SL Paper 3

Materials science involves understanding the properties of materials and applying those properties to desired structures.

a. Magnesium oxide, MgO, and silicon carbide, SiC, are examples of ceramic materials. State the name of the predominant type of bonding in each material. [1]

b. Predict the predominant type of bonding for a binary compound AB in which the electronegativity of both atoms is low. Use section 29 of the data booklet. [1]

Markscheme

a. *MgO*: ionic ***AND*** *SiC*: covalent

Accept "covalent network/network covalent" for "covalent" but not just "network".

b. metallic «bonding»

Examiners report

a. [N/A]
b. [N/A]

Aluminium is produced by the electrolysis of a molten electrolyte containing bauxite.

Determine the mass, in g, of aluminium produced by the passage of a charge of 1.296×10^{13} C. Use sections 2 and 6 of the data booklet.

Markscheme

ratio of electrons : aluminium ions = 3 : 1

amount Al «$\frac{1.296 \times 10^{13}\ \text{C}}{96500\ \text{C mol}^{-1} \times 3}$ » = 4.48×10^{7} «mol»

mass Al «= 4.48×10^{7} mol × 26.98 g mol^{-1}» = 1.21×10^{9} «g»

*Award **[3]** for correct final answer.*

[3 marks]

Examiners report

[N/A]

Nanocatalysts have large surface areas per unit mass.

a. Identify **one** concern of using nanoscale catalysts. [1]

b. Explain how zeolites act as selective catalysts. [2]

c. Carbon nanotubes, which can be produced by the HIPCO process, show great potential as nanocatalysts. Identify the catalyst and conditions used in the HIPCO process. [2]

Catalyst:

Conditions:

Markscheme

a. possible toxicity «of small airborne particles»

OR

unknown health effects

OR

small particle size «and large surface area» may increase reaction rate to dangerous levels

OR

immune system/allergy concerns

OR

uncertain impact on environment

Accept specific health effect (eg. may cause cancer/effect on respiratory system, etc).

b. pores/cavities/channels/holes/cage-like structures «in zeolites» have specific shape/size

only reactants «with appropriate size/geometry» fit inside/go through/are activated/can react

c. *Catalyst*:

iron/Fe

OR

iron«0» «penta» carbonyl/Fe $(CO)_5$

Conditions:
high temperature/any value or range within the range 900–1600 °C
AND
high pressure/any value or range within the range 10–100 atm

Accept “cobalt-molybdenum/Co-Mo/CoMo”.

Accept high pressures expressed in kPa/Pa.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Since the accidental discovery of polyethene in the 1930s, polymers have played an essential role in daily life because of their wide range of properties and uses.

a. Titanium compounds are used as catalysts in the manufacture of high-density polyethene (HDPE). Discuss **two** factors scientists would have considered in choosing these catalysts. [2]

b. Describe a structural feature of low-density polyethene (LDPE) that explains why LDPE has a different melting point from that of HDPE. [4]

c. State **one** environmental impact of the disposal of these polyethenes by using incineration. [1]

Markscheme

a. no other product formed (except HDPE);

expensive but effective;
little or no environmental/health impact;
not easily poisoned by impurities;
cause (considerable) increase in rate;
ability to work under mild/severe conditions;

b. side-chains / branching present (in LDPE);

limits closer packing / chains further apart / *OWTTE*;
less van der Waals’/dispersion/London forces / *OWTTE*;
*Award mark for less intermolecular forces. Do **not** accept weaker.*
low(er) melting point (than HDPE);
No mark for different melting point.
Accept reverse argument for HDPE.

c. CO_2 is a greenhouse gas / causes climate change / global warming / formation of soot/particulates / melting of polar ice caps / rising sea levels / *OWTTE*;

Accept CO produced is toxic/poisonous.

Examiners report

a. (a) was surprisingly poorly answered, with very few candidates understanding how to discuss two factors in choosing catalysts, although they should have studied several factors.

b. (b) was answered well.

c. (c) was answered well.

Lanthanum metal may be produced by the electrolysis of molten $LaBr_3$.

a. State why lanthanum cannot be produced by reducing its oxide with carbon. [1]

b. Calculate the current (*I*), in A, required to produce 1.00 kg of lanthanum metal per hour. Use the formula $Q(C) = I(A) \times t(s)$ and sections 2 and 6 of the data booklet. [3]

Markscheme

a. too high/higher than carbon in the reactivity series

OR

carbon/C is a weaker reducing agent than lanthanum/La

Accept "lanthanum is more reactive than carbon".

Accept "lanthanum is a weaker oxidizing agent than carbon".

Accept converse arguments.

[1 mark]

b. amount of La «$= \frac{1000\text{ g}}{138.91\text{ g mol}^{-1}}$» = 7.20 «mol»

Q «= 7.20 mol x 3 x 96 500 C mol^{-1}» = 2.08 x 10^6 «C»

I «$\frac{2.08\times10^6\text{ C}}{60\times60\text{ s}}$» = 579 «A»

Award [3] for "578 «A»" (from premature rounding) or "579 «A»".

[3 marks]

Examiners report

a. [N/A]
b. [N/A]

Lanthanum, La, and antimony, Sb, form compounds with bromine that have similar formulas, $LaBr_3$ and $SbBr_3$.

a. Determine the type of bond present in $SbBr_3$, showing your method. Use sections 8 and 29 of the data booklet. [2]

b. Lanthanum has a similar electronegativity to group 2 metals. Explain, in terms of bonding and structure, why crystalline lanthanum bromide is brittle. [2]

Markscheme

a. polar covalent

average electronegativity «= $\frac{1}{2}$(3.0 + 2.0)» = 2.5 ***AND*** electronegativity difference «= 3.0 – 2.0» = 1.0

[2 marks]

b. ionic bonding

OR

electrostatic forces between ions

«slight» movement brings ions of same charge adjacent to each other «causing the crystal to break»
OR
«slight» movement results in repulsion between layers «causing the crystal to break»

[2 marks]

Examiners report

a. [N/A]
b. [N/A]

Aluminium and high density polyethene (HDPE) are both materials readily found in the kitchen, for example as saucepans and mixing bowls respectively. In these applications it is important that they are impermeable to water.

Both materials are also used in other applications that are more demanding of their physical properties. Carbon nanotubes are often incorporated into their structures to improve certain properties.

a. Discuss, in terms of its structure, why an aluminium saucepan is impermeable to water. [2]

b.i. State the name given to a material composed of two distinct solid phases. [1]

b.ii. State one physical property of HDPE that will be affected by the incorporation of carbon nanotubes. [1]

b.iii. Describe how carbon nanotubes are produced by chemical vapour deposition (CVD). [3]

b.iv. State the property of carbon nanotubes that enables them to form a nematic liquid crystal phase. [1]

Markscheme

a. «close packed» lattice of metal atoms/ions

no spaces for water molecules to pass though the structure

[2 marks]

b.i. composite

[1 mark]

b.ii. melting point

OR

permeability

OR

density

OR

conductivity

OR

elasticity/stiffness

OR

brittleness/flexibility

OR

«tensile» strength

Accept "colour/transparency".

[1 mark]

b.iii. *Any three of:*

hydrocarbon/carbon-containing gas/compound

mixed with inert gas

heat/high temperature

«transition» metal catalyst

hydrocarbon/carbon compound decomposes to form carbon «nanotubes»

nanotubes form on catalyst surface

Accept "ethanol" or specific hydrocarbons.

Accept "N_2", "H_2", "NH_3" or specific inert gases.

Accept temperature or range within 600–800 °C.

Accept specific metals such as Ni, Co or Fe.

[3 marks]

b.iv. rod shaped molecules

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
b.iii. [N/A]
b.iv. [N/A]

Chemical vapour deposition (CVD) produces multi-walled carbon nanotubes (MWCNT) of a more appropriate size for use in liquid crystals than production by arc discharge.

a. State the source of carbon for MWCNT produced by arc discharge and by CVD. [2]

Arc discharge:

. . . . . .

CVD:

. . . . . .

b. Discuss **three** properties a substance should have to be suitable for use in liquid crystal displays. [3]

Markscheme

a. *Arc discharge:*

graphite electrode

OR

hydrocarbon solvent

CVD:

gaseous hydrocarbons

Accept "carbon electrode".

*Accept specific examples of suitable hydrocarbon solvents (eg, methyl benzene/toluene **OR** cyclohexane).*

*Accept specific examples of suitable gaseous hydrocarbons (eg, methane, ethane, ethyne/acetylene) **OR** carbon monoxide **OR** carbon dioxide.*

[2 marks]

b. *Any three from:*

chemically stable ***AND*** does not «chemically» degrade over time

stable over range of temperatures ***AND*** to avoid «voltage/random shift» fluctuations ✔

polar ***AND*** influenced by an electric field

strong intermolecular forces ***AND*** allow molecule to align in specific orientations ✔

rapid switching speed/low viscosity ***AND*** change orientation «quickly» when electric field is applied/reversed

*Award **[1 max]** for identifying three correct properties without any discussion or incorrect interpretation of suitability.*

Accept “voltage” for “electric field”.

[3 marks]

Examiners report

a. [N/A]
b. [N/A]

Catalysts can take many forms and are used in many industrial processes.

Suggest two reasons why it might be worth using a more expensive catalyst to increase the rate of a reaction.

Markscheme

Any two of:

greater selectivity

higher efficiency

longer life expectancy

OR

not easily poisoned

easier to recover

low«er» environmental impact

large range of conditions/temperatures/pressures supported

lower energy costs

increase in yield «per unit time» offsets cost of catalyst

[Max 2 Marks]

Examiners report

[N/A]

Nanotechnology has many applications.

a. State equations for the formation of iron nanoparticles and carbon atoms from $Fe(CO)_5$ in the HIPCO process. [2]

b. Outline why the iron nanoparticle catalysts produced by the HIPCO process are more efficient than solid iron catalysts. [1]

c. Discuss one possible risk associated with the use of nanotechnology. [1]

Markscheme

a. $Fe(CO)_5$ (g) → Fe (s) + 5CO (g)

$2CO$ (g) → C (s) + CO_2 (g)

b. large surface area «on which carbon nanotubes form»

c. unknown health effects

OR

unknown effect on immune systems

OR

unknown environmental effects

OR

greater inflammatory response

OR

lung damage/toxicity

OR

hazardous effect on biodiversity

OR

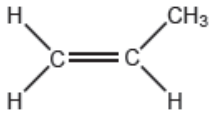
risk of explosion

*Do **not** accept vague responses.*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Propene can polymerize to form polypropene.

Propene monomer: 

a. Sketch four repeating units of the polymer to show atactic and isotactic polypropene. [2]

Atactic:

Isotactic:

b.i. State the chemical reason why plastics do not degrade easily. [1]

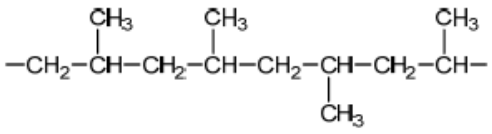
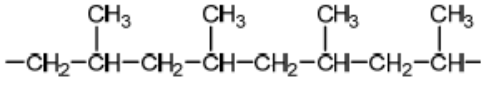
b.ii. Compare **two** ways in which recycling differs from reusing plastics. [2]

c. Civilizations are often characterized by the materials they use. [1]

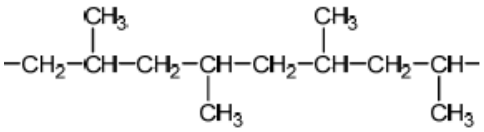
Suggest an advantage polymers have over materials from the iron age.

Markscheme

a.

Atactic	 ✓
Isotactic	 ✓

*Do **not** accept syndiotactic (alternating orientation of the CH_3 groups), eg,*



for M1 or M2.

Accept any correct atactic ordering of CH_3 groups.

Penalize missing hydrogens or incorrect bond connectivities once only.

Accept skeletal structures.

Ignore continuation bonds, brackets and "n" indices in structures.

[2 marks]

b.i. strong covalent bonds

Accept "moisture cannot get inside the plastic matrix, and bacteria cannot live without moisture, so they cannot attack the polymer chains".

Accept "bacteria lack the enzymes required to break down the hydrocarbon chains".

[1 mark]

b.ii *Any two of:*

Recycling: shredded/melted/reformed ***AND*** *Reuse*: used in its current form

recycling is more energy intensive «than reusing»

recycling degrades the quality of plastic but reusing «typically» does not

recycling breaks down original product to form a new product whereas reuse extends product life

[2 marks]

c. more pliable/flexible materials

OR

more durable/non-corrosive/longer-lasting materials

OR

greater variety of materials

OR

lower density

OR

can be clear/translucent

Accept "more adaptable".

*Do **not** accept just "more useful".*

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

Liquid Crystal on Silicon, LCoS, uses liquid crystals to control pixel brightness. The degree of rotation of plane polarized light is controlled by the voltage received from the silicon chip.

a. Two important properties of a liquid crystal molecule are being a polar molecule and having a long alkyl chain. Explain why these are essential components of a liquid crystal molecule. [2]

Polar molecule:

. . . . . .

. . . . . .

Long alkyl chain:

. . . . . .

. . . . . .

b. Metal impurities during the production of LCoS can be analysed using ICP-MS. Each metal has a detection limit below which the uncertainty of data is too high to be valid. Suggest **one** factor which might influence a detection limit in ICP-MS/ICP-OES. [1]

Markscheme

a. *Polar molecule:*

«orientation of molecule» influenced by electric field/«applied» voltage/«applied» potential «difference»/«applied» current

OR

can be switched on and off

Long alkyl chain:
prevent close packing of molecules
OR
molecules can align
OR
reduces the melting point of the liquid crystal/LC «phase making liquid at room temperature»

Accept "makes molecule rod-shaped" for M2.

[2 marks]

b. inability to replicate calibrations below certain levels

OR

variation in methodology

OR

variation between machines calibrated with the same samples

OR

variation in plasma torches

OR

different detection limits for MS ***AND*** OES

OR

interference from solvents/other chemicals

OR

inability to produce pure standards

OR

chance that low signal ***AND*** blank are same

[1 mark]

Examiners report

a. [N/A]
b. [N/A]

Both HDPE (high density polyethene) and LDPE (low density polyethene) are produced by the polymerization of ethene.

a. Both of these are thermoplastic polymers. Outline what this term means. [1]

b.i. Compare and contrast the structures of HDPE and LDPE. [2]

b.ii. State **one** way in which a physical property of HDPE, other than density, differs from that of LDPE as a result of this structural difference. [1]

c.i. The production of HDPE involves the use of homogeneous catalysts. Outline how homogeneous catalysts reduce the activation energy of reactions. [1]

c.ii. Trace amounts of metal from the catalysts used in the production of HDPE sometimes remain in the product. State a technique that could be used to measure the concentration of the metal. [1]

d. Suggest **two** of the major obstacles, other than collection and economic factors, which have to be overcome in plastic recycling. [2]

e. Suggest why there are so many different ways in which plastics can be classified. HDPE can, for example, be categorized thermoplastic, an addition polymer, having Resin Identification Code (RIC) 2, *etc*. [1]

Markscheme

a. soften/melt when heated

OR

can be melted and moulded

Accept "low melting point" ***OR*** *"can be moulded when heated".*

[1 mark]

b.i. both have «long» hydrocarbon chains

OR

both have chains comprising CH_2 units

HDPE has little/no branching ***AND*** LDPE has «more» branching

Accept "CH_2–CH_2 units".

Accept "HDPE more crystalline".

[2 marks]

b.ii. HDPE is more rigid/less flexible

OR

HDPE has a higher melting point

OR

HDPE has greater «tensile» strength

Accept "HDPE has lower ductility".

[1 mark]

c.i. form «temporary» activated complexes/reaction intermediates

*Accept "consumed in one reaction/step **AND** regenerated in a later reaction/step".*

Accept "provides alternative mechanism".

[1 mark]

c.ii. inductively coupled plasma/ICP spectroscopy using mass spectroscopy/mass spectrometry/MS/ICP-MS

OR

inductively coupled plasma/ICP spectroscopy using optical emission spectroscopy/OES/ICP-OES

Accept "atomic absorption/aa spectroscopy" or "MS/massspectroscopy/mass spectrometry".

[1 mark]

d. *Any two of:*

many types «of plastics» exist

OR

«plastics» require sorting «by type»

«plastics» need to be separated from non-plastic materials

OR

«often» composites/moulded on/bound to non-plastic/other components

Accept other valid factors such as thermal decomposition of some plastics, production of toxic fumes, etc.

[2 marks]

e. «different classifications are appropriate for» different properties/applications/purposes

[1 mark]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]
d. [N/A]
e. [N/A]

It is wise to fill dental cavities before irreversible tooth decay sets in. An amalgam (alloy of mercury, silver, and other metals) is often used although many prefer a white composite material.

a. Outline the composition of an alloy and a composite. [2]

Alloy:

. . . . . .

. . . . . .

Composite:

. . . . . .

