rightarrow 2CO_2(g) + N_2(g)$ (1)

Q4 (e) [2]

- Fuels contain sulfur impurities, which are oxidised during combustion to form sulfur dioxide. (1)
- Sulfur dioxide dissolves in atmospheric water to form acid rain, damaging buildings/vegetation/aquatic life (any one). (1)

Q5 (a) [1]

- Free-radical substitution. (1)

Q5 (b) [2]

- $Cl_2 \rightarrow 2Cl\bullet$ (1)
- Homolytic fission (of the Cl–Cl bond, caused by UV light). (1)

Q5 (c) [3]

- $CH_4 + Cl\bullet \rightarrow \bullet CH_3 + HCl$ (1)
- $\bullet CH_3 + Cl_2 \rightarrow CH_3Cl + Cl\bullet$ (1)
- Both equations correctly balanced with radical dots shown. (1)

Q5 (d) [2]

- Fish-hook (single-barbed) curly arrow starting from the middle of the Cl–Cl bond. (1)
- Two separate fish-hook arrows, each pointing outward to one Cl atom, showing formation of two Cl• radicals. (1)

Q5 (e) [2]

- Any correctly balanced termination equation combining two radicals, e.g. $Cl\bullet + Cl\bullet \rightarrow Cl_2$, or $\bullet CH_3 + Cl\bullet \rightarrow CH_3Cl$, or $\bullet CH_3 + \bullet CH_3 \rightarrow C_2H_6$ (2; 1 for correct radicals combined, 1 for correct product/balancing)

Q5 (f) [2]

- Termination requires two radicals to collide/meet each other. (1)
- Radical concentration is very low compared with the concentration of CH_4 and Cl_2 molecules, so such collisions are much less frequent than propagation (radical + molecule) collisions. (1)

Q5 (g) [2]

- Once some CH_3Cl has formed, it can also react with a Cl• radical (further substitution), since it also contains C–H bonds. (1)
- This produces CH_2Cl_2, $CHCl_3$ and CCl_4 in addition to CH_3Cl, giving a mixture of products. (1)

Q6 (a) [2]

- Dichloromethane, CH_2Cl_2. (1)
- Trichloromethane, $CHCl_3$ (accept tetrachloromethane, CCl_4). (1)

Q6 (b) [2]

- The mixture of products must be separated (e.g. by fractional distillation), which is costly/time-consuming and reduces the overall yield of the desired product. (1)
- This makes the reaction inefficient as a way of making a single, pure organic product on an industrial scale. (1)

Q6 (c) [1]

- Use a large excess of methane relative to chlorine, so a Cl• radical is much more likely to collide with a CH_4 molecule than with a CH_3Cl molecule. (1)

Q6 (d) [1]

- The mechanism gives poor control/selectivity over exactly where or how many substitutions occur. (1)

Q7 (a) [2]

- Cracking is the breaking down of larger (long-chain) alkane molecules into smaller alkane and alkene molecules. (1)
- This is done by breaking C–C bonds, using heat (and sometimes a catalyst). (1)

Q7 (b) [4]

- Thermal cracking: high temperature (approximately 700–1200 K) and high pressure (approximately 7000 kPa), no catalyst. (2)
- Catalytic cracking: lower temperature (approximately 720 K), a slight/moderate pressure, using a zeolite catalyst. (2)

Q7 (c) [2]

- To convert less useful long-chain hydrocarbons (in excess supply from crude oil distillation) into more useful shorter-chain hydrocarbons (e.g. petrol/fuels), matching supply to demand. (1)
- To produce alkenes, used as a feedstock for the polymer (plastics) industry. (1)

Q7 (d) [2]

- $C_{12}H_{26} \rightarrow C_8H_{18} + C_4H_8$ (1)
- The other product is but-1-ene (or a named/isomeric butene). (1)

Q7 (e) [2]

- $C_8H_{18} \rightarrow C_2H_4 + C_6H_{14}$ (2; 1 for correct products chosen to conserve atoms, 1 for correct balancing; any valid alkane + ethene combination accepted)

Q8 [6] — Level of response

- **Level 3 (5–6):** Gives a full and accurate explanation linking the supply of long-chain fractions from distillation to demand for short-chain fuels and alkenes, and describes both thermal and catalytic cracking with correct conditions and typical products/uses.
- **Level 2 (3–4):** Explains the general idea of matching supply and demand and describes cracking, but with only one type of cracking described, or with incomplete detail on conditions/products.
- **Level 1 (1–2):** States that cracking breaks long-chain hydrocarbons into smaller ones, with limited link to supply/demand or economics.

Indicative content: *Fractional distillation of crude oil produces a much larger proportion of long-chain fractions (e.g. fuel oil, bitumen) than there is demand for, while shorter-chain fractions (e.g. petrol, naphtha) and alkenes are in high demand — for use as fuels and as the raw material (feedstock) for the polymer industry respectively. Cracking breaks C–C bonds in long-chain alkane molecules to produce a mixture of shorter alkanes and alkenes, converting excess long-chain material into the more valuable, more marketable products. Thermal cracking (high temperature ~700–1200 K, high pressure, no catalyst, via a free-radical mechanism) tends to produce a higher proportion of alkenes, useful for the polymer industry, while catalytic cracking (lower temperature ~720 K, a zeolite catalyst, via a carbocation mechanism) is used mainly to*

produce motor fuels including branched and aromatic hydrocarbons for higher-quality petrol. Together, these processes allow the petrochemical industry to match the supply of hydrocarbons from crude oil to what consumers and industry actually need.

END OF MARK SCHEME · 78 marks