. . . . . .

b.i. Outline why an alloy is usually harder than its components by referring to its structure. [1]

b.ii At present, composite fillings are more expensive than amalgam fillings. [1]

Suggest why a patient might choose a composite filling.

c. Explain how Inductively Coupled Plasma (ICP) Spectroscopy could be used to determine the concentration of mercury in a sample of dental filling. [3]

Markscheme

a. *Alloy:*

mixture of metal with other metals/non-metals

OR

mixture of elements that retains the properties of a metal

Composite:
reinforcing phase embedded in matrix phase

*Award **[1 max]** for implying "composites only have heterogeneous/nonhomogeneous compositions".*

[Max 2 Marks]

b.i. difference in ionic/atomic radius prevents layers sliding over each other

Accept “difference in diameter/packing of cations prevents layers sliding over each other”.

b.ii. concern about Hg poisoning

OR

«composite» is white «so looks more like tooth»

OR

galvanic response potential exists

OR

local allergic potential

OR

less damage/destruction of healthy tooth tissue

OR

long term corrosion requires replacement

OR

gradual darkening of tooth

Accept other correct responses.

c. *Any three of:*

sample injected into argon «plasma»

atoms «of sample» are excited/ionised

OR

electrons are promoted

electrons drop back/recombine with ions ***AND*** emit photons of characteristic energies/wavelengths/frequencies

total number of photons is proportional to concentration of element

actual concentration found from calibration/standard curve

Accept "graph/plot" for “curve”.

[Max 3 Marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

Rhodium and palladium are often used together in catalytic converters. Rhodium is a good reduction catalyst whereas palladium is a good oxidation catalyst.

a. In a catalytic converter, carbon monoxide is converted to carbon dioxide. Outline the process for this conversion referring to the metal used. [3]

b.i. Nickel is also used as a catalyst. It is processed from an ore until nickel(II) chloride solution is obtained. Identify **one** metal, using sections 24 and 25 of the data booklet, which will not react with water and can be used to extract nickel from the solution. [1]

b.ii. Deduce the redox equation for the reaction of nickel(II) chloride solution with the metal identified in (b)(i). [1]

c. Another method of obtaining nickel is by electrolysis of a nickel(II) chloride solution. Calculate the mass of nickel, in g, obtained by passing a current of 2.50 A through the solution for exactly 1 hour. Charge (Q) = current (I) × time (t). [2]

Markscheme

a. carbon monoxide/CO adsorbs onto palladium/Pd

bonds stretched/weakened/broken
OR
«new» bonds formed
OR
activation energy/E_a «barrier» lowered «in both forward and reverse reactions»

products/CO_2 desorb «from catalyst surface»

[3 marks]

b.i. Fe/iron

OR

Zn/zinc

OR

Co/cobalt

OR

Cd/cadmium

OR

Cr/chromium

Accept "Mn/manganese".

[1 mark]

b.ii. $Ni^{2+}(aq) + Fe(s) \rightarrow Ni(s) + Fe^{2+}(aq)$

OR

$Ni^{2+}(aq) + Zn(s) \rightarrow Ni(s) + Zn^{2+}(aq)$

OR

$Ni^{2+}(aq) + Co(s) \rightarrow Ni(s) + Co^{2+}(aq)$

OR

$Ni^{2+}(aq) + Cd(s) \rightarrow Ni(s) + Cd^{2+}(aq)$

OR

$Ni^{2+}(aq) + Cr(s) \rightarrow Ni(s) + Cr^{2+}(aq)$

Accept "$3Ni^{2+}(aq) + 2Cr(s) \rightarrow 3Ni(s) + 2Cr^{3+}(aq)$".

*Do **not** penalize similar equations involving formation of $Fe^{3+}(aq)$, $Mn^{2+}(aq)$ **OR** $Co^{3+}(aq)$.*

Ignore Cl^- ions.

Accept correctly balanced non-ionic equations eg, "$NiCl_2(aq) + Zn(s) \rightarrow Ni(s) + ZnCl_2(aq)$" etc.

Do not allow ECF from (b)(i).

[2 mark]

c. $n(e^-)$ «$= \frac{2.50\ A \times 3600\ s}{96500\ C\ mol^{-1}}$» = 0.09326 «mol»

OR

$n(Ni)$ «$= \frac{0.09326\ mol}{2}$» = 0.04663 «mol»

$m(Ni)$ «= 0.04663 mol x 58.69 g mol^{-1}» = 2.74 «g»

*Award **[2]** for correct final answer.*

[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

Research has led to the discovery of new catalysts that are in high demand and used in many chemical industries.

a. Explain, with reference to their structure, the great selectivity of zeolites as catalysts. [2]

b. Nanocatalysts play an essential role in the manufacture of industrial chemicals. [3]

(i) Describe the high pressure carbon monoxide (HIPCO) method for the production of carbon nanotubes.

(ii) Outline one benefit of using nanocatalysts compared to traditional catalysts in industry.

Markscheme

a. pores/cavities/channels/holes/cage-like structures

«only» reactants with appropriate/specific size/geometry fit inside/go through/are activated/can react

Accept "molecules/ions" for reactants.

b. i

iron«0»«penta»carbonyl/$Fe(CO)_5$ catalyst decomposes
OR
$Fe(CO)_5$ (g) → Fe(s) + 5CO(g)
OR
metal nanocatalyst/clusters/particles formed «in situ»

Accept "cobalt-molybdenum/Co-Mo/CoMo" as a catalyst

$2CO(g) \rightarrow CO_2(g) + C(s)$

Accept "conversion of CO molecules into CNTs/ SWNTs" for M2.

ii

higher efficiency per unit mass/volume of the catalyst «due to higher surface to mass/volume ratio»
OR
greater selectivity «due to metal nanoclusters/surface topology/pore size»
OR
higher stability of the catalyst «due to lower tendency to aggregation»
OR
reduced cost of the catalyst/product/chemicals «as precious metals can be replaced with nanocatalysts made of inexpensive materials»

Accept "high conversion efficiency".

Accept specific examples such as use of nanocatalysts in fuel cells/catalytic converters «leading to reduced use of Pt/Rh/Pd».

Accept "nanocatalysts often operate under milder conditions «so less energy consumption involved/so promotes principles of green chemistry»".

*Accept "lower energy consumption" **OR** "reduced carbon footprint" **OR** "reduced global warming".*

Accept "nanocatalysts often have long lifetimes «so more economical».

Accept "some nanocatalysts have enzyme mimicking activities".

Examiners report

a. [N/A]
b. [N/A]

Both carbon monoxide and hydrogen can be used to reduce iron ores. State the equations for the reduction of magnetite, Fe_3O_4, with

a. Explain why iron is obtained from its ores using chemical reducing agents but aluminium is obtained from its ores using electrolysis. [2]

b. Both carbon monoxide and hydrogen can be used to reduce iron ores. State the equations for the reduction of magnetite, Fe_3O_4, with [2]

(i) carbon monoxide.

(ii) hydrogen.

c. Explain why much of the iron produced in a blast furnace is converted into steel. [2]

d. State the materials used for the positive and negative electrodes in the production of aluminium by electrolysis. [2]

Positive electrode:

Negative electrode:

Markscheme

a. Al is more reactive than Fe / Al is higher than Fe in the reactivity series;

it is harder to reduce aluminium ores compared to iron ores / Fe^{3+} is a better oxidizing agent than Al^{3+} / *OWTTE*;

b. (i) $Fe_3O_4 + 4CO \rightarrow 3Fe + 4CO_2$;

(ii) $Fe_3O_4 + 4H_2 \rightarrow 3Fe + 4H_2O$;

c. steel has more desirable (physical) characteristics than iron / steel is stronger than iron / *OWTTE*;

by adjusting the composition of steel it can be given specific properties / *OWTTE*;

d. *Positive electrode*

graphite/carbon;

Negative electrode

graphite/carbon (on a steel liner);

Examiners report

a. Part (a), which required candidates to explain the relative reactivity of iron and aluminium, proved challenging for most candidates.

b. Many candidates could correctly state the products of reduction of magnetite but several failed to balance the equations and thus lost marks.

c. Most candidates could explain the advantages of steel over iron in part (c).

d. Very few candidates could identify the electrodes used in the production of aluminium, but most could explain the importance of recycling aluminium in part (d).

Lanthanum nanoparticles are incorporated into certain catalysts and the electrodes of some fuel cells.

a. State the major advantage that nanoparticles have in these applications. [1]

b. Suggest why nanoparticles need to be handled with care. [1]

Markscheme

a. large surface area

[1 mark]

b. «potentially» explosive

OR

small size/large surface area could give dangerously fast reactions

OR

unknown health effects

OR

potentially toxic

OR

immune system/allergy concerns

*Do **not** accept just "dangerous/poisonous/toxic".*

Accept other valid concerns.

[1 mark]

Examiners report

a. [N/A]
b. [N/A]

Describe how the structures of ceramics differ from those of metals.

Markscheme

ceramics have «giant» ionic/covalent/ionic ***AND*** covalent structures

metals contain lattice of positive ions/cations in sea of delocalized electrons

*Accept **[1 max]** for "ionic/covalent/ionic and covalent bonds in ceramics **AND** metallic bonds in metals".*

Accept suitable diagram for M2.

Examiners report

[N/A]

Petroleum (mineral oil) can be used either as a fuel or a chemical feedstock.

a. Name **two** fuels that are obtained from petroleum. [1]

b. Describe **one** environmental problem that can result from the combustion of these fuels in the internal combustion engine and identify the specific combustion product responsible. [2]

c. Plastic litter is an environmental problem that results from the use of petroleum as a chemical feedstock. Identify the property of plastics that is responsible for this. [1]

d. One product that is made from crude oil is the chemical feedstock that can be used to synthesize commercial liquid-crystal displays. Discuss the properties that a substance must have to make it suitable for use as a liquid-crystal display. [2]

Markscheme

a. *Any two for **[1]***

petrol/gasoline

kerosene/paraffin/aviation fuel

diesel

fuel oil/gas oil

petroleum gas/refinery gas

b. global warming;

carbon dioxide;

OR

air pollution;

carbon monoxide / particulates / oxides of nitrogen/NO/NO_2 / $VOCs$;

Accept oxides of sulphur/SO_2.

OR

acid rain;

oxides of nitrogen/NO/NO_2;

Accept oxides of sulphur/SO_2.

c. slow decomposition / not biodegradeable;

d. chemically stable;

liquid crystal phase over a suitable range of temperatures;

rapid switching speed;

Examiners report

a. In part (a) a significant number of candidates named two fuels obtained from petroleum.

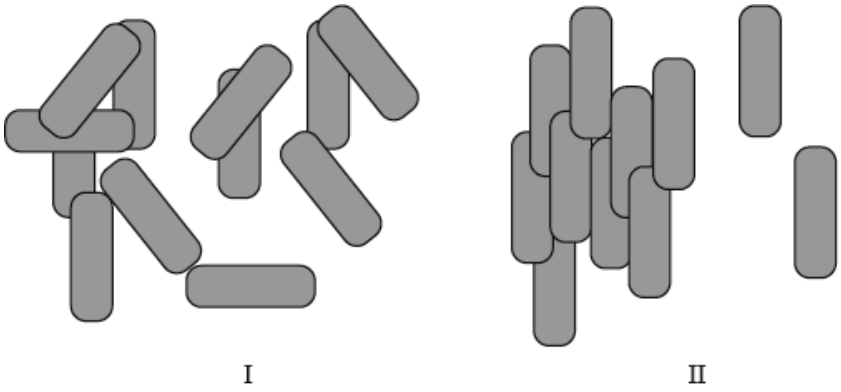
b. A significant number of candidates described the environmental problem.

c. The non-biodegradable property of plastics was stated correctly by many candidates.

d. The properties of a material that made it suitable for use as a liquid crystal display demonstrated poor understanding by many candidates.

Liquid crystals are widely used in electrically controlled liquid crystal display (LCD) devices such as calculators, computers and watches.

a. Describe the meaning of the term *liquid crystals*. State and explain which diagram, I or II, represents molecules that are in a liquid crystalline phase. [2]



b. Distinguish between *thermotropic* and *lyotropic* liquid crystals and state **one** example of each type. [4]

c. Discuss the properties needed for a substance to be used in liquid crystal displays. [2]

Markscheme

a. liquid crystals are fluids that exhibit orientation of the molecules/an orderly arrangement of molecules;

II, since there is one-dimensional order (characteristic of a liquid crystalline phase);

b. *thermotropic liquid crystals* are pure substances that show liquid crystal behaviour over a temperature range (between the solid and liquid states);

example (of thermotropic liquid crystals) is biphenyl nitriles;

lyotropic liquid crystals are solutions that show the liquid crystal state at certain concentrations;

example (of lyotropic liquid crystals) is soap in water;

Award marks for examples, only if they are associated with the correct class of liquid crystals.

c. chemically stable;

a liquid crystal phase stable over a suitable range of temperatures;

polar in order to change orientation when an electric field is applied;

rapid switching speed;

Examiners report

a. Candidates were able to define liquid crystals but often confused the two diagrams.

b. Candidates also had difficulty distinguishing between thermotropic and lyotropic crystals and providing suitable examples for each. This emphasised again that candidates had not learnt definitions accurately with correct chemical terminology.

c. [N/A]

Liquid-crystal displays are used in digital watches, calculators and laptops.

a. Describe the liquid-crystal state, in terms of molecular arrangement, and explain what happens as temperature increases. [3]

b. Discuss **three** properties a substance should have if it is to be used in liquid-crystal displays. [3]

Markscheme

a. (rod-shaped) molecules aligned in the same direction;

increasing temperature causes arrangement to lose its directional order/molecules to become more randomly arranged;

until normal liquid state occurs;

b. chemically stable so that it does not undergo reactions;

liquid-crystal phase stable over a range of temperatures so that frequent malfunctions do not occur;

molecules should be polar so the electronic current can influence direction;

there should be a rapid change in direction / fast switching speed;

Award [2 max] if no reasons are given.

Examiners report

a. Liquid-crystals were known well by many candidates. Some were ill-prepared to answer these questions.

b. Liquid-crystals were known well by many candidates. Some were ill-prepared to answer these questions.

Poly(ethene) can be produced in a low density (LDPE) or a high density (HDPE) form.

a.i. Describe how the two forms differ in their chemical structure. [1]

a.ii. Explain in terms of their structures how the flexibility of the two forms of poly(ethene) differ. [2]

b.i. Describe why pentane is sometimes added during the formation ofpoly(phenylethene), also known as polystyrene. [1]

b.ii. State **one** use for the product formed from this process. [1]

Markscheme

a.i. HDPE/high density polyethene has little/no branching/side chains **and** low density has (many) branches/side chains;

a.ii. branching in LDPE/ low density polyethene prevents chains fitting closely together;

weaker intermolecular/van der Waals'/London/dispersion forces so more flexible;

Accept opposite statements for HDPE/high density polyethene.

b.i. vaporizes causing it to expand/form expanded polystyrene / *OWTTE*;

b.ii. (thermal) insulator / packaging material / absorb shock;

Do not accept just cups.

Examiners report

a.i. The answers to this often betrayed a confusion between isotactic and atactic polypropene. That being said the link between packing and the strength of the dispersion forces was relatively well understood at least to the extent of gaining one of the marks. Most candidates were aware of the role of pentane and even the weakest were scoring the mark for a use of expanded polystyrene.

a.ii. The answers to this often betrayed a confusion between isotactic and atactic polypropene. That being said the link between packing and the strength of the dispersion forces was relatively well understood at least to the extent of gaining one of the marks. Most candidates were aware of the role of pentane and even the weakest were scoring the mark for a use of expanded polystyrene.

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Exciting developments have taken place in recent years in the area of nanotechnology.

Carbon nanotubes can be used to make *designer catalysts*.

a. Define the term *nanotechnology*, and state why it is of interest to chemists. [2]

b. (i) Describe the structure of carbon nanotubes. [3]

(ii) State **one** physical property of carbon nanotubes.

c. Suggest **two** concerns about the use of nanotechnology. [2]

Markscheme

a. nanotechnology involves research and technology developments at the 1 nm to 100 nm range;

structures with novel properties (because of their small size);

ability to manipulate on the atomic scale;

Overlap here between definition and matters of interest, so accept any two.

b. (i) (main) cylinder consists of carbon hexagons / OWTTE;

pentagons close structures/tubes at ends / *OWTTE*;

Marks may also be scored by means of a suitable diagram showing above.

(ii) high tensile strength / low density / high thermal conductivity / (electrical) conductors / (electrical) semi-conductors / high melting points;

c. health concerns / concern that the human immune system will be defenceless against particles on the nanoscale;

potential toxicity of materials / toxicity regulations are difficult (to apply);

possible explosive nature of large scale manufacture of nanoparticles;

political issues;

Apply OWTTE throughout.

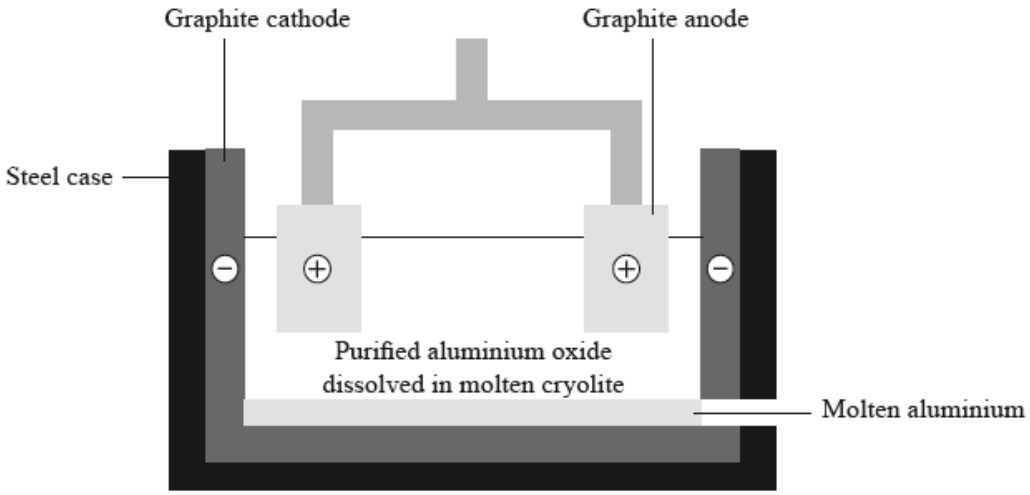
Examiners report

a. Many candidates were able to define the term nanotechnology and scored M1 but only about half managed to score M2.

b. In (b)(i), although most mentioned hexagons and pentagons, many failed to mention cylinders and ends of tubes.

c. In (c) many candidates were able to score at least one mark, some scored both marks but, again, some vague answers were seen.

Aluminium is chemically reactive so it has to be extracted by the electrolysis of aluminium oxide dissolved in molten cryolite.



a. Deduce an equation for the discharge of the ions at each electrode. [2]

Positive electrode (anode):

Negative electrode (cathode):

b. (i) Outline why aluminium is alloyed with copper and magnesium when used to construct aircraft bodies. [2]

(ii) State **two** properties of aluminium that make it suitable for use in overhead power cables.

Markscheme

a. *Positive electrode (anode):*

$2O^{2-} \rightarrow O_2(g) + 4e^- / O^{2-} \rightarrow \frac{1}{2}O_2(g) + 2e^- / 2O^{2-} - 4e^- \rightarrow O_2(g) /$

$O^{2-} - 2e^- \rightarrow \frac{1}{2}O_2(g);$

Allow C(s) + $2O^{2-} \rightarrow CO_2(g) + 4e^-$.

Negative electrode (cathode):

$Al^{3+} + 3e^- \rightarrow Al(l);$

Accept e instead of e^-.

Ignore state symbols.

*If correct equations shown at wrong electrodes, award **[1 max]**.*

b. (i) harder/stronger (than pure aluminium);

(ii) *Award **[1]** for any two of*:

good conductor of electricity;

resists corrosion;

Do not allow rusting.

low density;

Do not allow lighter/light mass/light weight.

ductile;

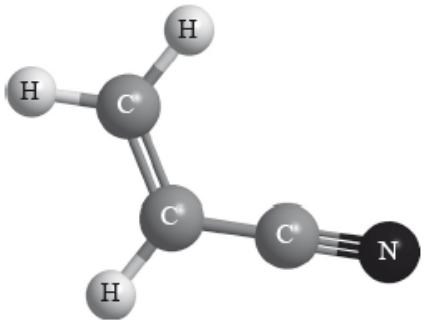
Do not allow malleable.

Examiners report

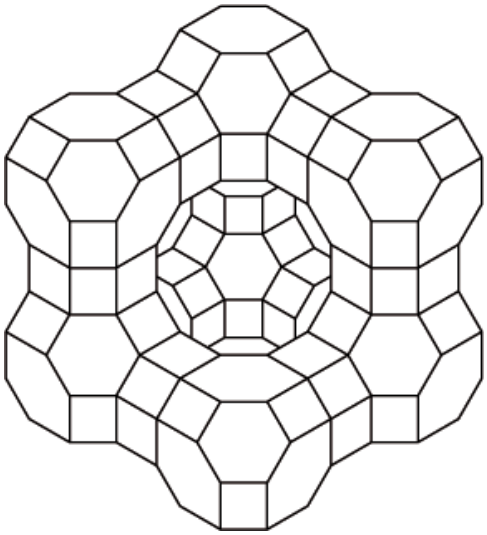
a. In (a), most were able to write the correct half-equation for the cathode though incorrect states were commonly seen, e.g. (aq). The anode half-equation was not well known.

b. Both parts of (b) were well done. In (ii), incorrect answers included malleability and light mass.

Polyacrylonitrile is an important polymer used in the manufacture of carbon fibres. The monomer has the structure below.



The rate of the polymerization reaction from the gaseous monomer is increased in the presence of a zeolite with the cage structure shown.



A new range of light batteries has been developed that uses open carbon nanotubes, covered with silicon, as electrodes.

a.i. Polyacrylonitrile is similar to polypropene and can exist in two forms. [2]

Draw the structure of the isotactic form of polyacrylonitrile showing **three** repeating units.

a.ii. Polyacrylonitrile is similar to polypropene and can exist in two forms. [2]

Explain why the isotactic form is more suitable for the manufacture of strong fibres.

b.i. Identify the role of the zeolite in the reaction. [1]

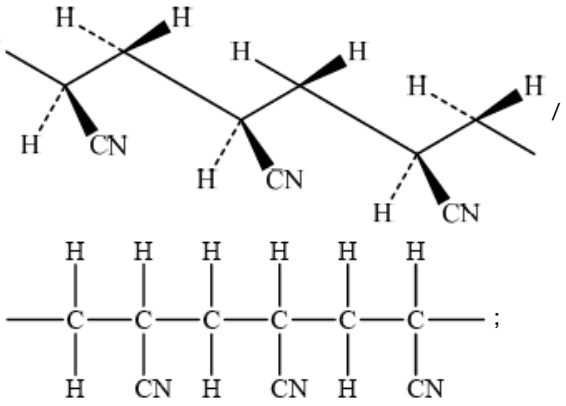
b.ii. Suggest an explanation for its efficiency in favouring the production of the crystalline polymer. [1]

c.i. Outline the structure of the open carbon nanotubes. [1]

c.ii. State a property of these nanotubes that makes them suitable for this use. [1]

Markscheme

a.i.



Continuation bonds at end of structure needed.

Hydrogen atoms must be included.

*Award **[1]** for chain with CN groups on alternate carbons.*

*Award **[2]** for correct chain with CN on alternate carbons with same orientation.*

a.ii. chains pack together better;

strong intermolecular/attractive forces between chains;

chains do not move past each other easily (so fibre strong/rigid);

b.i. catalyst;

b.ii. (selective) because of dimensions/shape/size (of cage);

Accept "large surface area".

c.i. cylinder with hexagons of carbon (atoms);

Accept suitable diagram.

Do not award mark if pentagons are also mentioned.

c.ii. (electrical) conductor;

Accept low density.

Do not accept light.

Examiners report

a.i. Some very strange polymers were suggested in (a) (i) with the –CN group becoming integrated into the carbon backbone. Candidates were, however, able to explain why the isotactic form is more suitable for fibres. The role of the zeolite in (b) was usually correctly identified but it was not known that the dimensions, size or shape of the cage were an explanation for its efficiency. Most were able to give a good account of carbon nanotubes although some introduced pentagons at the end. This was specifically ruled out in the question – *open* carbon nano-tubes.

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Nitrogen dioxide and sulfur dioxide are two air pollutants.

a. Nitrogen dioxide is formed in a two-stage process. Describe **one** anthropogenic (man-made) source of nitrogen dioxide and state the **two** chemical equations for its formation. [2]

c. Both of these air pollutants also contribute to acid deposition. State **one** chemical equation for **each** gas to describe how each forms an acidic solution. [2]

Markscheme

a. combustion of fuels (at high temperature);

Accept internal combustion/aircraft/jet engines.

$N_2 + O_2 \rightarrow 2NO$ **and** $2NO + O_2 \rightarrow 2NO_2$;

c. $2NO_2 + H_2O \rightarrow HNO_2 + HNO_3 / 4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$;

$SO_2 + H_2O \rightarrow H_2SO_3 / 2SO_2 + 2H_2O + O_2 \rightarrow 2H_2SO_4$;

Examiners report

a. The man-made source of nitrogen oxide was generally very well answered, although the equations for its formation proved demanding.

c. The chemical equation for the formation of sulfuric acid was given correctly by many candidates, but it was surprising to see that a significant number of candidates did not know the chemical formula for nitric acid.

A student wanted to determine the formula of indium sulfate. She applied an electrical current of 0.300A to an aqueous solution of indium sulfate for 9.00×10^3 s and found that 1.07 g of indium metal deposited on the cathode.

a. Calculate the charge, in coulombs, passed during the electrolysis. [1]

$\left(\text{current } I = \frac{\text{charge } Q}{\text{time } t}\right)$

b. Calculate the amount, in mol, of electrons passed using section 2 of the data booklet. [1]

c. Calculate the mass of indium deposited by one mole of electrons. [1]

d. Calculate the number of moles of electrons required to deposit one mole of indium. Relative atomic mass of indium, A_r=114.82. [1]

e. Deduce the charge on the indium ion and the formula of indium sulfate. [1]

Markscheme

a. «0.300A × 9.00 × 10^3 s =» 2.70 × 10^3 «C»

b. «mol e^- = $\frac{2700\ \text{C}}{96\,500\ \text{C mol}^{-1}}$ =» 2.80 × 10^{-2} «mol»

c. «$\frac{1.07\text{g}}{0.0280\text{mol}}$=» 38.2 «g»

d. «$\frac{114.82\ \text{g}}{38.2\ \text{g mol}^{-1}}$ e^- =» 3.01/3.00 «mol e^-»

e. In^{3+} /3+ ***AND*** $In_2(SO_4)_3$

*Do **not** accept "+3/3"*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]

It was over a hundred years after the accidental discovery of liquid crystals that liquid-crystal displays (LCDs) came into common use in the 1990s.

Liquid crystals are formed over a temperature range between the solid and the liquid state.

a. Describe the nematic liquid-crystal phase in terms of the arrangement of the molecules. [2]

b. Explain the effect of increasing the temperature on the nematic liquid crystal. [2]

Markscheme

a. no layered arrangement / molecules distributed randomly;

(on average) molecules point in same direction/orientation/directional order;

Accept suitable diagram.

b. directional order decreases/is lost / starts to behave like a liquid;

extra energy causes greater movement/overcomes intermolecular forces;

Examiners report

a. Very few of the candidates scored full marks on the description of the nematic liquid-crystal phase.

b. Probably because of the difficulty of selecting the correct words, and surprisingly only a few scored the mark in terms of the effect of the extra energy, namely causing greater movement or overcoming intermolecular forces.

Addition polymers are extensively used in society. The properties of addition polymers may be modified by the introduction of certain substances.

(a) For two different addition polymers, describe and explain **one** way in which the properties of addition polymers may be modified.

Polymer one:

Polymer two:

(b) Describe and explain how the extent of branching affects the properties of poly(ethene).

(c) Discuss **two** advantages and **two** disadvantages of using poly(ethene).

Markscheme

(a) *Accept **two** of the following four pairs of answers.*

plasticizers in polyvinyl chloride;

the more plasticizer the more flexible the plastic;

OR

volatile hydrocarbons in the formation of (expanded) polystyrene;

volatile hydrocarbons vaporize during the formation of the polystyrene and reduce the density of (expanded) polystyrene / improving insulating properties;

OR

sulfur added to diene/2-methyl-1,3-butadiene/rubber (produces cross-link polymer);

maintains its spring/softness (for longer periods of time);

OR

blowing air/steam during the polymerisation to form polyurethane;

reduces density/increases springiness

(b) high degree of branching produces low density polyethene;

small degree of branching produces high density polyethenes;

HDPE/low branching is stiffer/stronger/more resistant to heat and corrosion/less permeable to gases / LDPE/high branching is more flexible/weaker/less resistant to heat and corrosion/more permeable to gases;

(c) *Advantages:*

polymer's properties can be customized / *OWTTE*

can be recycled/reused

cheap

chemically inert

transparent

non-toxic

*Any two correct answers scores **[1]**.*

Disadvantages:

rely on non-renewable energy sources

volume occupied by plastics in landfill

non-biodegradability

burning produces toxic gases

burning produces carbon dioxide (greenhouse gas)

burning printed polyethene can release toxic (heavy) metals/substances

may cause suffocation/death of animals

*Any two correct answers scores **[1]**.*

Examiners report

The way in which the properties of addition polymers depend on their structure and methods for modifying this appeared to be very poorly understood, with only a handful of candidates scoring well on any parts of this question. In Part (b) many candidates discussed the difference between isotactic and atactic polymers rather than the effects of branching.

Aluminium is extracted by the electrolysis of a molten mixture containing alumina, Al_2O_3, using graphite electrodes.

a.i. Explain why the molten electrolyte also contains cryolite. [1]

a.ii. State a half-equation for the reaction at the negative electrode (cathode). [1]

a.iii Oxygen is produced at the positive electrode (anode). State the name of another gas produced at this electrode. [1]

b.i. State **two** properties of aluminium that make it suitable for use as an overhead electric cable. [1]

b.ii Alloys of aluminium with nickel are used to make engine parts. Explain, by referring to the structure of these alloys, why they are less malleable than pure aluminium. [2]

Markscheme

a.i. it lowers the operating temperature/melting point (of alumina) / it saves heat/energy / improves conductivity / acts as a solvent;

Do not accept lowers melting point of aluminium.

Do not accept "lowers boiling point".

a.ii. $\mathrm{Al(l)}^{3+} + 3\mathrm{e}^- \rightarrow \mathrm{Al\ (l)}$;

Ignore state symbols.

Accept e instead of e^-.

a.iii carbon dioxide / carbon monoxide / fluorine / tetrafluoromethane;

Do not accept formulas since the name is asked for specifically.

b.i. high/good (electrical) conductivity **and** low density;

Do not accept lighter.

Accept malleable/ductile/resistant to (further) corrosion as one property.

Reference to high/good conductivity **or** *low density needed.*

b.ii in alloy different sized/Ni atoms/ions/particles disrupt regular structure;

stops layers from slipping/sliding / *OWTTE*;

Do not accept "stop layers moving".

Accept diagrams if explanation clear.

Examiners report

a.i. This was reasonably well answered. However a surprising number of candidates were unable to write the half equation for reaction at the negative electrode in (a) (ii), and few candidates were able to give an explanation of the reduced malleability of the alloys in terms of their structure in b (ii).

a.ii. This was reasonably well answered. However a surprising number of candidates were unable to write the half equation for reaction at the negative electrode in (a) (ii), and few candidates were able to give an explanation of the reduced malleability of the alloys in terms of their structure in b (ii).

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The Industrial Revolution was the result of large-scale extraction of iron from its ore and had significant impact worldwide.

In a blast furnace, a large volume of air is introduced under pressure near the bottom while a mixture of limestone, coke and iron(III) oxide is introduced at the top.

a.i. State the equation for the reaction of coke with air in the blast furnace. [1]

a.ii. The product formed in part (i) reacts with coke to produce carbon monoxide. Explain, giving an equation, why this reaction is important in the extraction of iron. [2]

Markscheme

a.i. $\mathrm{C(s) + O_2(g) \rightarrow CO_2(g)}$;

Ignore state symbols.

a.ii. CO acts as a reducing agent / reaction is endothermic/cools (this part of) furnace;

$\mathrm{CO_2(g) + C(s) \rightarrow 2CO(g)}$/$\mathrm{Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)}$;

Ignore state symbols.

Examiners report

a.i. Generally the equation for the reaction of coke with air was given correctly.

a.ii. The correct equation for the reaction of $\mathrm{CO_2}$ with coke was sometimes missing

---

Catalytic cracking uses heterogeneous catalysts.

a. The initial products of the fractional distillation of oil often undergo cracking. This can be carried out in a number of ways. State the **major** reason for choosing each of the following techniques. [3]

Catalytic cracking:

Thermal cracking:

Steam cracking:

b.i. Explain how these differ from homogeneous catalysts. [1]

b.ii. Identify **one** disadvantage of using heterogeneous catalysts. [1]

c. Many of the compounds produced by cracking are used in the manufacture of addition polymers. State the essential structural feature of these compounds and explain its importance. [2]

d. The polymers often have other substances added to modify their properties. One group of additives are plasticizers. State how plasticizers modify the physical properties of polyvinyl chloride and explain at the molecular level how this is achieved. [2]

Markscheme

a. *Catalytic cracking:*

used to produce moderate length alkanes (for fuels) / lower temperature / lower energy consumption / more control of product;

Thermal cracking:

used to crack very long chain starting material;

Steam cracking:

used to produce low molar mass alkenes (for petrochemicals);

b.i. heterogeneous catalysts in a different phase to the reactants / homogeneous catalysts in the same phase as reactants;

b.ii. easily poisoned / efficiency decreases over time / forms clumps / only effective on surface / require high surface area;

c. carbon-carbon double bond;

breaks allowing addition reaction / allows monomers/molecules to join together/polymerize;

d. make the polymer more flexible;

fits between/increases separation between polymer chains / allow polymer chains to slide past each other more easily / weaken intermolecular attraction;

Examiners report

a. Few candidates appear to have any knowledge of the different cracking techniques, though more appeared familiar with issues relating to catalysts. Quite a number of candidates were aware carbon-carbon double bonds were needed for addition polymerization, though the nature and effect of plasticizers was less well known

b.i. Few candidates appear to have any knowledge of the different cracking techniques, though more appeared familiar with issues relating to catalysts. Quite a number of candidates were aware carbon-carbon double bonds were needed for addition polymerization, though the nature and effect of plasticizers was less well known

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d. Few candidates appear to have any knowledge of the different cracking techniques, though more appeared familiar with issues relating to catalysts. Quite a number of candidates were aware carbon-carbon double bonds were needed for addition polymerization, though the nature and effect of plasticizers was less well known

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Nanotechnology creates and uses structures that have novel properties because of their size.

a. State the size range of structures which are involved in nanotechnology. [1]

c. Discuss **two** implications of nanotechnology. [2]

Markscheme

a. 1 nm to 100 nm;

c. reference to effect on human health (*e.g*. unknown, immune system may not cope, unsatisfactory toxicity regulations);

reference to effect on employment (*e.g*. increased job opportunities, adverse effect on traditional industries);
reference to effect on quality of life (*e.g*. medical advances, faster computers, improved performance of electronic equipment);
reference to public opinion (*e.g*. need to improve information, encourage discussion, seek approval);
reference to nanotechnology being developed in wealthier nations hence increasing the divide between different nations;

Examiners report

a. As a relatively new topic, nanotechnology still seems to present a significant challenge to the small proportion of candidates studying Option C and whilst many knew the scale upon which it operated and a few could gain credit for implications, usually related to health concerns, hardly any could distinguish between physical and chemical techniques.

c. As a relatively new topic, nanotechnology still seems to present a significant challenge to the small proportion of candidates studying Option C and whilst many knew the scale upon which it operated and a few could gain credit for implications, usually related to health concerns, hardly any could distinguish between physical and chemical techniques.

---

a. State the difference between homogeneous and heterogeneous catalysts. [1]

b. State **one** advantage and **one** disadvantage that homogeneous catalysts have over heterogeneous catalysts. [2]

Advantage:
Disadvantage:

c. Apart from their selectivity to form the required product and their cost, discuss **two** other factors which should be considered when choosing a suitable catalyst for an industrial process. [2]

Markscheme

a. homogeneous catalysts are in the same phase/state as the reactants and heterogeneous catalysts are in a different phase/state to the reactants;

b. *Advantage*

often works faster / all the catalyst is exposed to the reactants / *OWTTE*;
Disadvantage
difficult to remove the catalyst from the products / more limited range of acceptable catalysts;

c. efficiency;

ability to work under a variety of conditions;
environmental impact;
problems with the catalyst becoming poisoned (by impurities);

Examiners report

a. Most candidates correctly stated the difference between homogeneous and heterogeneous catalysts.

b. Most candidates could state one advantage and one disadvantage of homogeneous catalysts.

c. Candidates were less successful in part (c) in discussing the choice of a suitable catalyst.

---

a. Ethene can be polymerized to form high-density poly(ethene), HDPE, or low-density poly(ethene), LDPE, depending on the reaction conditions. [3]

Describe the main structural difference between HDPE and LDPE and explain how this accounts for their different properties.

b. (i) The repeating unit of poly(propene) has the formula: [3]

$$-[-CH_2-CH(CH_3)-]-$$

Draw a section of the polymer containing **five** repeating units to illustrate atactic

poly(propene).

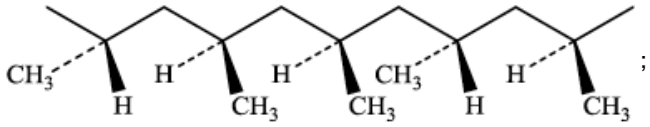
(ii) Explain why isotactic poly(propene) is tough and can be used to make car bumpers (fenders), whereas atactic poly(propene) is soft and flexible making it suitable for sealants.

Markscheme

a. HDPE has little branching whereas LDPE has branching/side chains / *OWTTE*;

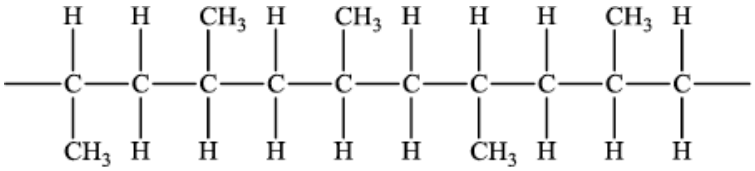
HDPE is stronger/more rigid / LDPE is weaker/more flexible/resilient;

HDPE chains pack more closely together / LDPE chains pack less closely together; HDPE has stronger van der Waals' forces / LDPE has weaker van der Waals' forces;

b. (i)  ;

There must be five –CH_3 groups and they must be shown in random orientation.

Allow the following structure:



(ii) isotactic has all methyl groups oriented/pointing in the same direction/has a more regular structure / atactic has the methyl groups oriented/pointing in different directions/arranged randomly/has an irregular structure;

in isotactic the chains can pack more closely together (making it more crystalline/tough) / in atactic the chains pack less closely together (making it soft/flexible);

isotactic has stronger van der Waals' forces / atactic has weaker van der Waals' forces;

Examiners report

a. In (a) most candidates were aware of the differences between HDPE and LDPE, but often failed to fully score as they referred to intermolecular forces in a rather vague, instead of specific, manner.

b. Most candidates found it difficult to draw the structure of atactic poly(propene) in part (b)(i). Most candidates were very familiar with the difference in structure of isotactic and atactic poly(propene), but many failed to fully score as their responses lacked the required specificity for the intermolecular forces.

Crude oil (petroleum) is initially separated into its components by fractional distillation, but subsequent cracking of the heavier fractions is usually required.

Ethene can be polymerized to form poly(ethene) and, depending on the conditions used, either high-density poly(ethene) (HDPE) or low-density poly(ethene) (LDPE) is formed.

a. State a balanced equation for the thermal cracking of $\mathrm{C_{20}H_{42}}$ in which octane and ethene are products. [2]

b. (i) Other than density, state **two** differences in the physical properties of HDPE and LDPE. [2]

(ii) Outline how the differences in (b)(i) relate to differences in their chemical structure.

c. It has been said that bitumen and heavy fuel oils are too valuable a resource to use for road surfacing and electricity generation. Comment on this statement. [1]

Markscheme

a. $\mathrm{C_{20}H_{42} \rightarrow C_8H_{18} + C_2H_4 + C_{10}H_{20}}$ / $\mathrm{C_{20}H_{42} \rightarrow C_8H_{18} + 6C_2H_4}$

Accept any correctly balanced equation that includes octane and at least one ethene molecule as products.

correct reactants **and** products;

balanced equation;

M2 can only be scored if M1 is correct.

b. (i) *Award **[1]** for any two.*

HDPE has higher mp;

HDPE is more rigid / less flexible;

HDPE is stronger**;**

Accept opposite statements for LDPE.

(ii) HDPE has straight chain **and** LDPE has branched chain / LDPE has more branched chains;

c. more valuable for (cracking to provide) chemical precursors/petrochemicals / may be cracked to produce same substances now obtained from lighter fractions / *OWTTE*;

Examiners report

a. Only about a third of the candidates were able to score both marks by giving a balanced equation producing octane and ethene. Others scored one mark as they failed to balance the equation.

b. (i) Less than half the candidates gave two physical properties that differed between LDPE and HDPE.

(ii) A small number of candidates attributed the difference to the branching in the chains.

c. The answers were mostly unsatisfactory as they failed to recognize the value of cracking products for the petrochemical industry.

Detergents are one example of lyotropic liquid crystals.

State **one** other example of a lyotropic liquid crystal and describe the difference between lyotropic and thermotropic liquid crystals.

Markscheme

soap / kevlar / fatty acids / lipid bilayer / cellulose / silk proteins / DNA;

lyotropic liquid crystals

solutions that show the liquid-crystal state at certain concentrations;

thermotropic liquid crystals

(pure substances that) show liquid-crystal behaviour over temperature ranges (between the solid and liquid states);

Examiners report

This was probably the best answered question in this option with many candidates being able to state the difference between the two types of liquid crystals, as well as give an example of a substance that can have a lytropic liquid crystal state.

Alloys are important substances in industries that use metals.

a. Describe an alloy. [1]

b. Explain how alloying can modify the structure and properties of metals. [2]

Markscheme

a. homogeneous mixture of metals/a metal and non-metal;

b. alloying element(s) disrupts regular/repeating (metal) lattice;

difficult for one layer to slide over another / atoms smaller than the metal cations can fit into the (holes of) metal lattice disrupting bonding;

can make metal harder/stronger/more corrosion resistant/brittle;

Examiners report

a. Many candidates did not gain the mark as they omitted the required word *homogeneous.*

b. Many candidates did not gain the mark as they omitted the required word *homogeneous* (a), but they could explain how alloying can modify the structure (b).

Nano-sized '*test-tubes*' with one open end, can be formed from carbon structures.

Carbon nanotubes can be used as catalysts.

a. Describe these '*test-tubes*' with reference to the structures of carbon allotropes. [2]

b. These tubes are believed to be stronger than steel. Explain the strength of these '*test-tubes*' on a molecular level. [1]

c.i. Suggest **two** reasons why they are effective heterogeneous catalysts. [2]

c.ii. State **one** potential concern associated with the use of carbon nanotubes. [1]

Markscheme

a. walls have rolled/single sheets of graphite/carbons bonded in hexagons;

ends have half a buckyball (fullerene)/carbons in pentagons (and hexagons);

b. covalent bonds are very strong;

c.i. large surface area;

Do not accept "reactive surface".

high selectivity related to dimensions of tube;

c.ii. unknown health effects;

Accept potentially harmful as easily ingested/inhaled.

Accept difficulty of preparing nanotubes in required amounts.

Examiners report

a. Responses to this question were generally poor perhaps reflecting the unfamiliarity of candidates with the new syllabus content.

b. Responses to this question were generally poor perhaps reflecting the unfamiliarity of candidates with the new syllabus content.

c.i. Responses to this question were generally poor perhaps reflecting the unfamiliarity of candidates with the new syllabus content.

c.ii. Responses to this question were generally poor perhaps reflecting the unfamiliarity of candidates with the new syllabus content.

In the last 15 years several Nobel prizes have been awarded in the area of nanotechnology, from the development of the scanning probe microscope, to the discovery of fullerenes. By 2015 nanotechnology could employ two million workers worldwide.

b. After the discovery of C_{60}, chemists discovered carbon nanotubes. Describe the structure and properties of carbon nanotubes. [4]

c. Nanotechnology could provide new solutions for developing countries where basic services such as good health care, education, safe drinking water and reliable energy are often lacking. Discuss some of the potential risks associated with developing nanotechnology. [4]

Markscheme

b. main cylinder is made only from carbon hexagons, with pentagons required to close the structure at the ends;

single or multiple walled tubes made from concentric nanotubes can be formed;

bundles of the tubes have high tensile strength;

other substances (elements, metal oxides etc.) can be inserted inside the tubes;

strong covalent bonding / no weak bonds;

behaviour of electrons depends on the length of a tube and hence some forms are conductors and some are semiconductors;

c. hazards associated with small airborne particles are not known / long term effects unknown / *OWTTE*;

may not be covered by current toxicology regulations (as properties depend on the size of the particle) / may be toxic / *OWWTE*;

human immune system may be defenceless against new nanoscale products / *OWTTE*;

(there may be social problems) as poorer societies may suffer as established technologies become redundant and demands for commodities change / *OWTTE*;

Examiners report

b. Candidates had considerable difficulty describing the structure and properties of carbon nanotubes and often speculated very vaguely on the impact of nanotechnology. Responses were often superficial.

c. Candidates had considerable difficulty describing the structure and properties of carbon nanotubes and often speculated very vaguely on the impact of nanotechnology. Responses were often superficial.

Many recent developments in chemistry have involved making use of devices that operate on a nanoscale.

a.i. State the scale at which nanotechnology takes place and outline the importance of working at this scale. [2]

a.ii. State **one** public concern regarding the development of nanotechnology. [1]

b. One development has been the production of nanotubes. Describe the way in which the arrangement of carbon atoms in the wall and sealed end of a nanotube differ. [2]

Markscheme

a.i. a scale of 1–100nm;

careful positioning of individual atoms / ability to control/manipulate at atomic scale / production of material with novel properties;

a.ii. health concerns / toxicity / effects on the human immune system / the lack of public involvement in policy discussions;

b. in the walls carbon atoms only form hexagons;

in the ends the carbon atoms form both hexagons and pentagons;

Examiners report

a.i. Though many candidates could quote the scale that nanotechnology deals with, few could state specific concerns about its implementation, and hardly any could distinguish between the bonding in the walls and the ends of nanotubes.

a.ii. Though many candidates could quote the scale that nanotechnology deals with, few could state specific concerns about its implementation, and hardly any could distinguish between the bonding in the walls and the ends of nanotubes.

b. Though many candidates could quote the scale that nanotechnology deals with, few could state specific concerns about its implementation, and hardly any could distinguish between the bonding in the walls and the ends of nanotubes.

Catalysts may be homogeneous or heterogeneous.

a. Distinguish between *homogeneous* and *heterogeneous* catalysts. [1]

c. Discuss **two** factors which need to be considered when selecting a catalyst for a particular chemical process. [2]

d.i. Identify the catalyst used in the catalytic cracking of long chain hydrocarbons and state **one** other condition needed. [2]

d.ii. State an equation for the catalytic cracking of the straight chain hydrocarbon pentadecane, $\mathrm{C_{15}H_{32}}$, to produce **two** products with similar masses. [1]

Markscheme

a. homogeneous catalysts are in the same phase/state as reactants **and** heterogeneous catalysts are in a different phase/state to reactants;

c. should produce only the desired product / selectivity;

efficiency;

should be able to work under both mild and severe conditions / should be able to work at high temperatures;

should not produce an (unwanted) environmental impact;

cost / economic viability / *OWTTE*;

ease of poisoning/contamination;

d.i. (catalyst a mixture of) silica/silicon dioxide/ $\mathrm{SiO_2}$ **and** alumina/aluminium oxide/$\mathrm{Al_2O_3}$ / zeolites/aluminosilicates;

high temperature / 500 °C;

d.ii. $\mathrm{C_{15}H_{32} \rightarrow C_8H_{18} + C_7H_{14}}$/$\mathrm{C_{15}H_{32} \rightarrow C_8H_{16} + C_7H_{16}}$;

Examiners report

a. Most candidates were aware of the differences between homogeneous and heterogeneous catalysts.

c. [N/A]

d.i. Few candidates could name the catalyst but knew one other condition needed for catalytic cracking.

d.ii. Most correctly stated an equation for the catalytic cracking of pentadecane, but some added oxygen or water, and some had too many hydrogen atoms in the products.

Iron may be extracted from an ore containing Fe_2O_3 in a blast furnace by reaction with coke, limestone and air. Aluminium is obtained by electrolysis of an ore containing Al_2O_3.

a. State the overall redox equation when carbon monoxide reduces Fe_2O_3 to Fe. [1]

b. Predict the magnetic properties of Fe_2O_3 and Al_2O_3 in terms of the electron structure of the metal ion, giving your reasons. [2]

Fe_2O_3:

Al_2O_3:

c. Molten alumina, $Al_2O_3(l)$, was electrolysed by passing 2.00×10^6 C through the cell. Calculate the mass of aluminium produced, using sections 2 and 6 of the data booklet. [2]

Markscheme

a. Fe_2O_3 (s) + 3CO (g) → 2Fe (l) + $3CO_2$ (g)

b. *Fe_2O_3:*

paramagnetic

AND

unpaired electrons present «so magnetic moments do not cancel out»

Al_2O_3:
diamagnetic
AND
no unpaired electrons/all electrons are paired «so magnetic moments cancel out»

*Award **[1 max]** for "Fe_2O_3 paramagnetic **AND** Al_2O_3 diamagnetic".*

*Award **[1 max]** for "Fe_2O_3 unpaired electrons present **AND** Al_2O_3 no unpaired electrons/all electrons are paired".*

*Award **[1 max]** for "Magnetic moments do not cancel out in Fe_2O_3 but do in Al_2O_3".*

Unpaired and paired electrons may also be conveyed by orbital diagrams for the respective ions.

c. $n\,(\mathrm{e}) = \frac{2.00\times10^{6}}{96500}/20.7 \ll \mathrm{mol} \gg$

OR
n(Al)=$\frac{1}{3}$n(e)/6.91«mol»

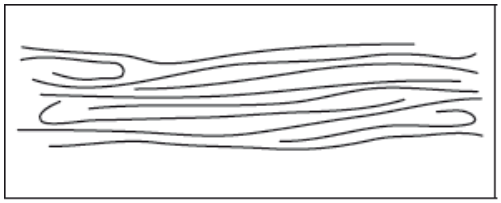
m(Al)=«6.91×26.98=»186«g»

*Award **[2]** for correct final answer for any value within the range 186–189 «g».*

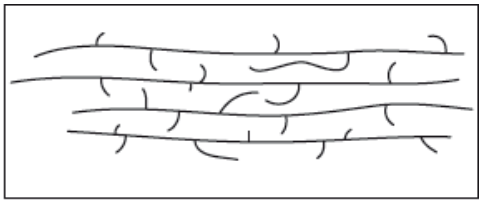
Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

The two diagrams below show the arrangement of molecules in two different types of polyethene, labelled **A** and **B**.



A



B

Predict which type of polyethene (**A** or **B**) has the strongest intermolecular forces, highest density and greatest flexibility.

a. (i) Strongest intermolecular forces: [3]

(ii) Highest density:

(iii) Greatest flexibility:

b. The polymer polyvinyl chloride (PVC), also known as poly(chloroethene), is hard and brittle when pure. Explain, in terms of intermolecular forces, [3]

how adding a plasticizer to PVC modifies the properties of the polymer.

Markscheme

a. (i) **A**;

(ii) **A**;

(iii) **B**;

b. closely packed molecules with crystalline structure;

(plasticizers) separate the PVC molecules/polymer chains / disrupt crystalline structure;

decrease/weaken intermolecular forces/intermolecular dipole-dipole interactions/van der Waals'/London Dispersion;

Do not accept mention of H-bonding

makes it (PVC) softer/more flexible/more easily moulded;

Examiners report

a. Many candidates were able to score three marks in (a) and most gave a good account of (b). Many, however, neglected to mention intermolecular forces, specifically requested in the question.

b. Many candidates were able to score three marks in (a) and most gave a good account of (b). Many, however, neglected to mention intermolecular forces, specifically requested in the question.

---

a. Use high-density poly(ethene) and low-density poly(ethene) as examples to explain the difference that branching can make to the properties of a polymer. [3]

b. During the formation of poly(styrene), a volatile hydrocarbon such as pentane is often added. Describe how this affects the properties of the polymer and give **one** use for this product. [2]

Markscheme

a. in HDPE there is little branching / in LDPE there is branching/side chains;

long chains can pack closely together/have greater forces of attraction so (HDPE) is more dense/more rigid/stronger;

side chains make (LDPE) more flexible/ideal for film products (such as food wrapping);

Accept opposite statements for marking points 2 and 3.

b. makes the polymer low density/good thermal insulator/expanded/softer/better shock absorber;

packaging/insulation;

*Award **[1 max]** if thermal insulation given for both answers.*

Examiners report

a. Most candidates had difficulty explaining the difference between HDPE and LDPE in terms of branching. Many mixed up the branching and properties, for example stating that increased branching led to a higher density.

b. Part (b), which required candidates to explain why pentane is added to poly(styrene) to improve its thermal insulation properties, was also difficult for most candidates.

The main ore used to produce aluminium by electrolysis is bauxite. Bauxite is mainly aluminium hydroxide, and contains iron(III) oxide and titanium(IV) oxide as impurities.

a.i. Explain how pure aluminium oxide is obtained from bauxite. [3]

a.ii. Explain why sodium hexafluoroaluminate, $\mathrm{Na_3AlF_6}$, (cryolite) is added to the aluminium oxide before electrolysis takes place to produce aluminium. [1]

a.iii. State the half-equations for the reactions taking place at the positive and negative electrodes during the production of aluminium by electrolysis. [3]

Positive electrode (anode):

Negative electrode (cathode):

b. Before the introduction of the electrolytic method by Hall and Héroult in the 1880s it was very difficult to obtain aluminium metal from its ores. Suggest **one** way in which it was achieved. [1]

c. The worldwide production of aluminium by electrolysis makes a significant impact on global warming. Suggest **two** different ways in which the process increases the amount of carbon dioxide in the atmosphere. [2]

Markscheme

a.i. (bauxite) is reacted with (concentrated) sodium hydroxide/NaOH (solution at high temperature);

forms sodium aluminate / $\mathrm{Al(OH)_3 + OH^- \rightarrow Al(OH)_4^-}$;

Accept both ionic and non-ionic equations and different, correct representations of the aluminate ion ($Al(OH)_4^-$, AlO_2^-).

solution is filtered / insoluble impurities removed (by filtration);

reaction reversed by cooling / diluting solution / adding water;

Accept passing CO_2 through the solution.

mixture seeded with alumina crystals;

pure hydroxide precipitated / $\mathrm{Al(OH)_4^- \rightarrow Al\ (OH)_3 + OH^-}$;

Accept both ionic and non-ionic equations and different, correct representations of the aluminate ion ($Al(OH)_4^-$, AlO_2^-).

(pure) $\mathrm{Al(OH)_3}$ heated / $\mathrm{2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O}$;

*Award **[1 max]** for "Alumina is soluble in alkali, but impurities are not" / OWTTE.*

Ignore state symbols.

a.ii. melting point of the cryolite solution is much lower than the melting point of alumina/Al_2O_3 / it lowers the melting point (of the mixture);

*Do **not** allow lowers melting point of aluminium.*

*Do **not** allow lowers required/operating temperature.*

Accept improves conductivity of the electrolyte/aluminium oxide.

a.iii. *Positive electrode (anode)*:

$2O^{2-} \rightarrow O_2 + 4e^- / O^{2-} \rightarrow \frac{1}{2}O_2 + 2e^- / C + 2O^{2-} \rightarrow CO_2 + 4e^-$;

Negative electrode (cathode):

$Al^{3+} + 3e^- \rightarrow Al$;

Allow e instead of e^-.

Accept multiples of the correct equations, such as $2Al^{3+} + 6e^- \rightarrow 2Al$.

*Award **[1 max]** if correct equations but at wrong electrodes.*

Ignore state symbols.

b. by reduction with a more reactive metal/metal above Al in electrochemical

series/ECS/reactivity series / *OWTTE*;

Accept equations for displacement reactions of Al_2O_3 with more reactive metals.

c. graphite/carbon electrodes converted/oxidized (into CO_2);

the fossil fuels used to provide energy/transport (produce CO_2);

Examiners report

a.i. This question was probably the worst answered question on the whole paper. In the first section many candidates confused the purification process with the electrolytic extraction and answers that scored any marks were rare. Many candidates knew the reasons for the addition of cryolite, but it was unusual to find both electrode equations correct and balanced. Hardly any had the lateral thinking skills to suggest displacement by a more reactive metal as a possible way of obtaining aluminium, but most students knew of at least one way in which aluminium production resulted in the emission of carbon dioxide.

a.ii. This question was probably the worst answered question on the whole paper. In the first section many candidates confused the purification process with the electrolytic extraction and answers that scored any marks were rare. Many candidates knew the reasons for the addition of cryolite, but it was unusual to find both electrode equations correct and balanced. Hardly any had the lateral thinking skills to suggest displacement by a more reactive metal as a possible way of obtaining aluminium, but most students knew of at least one way in which aluminium production resulted in the emission of carbon dioxide.

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displacement by a more reactive metal as a possible way of obtaining aluminium, but most students knew of at least one way in which aluminium production resulted in the emission of carbon dioxide.

b. This question was probably the worst answered question on the whole paper. In the first section many candidates confused the purification process with the electrolytic extraction and answers that scored any marks were rare. Many candidates knew the reasons for the addition of cryolite, but it was unusual to find both electrode equations correct and balanced. Hardly any had the lateral thinking skills to suggest displacement by a more reactive metal as a possible way of obtaining aluminium, but most students knew of at least one way in which aluminium production resulted in the emission of carbon dioxide.

c. This question was probably the worst answered question on the whole paper. In the first section many candidates confused the purification process with the electrolytic extraction and answers that scored any marks were rare. Many candidates knew the reasons for the addition of cryolite, but it was unusual to find both electrode equations correct and balanced. Hardly any had the lateral thinking skills to suggest displacement by a more reactive metal as a possible way of obtaining aluminium, but most students knew of at least one way in which aluminium production resulted in the emission of carbon dioxide.

Nanotechnology has expanded in the past 30 years.

b. Distinguish between the arrangement of carbon atoms at the sides and at the ends of carbon nanotubes. [1]

Sides:

Ends:

c. Outline why bundles of carbon nanotubes have high tensile strength. [1]

d. Discuss **two** concerns regarding the development of nanotechnology. [2]

Markscheme

b. *Sides:*

(atoms arranged in) hexagons

and

Ends:

(atoms arranged in) pentagons (and hexagons);

c. strong covalent/C–C bonding (in the walls of the nanotubes) / *OWTTE*;

d. possible toxicity of small (airborne) particles;

explosive / small size/large surface area means dangerously fast reactions;

unknown health effects / immune system/allergy concerns;

uncertain impact on environment;

lack of public awareness about dangers;

increasing economic disparity between developed and developing nations;

Accept other valid concerns.

Examiners report

b. A correct definition of nanotechnology was often seen and many candidates knew the difference between the arrangement of carbon atoms at the sides and at the ends of carbon nanotubes. Reference to the presence of strong covalent bonding between the carbon atoms to explain the high tensile strength of the bundles of nanotubes was not seen in most scripts.

c. A correct definition of nanotechnology was often seen and many candidates knew the difference between the arrangement of carbon atoms at the sides and at the ends of carbon nanotubes. Reference to the presence of strong covalent bonding between the carbon atoms to explain the high tensile strength of the bundles of nanotubes was not seen in most scripts.

d. A correct definition of nanotechnology was often seen and many candidates knew the difference between the arrangement of carbon atoms at the sides and at the ends of carbon nanotubes. Reference to the presence of strong covalent bonding between the carbon atoms to explain the high tensile strength of the bundles of nanotubes was not seen in most scripts.

Poly(propene) has different forms. Isotactic poly(propene) is tough, while atactic poly(propene) is flexible.

a. State the difference in the structure of the two polymers. [1]

Isotactic:

Atactic:

b. Explain how the difference in structure results in the different properties of isotactic and atactic poly(propene). [2]

Markscheme

a. *Isotactic:* methyl groups all oriented on same side of polymer chain **and**

Atactic: methyl groups oriented randomly;

Diagram alone is not sufficient – unless difference stated in words.

b. closer packing of isotactic chains;

isotactic has stronger van der Waals'/London/dispersion/intermolecular forces (than atactic);

Accept opposite statements for atactic.

Allow vdW as abbreviation for van der Waals' or FDL for London/dispersion.

Examiners report

a. The orientations of methyl groups in isotactic and atactic poly(propene) were known by more than half of the candidates, but the explanations of the properties did not involve intermolecular forces for the majority of candidates.

b. The orientations of methyl groups in isotactic and atactic poly(propene) were known by more than half of the candidates, but the explanations of the properties did not involve intermolecular forces for the majority of candidates.

Iron acts as a catalyst in the chemical reactions below.

Reaction I, catalysed by $\mathrm{Fe^{2+}(aq)}$: $\mathrm{S_2O_8^{2-}(aq) + 2I^-(aq) \rightarrow 2SO_4^{2-}(aq) + I_2(aq)}$

Reaction II, catalysed by Fe(s): $\mathrm{3H_2(g) + N_2(g) \rightleftharpoons 2NH_3(g)}$

a. State the type of catalysis occurring in reaction I. [1]

b. Outline the mechanism by which each catalyst lowers the activation energy in the reactions above, and state a particular disadvantage of each type of catalysis. [4]

Catalyst	Mechanism	Disadvantage
$\mathrm{Fe^{2+}(aq)}$	....	....
$\mathrm{Fe(s)}$	....	....

Markscheme

a. homogeneous;

b.

Catalyst	Mechanism	Disadvantage
Fe^{2+} (aq)	oxidized (by the OA) and subsequently reduced (by the RA) / undergoes redox reaction / changes oxidation state/number;	difficult to separate from reaction mixture; prone to poisoning;
Fe (s)	reactants are adsorbed onto surface (where reaction takes place) / reaction occurs on surface / weakens reactant bonds;	only effective on surface / must be finely divided; prone to poisoning; *Allow "must be cleaned/refreshed / OWTTE".*

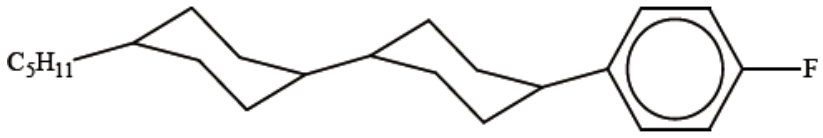
Allow "prone to poisoning" as a disadvantage for either but not both.

Examiners report

a. Homogeneous catalysis was usually identified in part (a). In (b), few got the correct mechanism for $\mathrm{Fe^{2+}(aq)}$, namely the fact that there is a change in the oxidation state. The command term outline needs to be differentiated from state. Correct disadvantages were usually identified and for Fe(s) most knew that the mechanism involved reactants being adsorbed onto the surface. Outline is an objective 2 command term, as given on P.11 of the guide and equates to giving a brief account or summary. Hence simply stating heterogeneous for the mechanism was incorrect for Fe(s) for example. Candidates need to pay close attention to the command terms as part of their examination preparation.

b. Homogeneous catalysis was usually identified in part (a). In (b), few got the correct mechanism for $\mathrm{Fe^{2+}(aq)}$, namely the fact that there is a change in the oxidation state. The command term outline needs to be differentiated from state. Correct disadvantages were usually identified and for Fe(s) most knew that the mechanism involved reactants being adsorbed onto the surface. Outline is an objective 2 command term, as given on P.11 of the guide and equates to giving a brief account or summary. Hence simply stating heterogeneous for the mechanism was incorrect for Fe(s) for example. Candidates need to pay close attention to the command terms as part of their examination preparation.

Liquid-crystal displays are used in many electronic appliances. The molecule below has liquid-crystal display properties.



Suggest **three** reasons why the molecule is suitable for use in liquid-crystal display devices.

Markscheme

rod shape / rigid;

chemically stable (due to hydrocarbon rings and chain);

polar (due to the presence of F) / *OWTTE*;

can change orientation / rapid switching in electric field/when voltage is applied;

Examiners report

Examiners reported an average understanding of liquid crystal properties.

---

a. Distinguish between a *homogeneous* and a *heterogeneous* catalyst. [1]

b. Other than cost, state **one** advantage and **one** disadvantage of using a homogeneous catalyst rather than a heterogeneous catalyst. [2]

Advantage:

Disadvantage:

c. Other than selectivity and cost, list **three** factors which should be considered when choosing a catalyst for a particular industrial process. [3]

Markscheme

a. homogeneous catalyst is in the same phase/state as the reactants **and** heterogeneous is in a different phase/state to the reactants;

b. *Advantage*:

all catalyst exposed to reactants / does not depend on surface area / react more rapidly / *OWTTE*;

Disadvantage:

difficult to remove from products;

Accept "Cannot always be used at high temperature".

Apply ECF if C2. (a) the wrong way round.

c. amount of reactant converted to product per amount of catalyst;

Accept efficiency / conversion rate.

ability to work under different/a range of conditions;

toxicity / environmental/health impact;

catalytic poisoning / active sites become blocked;

lifetime of catalyst;

ease of removal;

Examiners report

a. This question was relatively well tackled. Almost all knew the difference between the two types of catalysts, though many referred to "state" than the more correct "phase" and could not identify an advantage and a disadvantage and knew of at least some of the factors that need to be considered in decisions relating to the choice of a catalyst.

b. This question was relatively well tackled. Almost all knew the difference between the two types of catalysts, though many referred to “state” than the more correct “phase” and could not identify an advantage and a disadvantage and knew of at least some of the factors that need to be considered in decisions relating to the choice of a catalyst.

c. This question was relatively well tackled. Almost all knew the difference between the two types of catalysts, though many referred to “state” than the more correct “phase” and could not identify an advantage and a disadvantage and knew of at least some of the factors that need to be considered in decisions relating to the choice of a catalyst.

Liquid crystals are sometimes used in the construction of “smart windows”.

Smart windows are milky white as their randomly arranged liquid crystals scatter light. When a voltage is applied, the liquid crystals align in the same direction. The light then passes through them without scattering, making the windows transparent.

a. State the property of the liquid-crystal molecules that allows them to align when a voltage is applied. [1]

b. List **two** substances that can behave as liquid crystals. [1]

c. Distinguish between *thermotropic* and *lyotropic* liquid crystals. [2]

Thermotropic liquid crystals:

Lyotropic liquid crystals:

Markscheme

a. polarity / presence of dipole (moment);

b. *Any two for **[1]***

graphite

cellulose

(spider) silk

DNA

biphenyl nitriles

soap

Kevlar

c. *Thermotropic liquid crystals:*

pure substances **and** exhibit liquid-crystal properties in a certain temperature range;

Lyotropic liquid crystals:

solutions **and** exhibit liquid-crystal properties in a certain concentration range;

*Award **[1 max]** for thermotropic pure substances and lyotropic solutions.*

*Award **[1 max]** for thermotropic in a certain temperature range and lyotropic solutions in a certain concentration range.*

Examiners report

a. The majority of candidates recognized polarity as the property of liquid crystals in part (a) and were able to give two substances that could act as liquid crystals in part (b).

b. The majority of candidates recognized polarity as the property of liquid crystals in part (a) and were able to give two substances that could act as liquid crystals in part (b).

c. Many candidates knew that thermotropic liquid crystals worked within a temperature range and lyotropic liquid crystals work within a concentration range in part (c), but only few candidates distinguished between the two types fully.

In order to make waste water acceptable for drinking, it is treated in a series of steps to remove hazardous substances.

Tertiary treatment removes phosphates, nitrates and heavy metal ions from water.

State an ionic equation, including the state symbols, to show how hydrogen sulfide gas, $\mathrm{H_2S(g)}$, is able to remove mercury(II) ions, $\mathrm{Hg^{2+}(aq)}$, when it is bubbled through a water sample.

Markscheme

$\mathrm{Hg^{2+}(aq) + S^{2-}(aq) \rightarrow HgS(s)}$/$\mathrm{H_2S(g) + Hg^{2+}(aq) \rightarrow HgS(s) + 2H^{+}(aq)}$/

$\mathrm{H_2S(aq) + Hg^{2+}(aq) \rightarrow HgS(s) + 2H^{+}(aq)}$;

correctly balanced equation;

correct state symbols;

Neither mark can be awarded for an incorrect equation.

Examiners report

Part a), relating to the reaction precipitating mercury sulfide, was very challenging and arguably marginal to the syllabus and as a result hardly any students gained any marks; unbalanced equations, especially yielding hydrogen as a product, proliferated. The process of eutrophication was better known, but many students incorrectly attributed the depletion of oxygen to the excessive growth of plants and algae rather than their subsequent death and decay.

Aluminium and its alloys are widely used in industry.

Aluminium metal is obtained by the electrolysis of alumina dissolved in molten cryolite.

a.i. Explain the function of the molten cryolite. [1]

a.ii. State the half-equations for the reactions that take place at each electrode. [2]

Positive electrode (anode):

Negative electrode (cathode):

b. Outline **two** different ways that carbon dioxide may be produced during the production of aluminium. [2]

Markscheme

a.i. melting point of the cryolite solution is much lower than the melting point of alumina/Al2O3 / it lowers the melting point of the mixture / cell operates at lower temperature;

Allow lowers melting point or lowers melting point of aluminium oxide.

Do not allow lowers melting point of aluminium.

a.ii. *Positive electrode*:

$2O^{2-} \rightarrow O_2 + 4e^- / O^{2-} \rightarrow \frac{1}{2}O_2 + 2e^-$;

Negative electrode:

$Al^{3+} + 3e^- \rightarrow Al$;

*Award **[1]** for correct equations but wrong electrodes.*

Allow e instead of e^-.

b. use of fossil fuels (to provide energy);

oxidation of the (graphite) positive electrode/anode;

Examiners report

a.i. This was either answered very well or very poorly.

a.ii. Only the best candidates could state half-equations for the electrolysis of aluminium.

b. Many candidates scored one mark out of two for outlining how carbon dioxide may be produced during aluminium production in (b). C.1.10 states that candidates should know the environmental impacts of aluminium production.

Cracking is the process by which long-chain alkanes found in oil are broken down into smaller molecules.

a. The following reaction occurs during the cracking of tetradecane, $\mathrm{C_{14}H_{30}}$. [2]

$$\mathrm{C_{14}H_{30}(g) \rightarrow C_{10}H_{22}(g) + 2C_2H_4(g)}$$

Suggest a use for each of the products formed in the reaction.

$\mathrm{C_{10}H_{22}}$:

$\mathrm{C_2H_4}$:

b. State the main type of product obtained from steam cracking. [1]

c. Catalytic cracking uses silica as a heterogeneous catalyst. Explain the mode of action of a heterogeneous catalyst. [2]

d. State **one** advantage of using a heterogeneous catalyst rather than a homogeneous catalyst. [1]

e. Discuss **two** factors that need to be considered when choosing a catalyst for a process. [2]

Markscheme

a. *$C_{10}H_{22}$:* gasoline/petrol / fuel / kerosene;

Do not allow just combustion or cars.

Allow gas for cars/automobiles instead of gasoline but not gas alone.

C_2H_4: chemical feedstock / *OWTTE*;

Accept suitable example such as manufacturing plastics/polymers but not just plastics.

b. alkenes;

c. solid surface has active sites / reactants adsorb on solid surface;

Do not accept absorb instead of adsorb.

brings reactants close together in correct orientation;

weakens reactant bonds / reactants bonds are easier to break;

d. can be easily removed/filtered from reaction mixture / large amount of reactant molecules pass over catalyst that is in a fixed position / can be used at high temperatures;

e. selectivity to produce (a high yield of) the desired product / *OWTTE*;

extent to which rate of reaction is increased/*E*a is lowered;

amount of reactant converted to product per amount of catalyst;

Accept efficiency / conversion rate.

ability to work under different/a range of conditions;

environmental/health impact;

catalytic poisoning / active sites become blocked;

cost in relation to life expectancy / *OWTTE*;

ease of removal from reaction mixture;

Examiners report

a. Less than half of the candidates knew the uses of the products of cracking in (a) and very few candidates knew the product of steam cracking in (b).

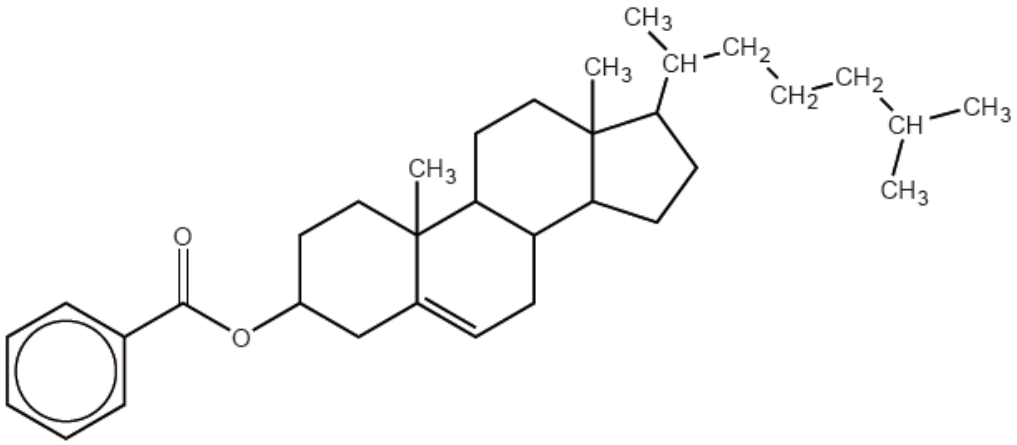
b. Less than half of the candidates knew the uses of the products of cracking in (a) and very few candidates knew the product of steam cracking in (b).

c. The mode of action of heterogeneous catalysts was also not well answered. The majority of candidates wrote about catalysts in general gaining no marks on part (c).

d. Parts (d) and (e) about the advantage of heterogeneous catalysts over homogeneous catalysts, and factors to be considered when selecting a catalyst were well answered by the majority of candidates.

e. Parts (d) and (e) about the advantage of heterogeneous catalysts over homogeneous catalysts, and factors to be considered when selecting a catalyst were well answered by the majority of candidates.

Cholesteryl benzoate was one of the first liquid crystals studied.



a. Identify the structural feature of cholesteryl benzoate which makes it suitable for use as a liquid crystal. [1]

b. Suggest the essential feature a liquid-crystal molecule must have so that the display can be turned “on” and “off”. [1]

Markscheme

a. rigid / rod-shaped;

b. polar (group/molecule);

Examiners report

a. Many candidates knew the essential feature that a liquid-crystal molecule must have for the display being turned off and on but the description of the principles of a liquid-crystal display device was often poorly presented and not clearly understood.

b. Many candidates knew the essential feature that a liquid-crystal molecule must have for the display being turned off and on but the description of the principles of a liquid-crystal display device was often poorly presented and not clearly understood.

There is much debate about the need for laws to regulate research and development into nanotechnology.

a. Define the term *nanotechnology*. [2]

b. Discuss **two** concerns about its development and use. [2]

Markscheme

a. (research/technology development at) 1–100 nm (range);

*Award **[1 max]** for any one of:*
creates/uses structures with novel properties (because of their small size) / *OWTTE*;
builds on ability to control/manipulate at atomic scale / *OWTTE*;

b. explosive / small size/large surface area means very fast reactions at possibly dangerous levels;

unknown health effects / immune system/allergy concerns;
industry not concerned about impact of product;
lack of public awareness about dangers;
nanoparticle waste products may require new methods of disposal;
nanoweapons more difficult to detect than conventional weapons (resulting in weapons of mass destruction);
possible toxicity (of small airborne particles);
Do not allow just "may cause environmental destruction".
Accept other valid concerns.
Accept OWTTE throughout.

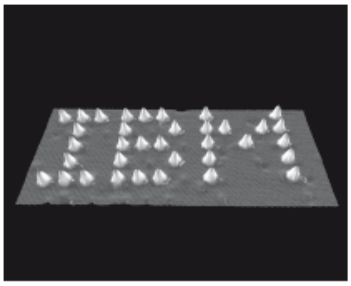
Examiners report

a. Both parts of question 12 were reasonably well answered, though a small minority of candidates either did not give the 1-100 nm range or failed to give correct units here. In (b) some vague answers such as "may cause environmental destruction" were cited, which did not score.

b. Both parts of question 12 were reasonably well answered, though a small minority of candidates either did not give the 1-100 nm range or failed to give correct units here. In (b) some vague answers such as "may cause environmental destruction" were cited, which did not score.

In 1989 Don Eigler and his team carried out one of the first experiments in nanotechnology.

They spelled out the IBM logo with 35 xenon atoms.



[Source: http://www-03.ibm.com (2013)]

a. Outline the technique used to manipulate the atoms in this way. [2]

b. The atomic radius of xenon is $1.36 \times 10^{-10}\ \mathrm{m}$. Estimate the approximate length, in m, of the "I" in the original IBM image. [1]

Markscheme

a. physical;

atoms placed in specific positions;

using a scanning tunnelling microscope/STM / atomic/scanning force microscope/AFM/SFM;

Accept "using a scanning probe/device/instrument".

b. any value in the range $10^{-9} - 10^{-8}\ (\mathrm{m})$;

Examiners report

a. Manipulating the atoms using an atomic force microscope was not well known.

b. With the help of the given diagram some candidates were able to estimate a reasonable length. The range of length accepted in the markscheme was generous.

Landfill sites are used to dispose of about 90% of the world's domestic waste, but incineration is being increasingly used in some countries.

b. Suggest why some biodegradable plastics do not decompose in landfill sites. [1]

c. High-level and low-level wastes are two types of radioactive waste. Compare the half-lives and the methods of disposal of the two types of waste. [3]

Markscheme

b. limited supply of oxygen (prevents the bacteria from acting);

Do not accept air.

c. high-level waste has longer half-life / low-level waste has shorter half-life;

high-level waste is vitrified/made into glass/buried underground/in granite/in deep mines/under water/in steel containers/in cooling ponds / *OWTTE*;

low-level waste is stored under water/in steel containers/in cooling ponds/filtered/discharged directly into sea / *OWTTE*;

Accept cooling ponds/steel containers/under water/concrete containers only once.

Examiners report

b. This was generally well done although few realised that oxygen was needed for the decomposition of the plastics in landfill sites.

c. This was generally well done although few realised that oxygen was needed for the decomposition of the plastics in landfill sites.

There has been a shift in the use of crude oil (petroleum) away from its use as an energy source and towards its use as a chemical feedstock.

a. Suggest **two** reasons for this shift. [2]

b. A lot of feedstock is used in the production of plastics. Discuss **two** advantages and **one** disadvantage of using plastic for packaging instead of cardboard. [3]

Two advantages:

One disadvantage:

Markscheme

a. increasing cost of oil (relative to other energy sources);

limited supply (of petroleum);

other sources of energy available / alternative energy sources;

(use as a raw material) reduces/delays greenhouse gas/global warming/climate change problems;

concerns about greenhouse gases/climate change causing changes in behaviour / *OWTTE;*

Do not accept just "greenhouse gases/climate change";

products from raw materials can be recycled / fuels cannot be recycled;

increasing demand as raw material from continued economic growth/demand for wider variety of products;

more profit to be made (by using as raw material);

reduced availability of other sources of hydrocarbons;

Accept political factors, such as "conflicts disrupting production".

b. *Advantages:*

*Any two for **[2 max]** of:*

waterproof so strong when wet;

can be transparent so contents can be seen;

better insulates the item it is packing if expanded plastic/bubble wrap used;

can be vacuum sealed to exclude air/keep food fresh;

better protection against knocks as it can be moulded to fit the item;

Disadvantages:

Any one of:

uses valuable petroleum resources which are non-renewable;

(may) not be burned safely because toxic gases are produced;

(may) not be bio-degradable/recyclable so will linger in landfill;

Accept other valid answers for both advantages and disadvantages.

Each answer must be qualified.

Examiners report

a. Many candidates did achieve at least one mark, usually referring to the increasing demand of crude oil as a raw material linked to demand for wider variety of products. Any other reasons were often inadequately communicated. There were many responses referring to the 'production of greenhouse gases' with no further qualification with respect to the shift in behaviour. The second part of this question produced answers which often failed to precisely address the advantages and disadvantages of the use of plastics versus cardboard specifically for packaging.

b. Many candidates did achieve at least one mark, usually referring to the increasing demand of crude oil as a raw material linked to demand for wider variety of products. Any other reasons were often inadequately communicated. There were many responses referring to the 'production of greenhouse gases' with no further qualification with respect to the shift in behaviour. The second part of this question produced answers which often failed to precisely address the advantages and disadvantages of the use of plastics versus cardboard specifically for packaging.

Steel is a vital structural material in modern society. Some of it is obtained from recycled iron and steel, but much of it is produced from iron ore using a blast furnace.

State **one** negative impact that the production of iron and steel has on the environment.

Markscheme

waste rock from mining / airborne ash from blast furnace / the mine destroys the (natural) environment / uses energy resources / acid rain / carbon dioxide / greenhouse gas emissions;

Examiners report

Many students confused the conversion of iron to steel with the smelting of iron ore. A significant number seemed to have memorised a method of heat treatment of steel and many could indentify ways in which the iron and steel industry has an environmental impact.

State **three** factors which need to be considered when an industrial catalyst is chosen. In **each** case explain why they are important.

Markscheme

This was related to assessment statement C.4.3. It proved to be challenging; candidates did not show a good understanding and answers were not well organized.

Examiners report

selectivity – does the catalyst give a good yield of the desired compound / *OWTTE*;

efficiency – how much faster does the reaction occur/reach equilibrium / *OWTTE*;

economic – cost / how long the catalyst will last / how easily is it poisoned / *OWTTE*;

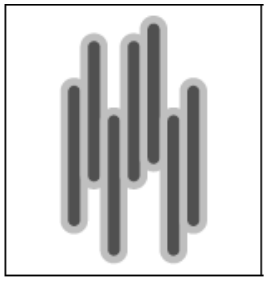
environmental impact – toxicity / regeneration / recyclability/ease of separation of catalyst from reaction mixture / *OWTTE*;

versatility – ability to work under a range of conditions / ability to work with a range of substances / *OWTTE*;

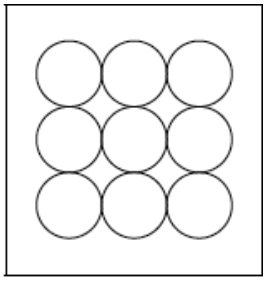
*Award **[1 max]** for any three correct factors without explanation.*

Liquid crystals are widely used in devices such as calculators, laptop computers and advanced optical materials.

a. (i) Describe the meaning of the term liquid crystals and state which of the representations below (A, B or C) best describes molecules present in the liquid-crystalline phase. [6]

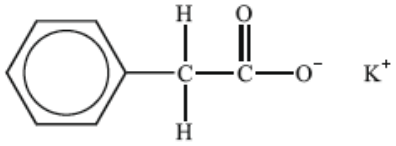
A. 

B. 

C. 

(ii) Deduce, with reasoning, which of the following substance(s) is/are most likely to show liquid-crystalline behaviour.

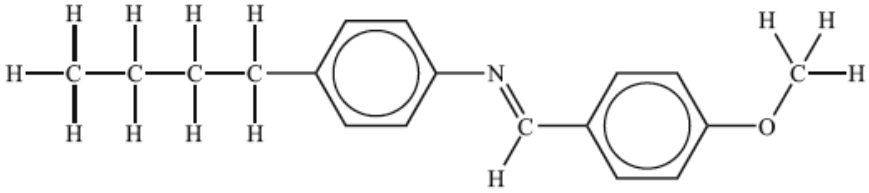
Substance I:



Liquid-crystalline behaviour (yes/no):

Reasoning:

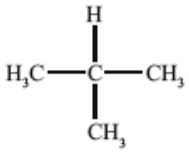
Substance II:



Liquid-crystalline behaviour (yes/no):

Reasoning:

Substance III:



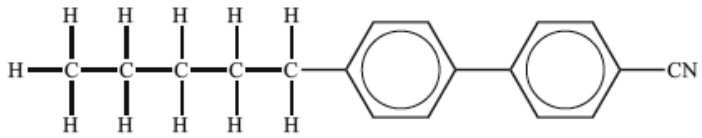
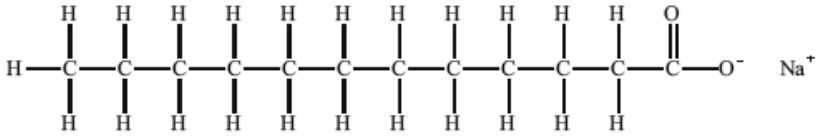
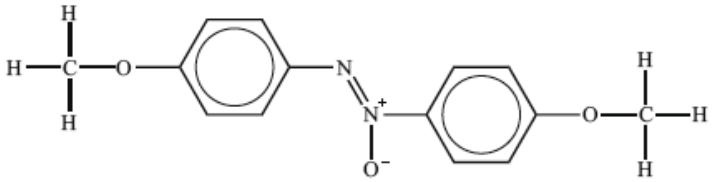
Liquid-crystalline behaviour (yes/no):

Reasoning:

(iii) Suggest why octane does not show liquid-crystalline behaviour.

b. (i) State **one** difference between thermotropic and lyotropic liquid crystals. [2]

(ii) Identify, by stating yes or no, the substance(s) which show(s) thermotropic liquid crystalline behaviour.

Substance	Thermotropic liquid-crystalline behaviour
X: 	
Y: 	
Z: 	

Markscheme

a. (i) (LCs are) fluids that exhibit molecular orientation/orderly molecular arrangement **and** A;

*Accept LCs show properties of liquids and crystals simultaneously **and** A.*

(ii) *I:* no, since ionic (so high mp) / lacks long axis;

Allow no since it is not a molecule/not rod-shaped.

II: yes, since has long axis present (so limits ability of molecules to pack lowering mp);

Allow yes since rod-shaped.

has polar functional group / is polar (increasing intermolecular interactions) / (planar/flat) benzene ring present (assists stacking);

III: no, since lacks long axis;

Allow no since non-polar.

Allow no since not rod-shaped.

*Award **[1 max]** for stating II only will show LC behaviour **OR** I: No, II: Yes **and** III: No.*

*Award **[2 max]** if **one** correct reason is given for **each** substance but LC behaviour is either incorrect or not given.*

*Award **[3 max]** if correct reasons are given for all three substances, but LC behaviour is either incorrect or not given.*

(iii) (free) rotation about carbon-carbon single bonds (hence greater flexibility) so octane molecules not rod-shaped / *OWTTE*;

Do not allow mark for non-polar (molecule) only.

b. (i) *Thermotropic:* pure substances **and** *lyotropic:* solutions / *thermotropic:* show LC behaviour over limited temperature range (between solid and liquid states) **and** *lyotropic:* shows LC behaviour at certain concentrations;

(ii) **X**: yes **and Y**: no **and Z**: yes;

*Award mark if no is stated only for **Y** or yes is only stated for **X** and **Z**.*

Examiners report

a. This proved to be the most challenging question in option C. Candidates were able to identify A as the molecules present in the liquid-crystalline phase but were unable to describe the state for part (a)(i). Majority of the candidates were not able to score more than two marks for part (ii). Most were unable to identify substance I as ionic and substance II was often identified as ‘yes’ but without sound support. For (a)(iii), again students struggled with explicit sound reasoning. Response for (a)(iii) was poor with most stating non-polar as the reason for inability of octane to show liquid-crystalline behavior. Very few candidates were able to identify and explain if molecules will behave as a liquid crystal. Majority of the candidates were unable to score the point. Candidates were able to state the difference between the two liquid crystals in (b)(i) correctly but were not able to apply the information correctly in (b)(ii) to identify which substances shoe thermotropic liquid-crystalline behaviour.

b. This proved to be the most challenging question in option C. Candidates were able to identify A as the molecules present in the liquid-crystalline phase but were unable to describe the state for part (a)(i). Majority of the candidates were not able to score more than two marks for part (ii). Most were unable to identify substance I as ionic and substance II was often identified as ‘yes’ but without sound support. For (a)(iii), again students struggled with explicit sound reasoning. Response for (a)(iii) was poor with most stating non-polar as the reason for inability of octane to show liquid-crystalline behavior. Very few candidates were able to identify and explain if molecules will behave as a liquid crystal. Majority of the candidates were unable to score the point. Candidates were able to state the difference between the two liquid crystals in (b)(i) correctly but were not able to apply the information correctly in (b)(ii) to identify which substances shoe thermotropic liquid-crystalline behaviour.

Aluminium is the most abundant metal on Earth and its alloys are widely used.

b. Describe what is meant by the term *alloy*. [1]

c. State the main improvement made to the properties of aluminium when it is alloyed. [1]

Markscheme

b. homogeneous mixture of metals/metal(s) and non-metal(s);

c. increase in aluminium’s strength;

Examiners report

b. Most candidates did not gain the mark for alloys in part (b) because they did not state that the mixture was homogeneous which was needed for the mark.

c. The majority of candidates knew that alloying aluminium increased its strength in part (c).

Polyvinyl chloride (PVC) and polyethene are both polymers made from crude oil.

a. Explain why PVC is less flexible than polyethene. [2]

b. State how PVC can be made more flexible during its manufacture and explain the increase in flexibility on a molecular level. [2]

c. PVC can exist in isotactic and atactic forms. Draw the structure of the isotactic form showing a chain of at least six carbon atoms. [1]

Markscheme

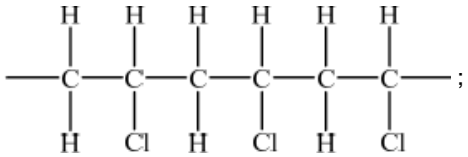
a. C–Cl bond / molecule is polar;

stronger intermolecular/van der Waals'/London/dispersion forces/dipole-dipole attraction;

b. addition of plasticizers;

Allow misspelling within reason.

get between polymer chains / keeps chains further apart **and** reduces attraction (between the chains);

c.  ;

Accept any structure with all the Cl atoms shown on the same side.

Continuation bonds at end of structure not needed.

Hydrogen atoms must be included.

Examiners report

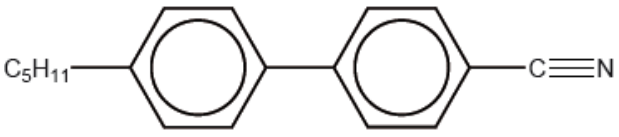
a. Most answers in (a) did not mention the polarity of the C–Cl bond.

b. The explanation of PVC's flexibility in (b) did not usually refer to the polymer chains being pushed apart.

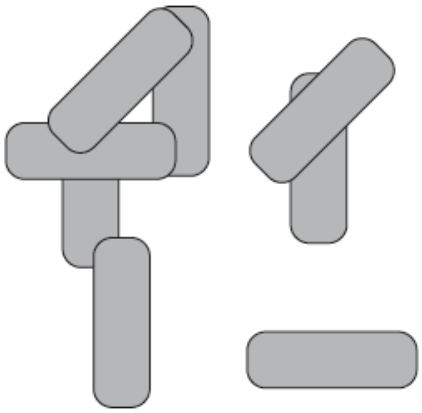
c. A significant number of candidates drew the isotactic form of polypropene instead of PVC in response to (c).

Thermotropic liquid crystals are widely used in display devices and sensors.

The structure of a material used in electrical display devices is shown below.



a. The diagram below shows eight molecules in the liquid state. Suggest, with a diagram, a possible arrangement that these rod-shaped molecules could adopt in the nematic liquid-crystal phase. [2]



b.i. Suggest, with reference to the structure, why the molecule is able to change orientation in an electric field. [1]

b.ii. Suggest how the C_5H_{11} chain contributes to the liquid-crystal properties of the compound. [1]

b.iii. Explain why a liquid-crystal device may be unreliable at low temperatures. [1]

Markscheme

a.

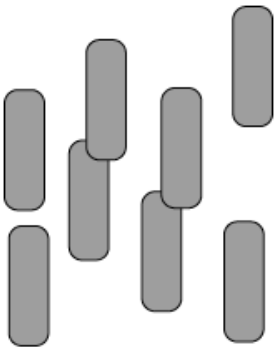


diagram should have molecules with a parallel alignment in any direction (not just upwards);

diagram should have molecules in an irregular arrangement in space;

Ignore relative separation between molecules.

*Award **[1 max]** if number of molecules < 7.*

*Award **[1 max]** if stated "molecules align parallel to each other but with an irregular arrangement in space / OWTTE" but with no diagram drawn.*

Allow the representation of molecules by lines.

b.i. polar/dipole moment due to the presence of C≡N (bond) / difference in electronegativity between C and N;

b.ii. prevents close packing of molecules / *OWTTE*;

makes the molecule (longer and) more rod-like;

b.iii. molecules become more ordered / molecules unable to change orientation (as they approach fixed arrangement of solid state) / molecules move slower / viscosity (of medium) increases (so LCD response time increases);

Examiners report

a. Well answered by many, although some candidates left the question blank. Candidates were more likely to align molecules in the same direction, but only some of them kept the arrangement of the molecules random and hence received the second mark.

b.i. The majority recognized that the alignment is due to the polarity, but only a few candidates attributed that to the CN bond.

b.ii. Quite well answered about the role of the pentyl group in the liquid-crystal properties of the compound.

b.iii. The better students were able to explain why a liquid-crystal device is unreliable at low temperature.

Aluminium is an important metal to modern society.

Aluminium is often used to produce lightweight alloys for use in the aerospace industry.

a. (i) Describe the production of aluminium from its purified ore. Explain the role of cryolite and deduce the equations for the reactions occurring at the two electrodes. [5]

Production of aluminium:

Role of cryolite:

Negative electrode (cathode):

Positive electrode (anode):

(ii) Outline why aluminium was not available in large quantities before 1900.

b. (i) State **one** advantage of using an alloy rather than the pure metal. [2]

(ii) Outline why the range of metals alloyed with aluminium for this use is very limited.

c. Suggest **one** possible environmental impact that can result from the large-scale production of aluminium. [1]

Markscheme

a. (i) *Production of aluminium*:

electrolysis of molten alumina/aluminium oxide/$\mathrm{Al_2O_3}$;

Role of cryolite:

(molten) cryolite (saves money due to) lower operating temperature / solvent with a lower melting point (than aluminium oxide);

Accept lowers the melting point of aluminium oxide.

Negative electrode (cathode):

$\mathrm{Al^{3+}(l) + 3e^- \rightarrow Al(l)}$;

Positive electrode (anode):

$\mathrm{2O^{2-}(l) \rightarrow O_2(g) + 4e^-}$;

Allow e for e⁻.

Ignore state symbols.

Penalize use of equilibrium sign once only.

*Award **[1 max]** for M3 and M4 if correct equations are given but at the wrong electrodes.*

(ii) no electricity / electricity not widely available before 1900;

b. (i) to control/improve properties / alloys are stronger/more durable/less reactive/less malleable/less ductile than pure metals;

(ii) only a small number of metals have low densities / many low density metals are too reactive / alloys need presence of other metallic atoms of slightly different size (few metals like this);

c. (purification of ore produces) waste $\mathrm{Fe_2O_3}$/iron(III) oxide/red mud;

carbon dioxide/ $\mathrm{CO_2}$ from burning electrodes;

environmental impacts of power generation;

aluminium production a significant contributor to global warming;

mining the ore damages the landscape/local ecology;

generation of fluorides/polyfluorinated carbons/fluorine containing waste products;

Examiners report

a. (i) Many candidates understood the principles behind the production of aluminium and the role of the cryolite, although not always managing to state the principles accurately to be able to score the first two marks, but many candidates showed weakness in writing the correct half-equations at the correct electrodes.

(ii) About half of the candidates stated the there was no electricity available at that time.

b. (i) More than half of the candidates were able to give an advantage of using an alloy over using the pure metal. A few candidates stated the misconception that alloys were less brittle than pure metals.

(ii) Some candidates offered sensible suggestions mainly focusing on the importance of finding a low density metal.

c. Quite well answered. Not many candidates discussed the impact of the purification of the bauxite or its mining. Candidates focused on the impact of the generation of large amounts of electricity and global warming.

The large-scale production of iron is important for the industrial development of many countries.

a.i. Magnetite, Fe_3O_4, is a common ore of iron. Calculate the average oxidation state of iron in the compound and comment on your answer. [2]

a.ii. State the equation for the reduction of this ore to iron with carbon monoxide. [1]

a.iiiOutline why iron is obtained from its ores using chemical reducing agents but aluminium is obtained using electrolysis. [1]

Markscheme

a.i. $+\frac{8}{3} / +2\frac{2}{3}$;

Accept +2.7 but not +3.

+2 **and** +3 / contains two (or more) iron ions with different oxidation states / contains Fe^{2+} **and** Fe^{3+};

Accept II and III oxidation number notation for oxidation states but not 2+ and 3+ unless ions are referred to explicitly.

*Accept "contains different iron compounds/FeO **and** Fe_2O_3".*

a.ii $\mathrm{Fe_3O_4(s) + 4CO(g) \rightarrow 3Fe(l) + 4CO_2(g)}$;

*Accept "Fe_3O_4(s) + CO(g) $\rightarrow$ 3FeO(s) + CO_2(g) **and***

FeO(s) + CO(g) $\rightarrow$ Fe(l) + CO_2(g)".

Ignore state symbols.

a.iiiAl is more reactive than Fe / Al is higher than Fe in the reactivity series / Al is a stronger reducing agent / it is harder to reduce aluminium ores compared to iron ores / $\mathrm{Fe}^{3+}/\mathrm{Fe}^{2+}$ is a stronger oxidizing agent / Al^{3+} has a very negative E° value;

Examiners report

a.i. This was a challenging question but some candidates managed to calculate the average oxidation state of iron as +8/3, and very few were able to deduce that both +2 and +3 oxidation states were present in the ore.

a.ii.It was disappointing that most candidates could not give a correct equation for the reduction, considering that both reactants and one product are already given in the question.

a.iiiSome candidates gave the higher reactivity of aluminium as the reason why it could not be extracted by the use of reducing agents.

Compare the positional and directional order in a crystalline solid, nematic phase liquid crystal and a pure liquid. Show your answer by stating **yes** or **no** in the table below.

	Crystalline solid	Nematic phase liquid crystal	Pure liquid
Positional order			
Directional order			

Markscheme

	Crystalline solid	Nematic phase liquid crystal	Pure liquid
Positional order	yes	no	no
Directional order	yes	yes	no

;

;

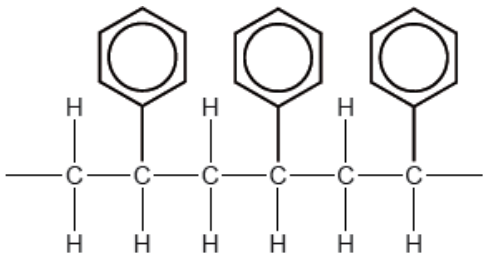
Need all three across table for each mark.

Examiners report

The positional and directional order were generally compared correctly.

The development and application of plastics was one of the most important technological developments of the last century.

The diagram below represents a section of a polymer.



a.i. Identify the **two** functional groups in the monomer from which this polymer is manufactured. [1]

a.ii. An expanded form of the plastic is often used in packaging. Describe how this is manufactured. [2]

b. Discuss **two** advantages and **one** disadvantage of using the expanded form as a packaging material. [3]

Two advantages:

One disadvantage:

Markscheme

a.i. alkenyl/C=C **and** phenyl/$-C_6H_5$;

Accept alkene and benzene ring/aromatic ring/arene but not benzene.

a.ii. pentane/volatile hydrocarbon added (during polymerization process);

heating causes pentane/volatile hydrocarbon to evaporate/vaporize/produce bubbles of gas (expanding the polystyrene);

Accept other suitable <u>identified</u> blowing agents such as carbon dioxide.

b. *Advantages:*

***Any two** for **[2 max]**:*

low/reduced density;

Accept "small mass".

Do not accept "light".

can be shaped (around object);

good shock absorber;

insulator;

Disadvantage:

*Award **[1]** for disadvantage:*

disposal takes up a lot of space (in landfill);

Accept "non-biodegradable/polluting/hazardous to wildlife".

Examiners report

a.i. Some candidates identified two functional groups in the monomer.

a.ii. About half of the candidates described how the expanded form of the plastic could be manufactured.

b. Most candidates were able to score one or two marks. "Good shock absorber" was a popular answer. Candidates should be encouraged to use precise terminology such as "has low density" instead of "light".

Modern society is very dependent on electrical power for portable devices.

Two common rechargeable batteries are lead-acid and nickel-cadmium (NiCad) batteries.

a. (i) State equations for the reactions that occur at each electrode in a **lead-acid battery** when it delivers a current. [4]

Positive electrode (cathode):

Negative electrode (anode):

(ii) State equations for the reactions that occur at each electrode in a **nickel-cadmium (NiCad) battery** when it delivers a current.

Positive electrode (cathode):

Negative electrode (anode):

b. Another source of power for portable devices is the fuel cell. Compare fuel cells with lead-acid rechargeable batteries, stating one similarity and two differences. [3]

Similarity:

Differences:

Markscheme

a. (i) *Lead-acid*:

Positive electrode (cathode):

$\mathrm{PbO_2(s) + SO_4^{2-}(aq) + 4H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l)}$ /

$\mathrm{PbO_2(s) + HSO_4^-(aq) + 3H^+(aq) + 2e^- \rightarrow PbSO_4(s) + 2H_2O(l);}$

Negative electrode (anode):

$\mathrm{Pb(s) + SO_4^{2-}(aq) \rightarrow PbSO_4(s) + 2e^-}$ /

$\mathrm{Pb(s) + HSO_4^-(aq) \rightarrow PbSO_4(s) + 2e^- + H^+(aq);}$

Allow e for e⁻ throughout.

Ignore state symbols.

*Award **[1 max]** if correct equations are given but at the wrong electrodes.*

(ii) *NiCad*:

Positive electrode (cathode):

$\mathrm{NiO(OH)(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq);}$

Negative electrode (anode):

$\mathrm{Cd(s) + 2OH^-(aq) \rightarrow Cd(OH)_2(s) + 2e^-;}$

Allow e for e⁻ throughout.

Ignore state symbols.

*Award **[1 max]** if correct equations are given but at the wrong electrodes.*

b. *Similarity*:

(both) convert chemical energy to electrical energy / (both are) voltaic cells;

Differences:

*Award **[2 max]** for any two*.

rechargeable batteries employ reversible reactions while fuel cells have irreversible reactions;

fuel cells work non-stop while rechargeable batteries take time to recharge;

fuel cells need a constant supply of reactants/fuel while rechargeable batteries do not need any other substances;

fuel cells convert energy **and** rechargeable batteries store energy;

fuel cell products must be constantly removed but not for rechargeable batteries;

fuel cells are less polluting/more expensive/weigh less/last longer (than lead-acid rechargeable batteries);

fuel cells have inert/Pt electrodes/components while lead-acid rechargeable batteries have active/non-inert/Pb and $\mathrm{PbO_2}$ electrodes;

fuel cells run at higher temperatures than rechargeable batteries;

fuel cells are less portable than rechargeable batteries / fuel cells require pumps/cooling systems while rechargeable batteries do not;

*Award **[2 max]** if three valid points (one similarity and two differences) are given without comparison and **[1 max]** if two valid points are given without comparison.*

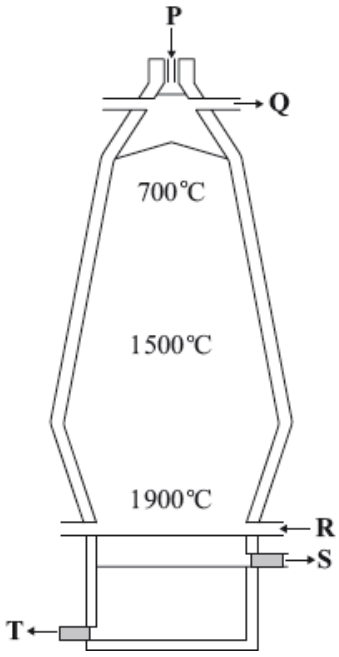
Examiners report

a. (i) Poorly answered even by strong candidates. Very few candidates gave the correct equations for the reactions occurring at the electrodes of a lead-acid battery.

(ii) This part-question was also poorly answered with very few candidates scoring one out of the two possible marks.

b. Many candidates scored at least one mark, but many answers only reflected a shallow understanding of fuel cells and lead-acid batteries. Quite a few candidates are still neglecting to satisfy the demands of the “compare” command term that requires reference to both items in every point of comparison.

Iron ore can be reduced in a blast furnace.



The properties of a metal can be altered by alloying or heat treatment.

Explain why alloying can modify the structure and properties of a metal.

Markscheme

(alloying element(s)) atoms/ions have different size;

Allow suitable diagram.

disrupts regular/repeating (metal) lattice;

difficult for one layer to slide over another / added atoms/ions smaller than metal atoms/ions can fit into the (holes of) metal lattice disrupting bonding;

If “particles” is penalised in M1, allow “particles” in M3.

Do not award mark for different or unique properties of alloys.

Examiners report

The common errors in (a) were to give a formula rather than the name of an ore and to add it at R. Whilst part (ii) was generally answered correctly it was slightly alarming to see oxygen given from time to time. Few seemed to know the equation of the reaction primarily responsible for the temperature of 1900 °C. Slag was usually correctly identified in (c) but the equations given seldom started from the raw material, $\mathrm{CaCO_3}$. Part (d) was often answered successfully whilst candidates were generally unable to earn both marks in (e) (i). Most understood the effect of tempering on steel.

Iron is extracted from its ore by reduction in a blast furnace.

State an equation for the reaction by which iron (III) oxide, Fe_2O_3, is reduced to iron in the blast furnace.

Markscheme

$\mathrm{Fe_2O_3(s) + 3CO(g) \rightarrow 2Fe(l) + 3CO_2(g)}$/$\mathrm{Fe_2O_3(s) + 3H_2(g) \rightarrow 2Fe(l) + 3H_2O(g)}$ /

$\mathrm{2Fe_2O_3(s) + 3C(s) \rightarrow 4Fe(l) + 3CO_2(g)}$/$\mathrm{Fe_2O_3(s) + 3C(s) \rightarrow 2Fe(l) + 3CO(g)}$;

Ignore state symbols.

Examiners report

It was pleasing to see a good number of correctly balanced equations here. The precise explanation of how alloying of steel affects physical properties was rarely seen. The correct description of how quenched steel is tempered was rarely seen with the most common answer being heated and rapidly cooled.

Liquid crystals are widely used in displays.

a. Describe the meaning of the term liquid crystals. [1]

b. When a liquid-crystal display is warmed with a hairdryer, the display loses its clarity and may no longer be visible. Explain why this happens on a molecular level. [2]

Markscheme

a. fluids that have physical properties dependent on molecular orientation/orderly molecular arrangement;

Allow "fluids that exhibit molecular orientation/orderly molecular arrangement".

Allow "(LCs) show properties of liquids and crystals simultaneously".

b. thermal agitation disrupts directional order of liquid crystal / *OWTTE*;

rotation of plane polarized light disrupted / crystals no longer have ability to affect light in same way / *OWTTE*;

Examiners report

a. An understanding of liquid crystals was generally conveyed. Some candidates stated that liquid crystals show properties of liquids and solids simultaneously which did not score as they did not mention the crystalline state explicitly for solids. In (b) only the really top-tier candidates were able to explain the question asked on a molecular level, i.e. the fact that thermal agitation disrupts the directional order of the liquid crystal and as a result the rotation of plane polarized light is disrupted. This question proved to be possibly one of the hardest questions on the paper overall for candidates.

b. An understanding of liquid crystals was generally conveyed. Some candidates stated that liquid crystals show properties of liquids and solids simultaneously which did not score as they did not mention the crystalline state explicitly for solids. In (b) only the really top-tier candidates were able to explain the question asked on a molecular level, i.e. the fact that thermal agitation disrupts the directional order of the liquid crystal and as a result the rotation of plane polarized light is disrupted. This question proved to be possibly one of the hardest questions on the paper overall for candidates.

The two major acids that cause acid rain originate from different sources.

a. State an equation that shows why rain water is naturally acidic. [1]

b.i. Outline the process responsible for the production of each acid and state an equation to show its formation. [4]

b.ii Acid rain has caused damage to limestone buildings and marble statues. State an equation to represent the reaction of acid rain with limestone or marble. [1]

Markscheme

a. $\mathrm{CO_2 + H_2O \rightleftharpoons H_2CO_3 / CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-}$;

Do not penalize absence of reversible sign.

Do not accept $CO_2 + H_2O \rightarrow 2H^+ + CO_3^{2-}$.

b.i. *Acid 1:*

$\mathrm{(HNO_2 / HNO_3)}$ high temperature in internal combustion/jet engine;

reaction between $\mathrm{N_2}$ and $\mathrm{O_2}$ at high temperature/lightning;

Accept either of the above for first mark.

$\mathrm{2NO_2 + H_2O \rightarrow HNO_3 + HNO_2 / 4NO_2 + O_2 + 2H_2O \rightarrow 4HNO_3}$;

Acid 2:

$\mathrm{(H_2SO_3 / H_2SO_4)}$ from burning of coal / smelting plants / sulfuric acid plants / volcanic activity;

Do not accept combustion of fossil fuels.

$SO_2 + H_2O \rightarrow H_2SO_3/SO_3 + H_2O \rightarrow H_2SO_4$;

Allow H_2SO_3/H_2SO_4 to be Acid 1 and HNO_2/HNO_3 to be Acid 2.

b.ii. $CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + CO_2 + H_2O$;

Accept equation with H_2SO_3 or H_2SO_4 or ionic equations.

Do not accept equations with H_2CO_3.

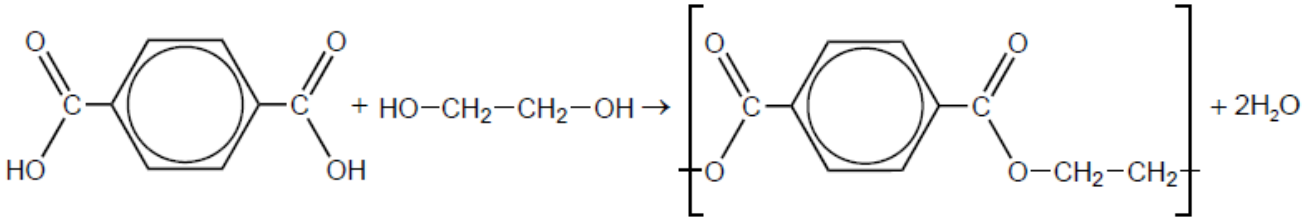
Examiners report

a. Most candidates correctly identified carbon dioxide as the source of natural water acidity and wrote an acceptable equation. Many also identified sources of nitric and sulphuric acid, though these equations often proved trickier, with many candidates writing equations for the formation of the oxide from which the acid is derived. Balanced equations for the reaction with limestone also proved to be a challenge, with carbonic acid often appearing as a product.

b.i. Most candidates correctly identified carbon dioxide as the source of natural water acidity and wrote an acceptable equation. Many also identified sources of nitric and sulphuric acid, though these equations often proved trickier, with many candidates writing equations for the formation of the oxide from which the acid is derived. Balanced equations for the reaction with limestone also proved to be a challenge, with carbonic acid often appearing as a product.

b.ii. Most candidates correctly identified carbon dioxide as the source of natural water acidity and wrote an acceptable equation. Many also identified sources of nitric and sulphuric acid, though these equations often proved trickier, with many candidates writing equations for the formation of the oxide from which the acid is derived. Balanced equations for the reaction with limestone also proved to be a challenge, with carbonic acid often appearing as a product.

Antimony oxide is widely used as a homogeneous catalyst in the reaction of benzene-1,4-dicarboxylic acid with ethane-1,2-diol in the production of polyethylene terephthalate (PETE) shown below.



a. Catalysts reduce the activation energy. Outline how homogeneous catalysts are involved in the reaction mechanism. [1]

b. Suggest why it is important to know how catalysts function. [1]

c. Antimony and its compounds are toxic, so it is important to check that the catalyst is removed from the final product. One technique to detect antimony is Inductively Coupled Plasma Mass Spectroscopy (ICP-MS). [2]

Outline the nature of the plasma state and how it is produced in ICP-MS.

Markscheme

a. combine with reactants to form a «temporary» activated complex/intermediate

OR

consumed in one reaction/step ***AND*** regenerated in a later reaction/step

[1 mark]

b. can modify/improve the catalyst/reaction «by making logical predictions»

OR

science relies on models to understand physical reality

Accept other reasonable, relevant answers.

Accept "to predict/select

[1 mark]

c. electrons ***AND*** positive ions «in gaseous state»

high frequency/alternating current passed through argon
OR
«oscillating» electromagnetic/magnetic field
OR
high frequency radio waves

Accept “gas” instead of “argon”.

[2 marks]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Chloroethene undergoes polymerization with a free-radical initiator to produce the atactic form of polychlorethene (PVC).

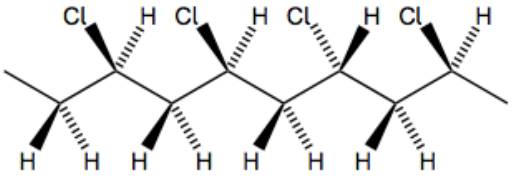
a. Sketch the atactic form of polychloroethene showing **four** units. [1]

b. (i) Explain, in molecular terms, why PVC becomes more flexible and softer when a plasticizer is added. [3]

(ii) State **one** type of compound which can be used as a plasticizer.

c. Suggest an environmental issue associated with the use of PVC. [1]

Markscheme

a. 

correct structure with random orientation of Cl atoms

Accept 2-dimensional diagrams.

Accept any random arrangement of Cl atoms providing the monomer units originate from chloroethene and Cl atoms are on alternate carbons.

Continuation bonds are necessary for the mark.

b. (i)

«plasticizer molecules» fit between chains

OR

«plasticizer molecules» prevent chains from forming crystalline regions

OR

«plasticizer molecules» keeps strands/chains/molecules separated

OR

«plasticizer molecules» increase space/volume between chains

weakens intermolecular/dipole-dipole/London/dispersion/instantaneous induced dipole-induced dipole/van der Waals/vdW forces

*Do **not** accept "«plasticizer molecules» lower density".*

(ii)
ester/phthalate/citrate

Accept other general or specific names of plasticizers.

c. does **not** degrade/biodegrade/break down **«**easily**»**

occupies more space in landfills

incineration produces dioxins/hydrochloric acid/HCl **«**which can contribute to acid rain**»**

Accept "plasticizer added to PVC can be a health hazard".

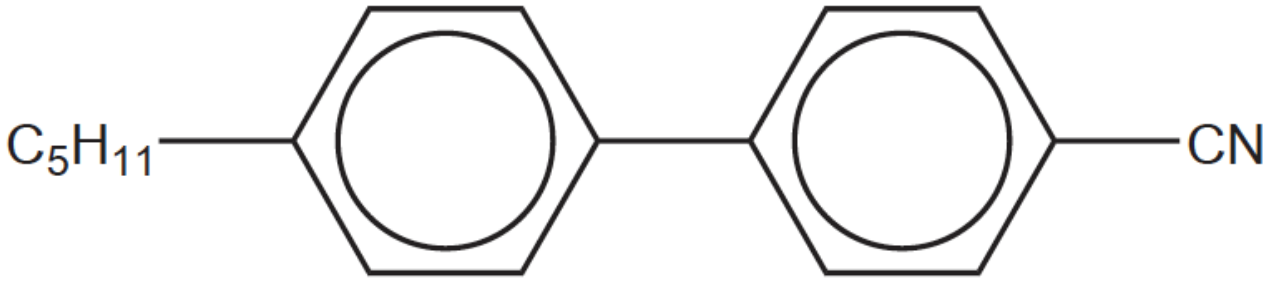
Accept "combustion" for "incineration".

*Do **not** accept simply "toxic compounds" for M3*

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Biphenyl nitriles, such as the molecule shown below, were the first thermotropic liquid crystal molecules to be synthesized.



a. Suggest how changing the size or shape of the hydrocarbon chain would affect the molecule's liquid crystal behaviour. [1]

b. Explain why the nitrile group enables these molecules to be used in liquid-crystal displays (LCDs). [2]

Markscheme

a. alters the temperature range of the liquid-crystal state

OR

alters sensitivity «of the liquid crystal» to electric field**«s»**

OR

prevents liquid crystal activity

b. «CN group makes» molecule polar

alignment/orientation of molecules can be controlled by electric field
OR
allows molecules to align in an electric field/when a voltage is applied

Accept "CN is polar".

Examiners report

a. [N/A]
b. [N/A]

Polymers are made up of repeating monomer units which can be manipulated in various ways to give structures with desired properties.

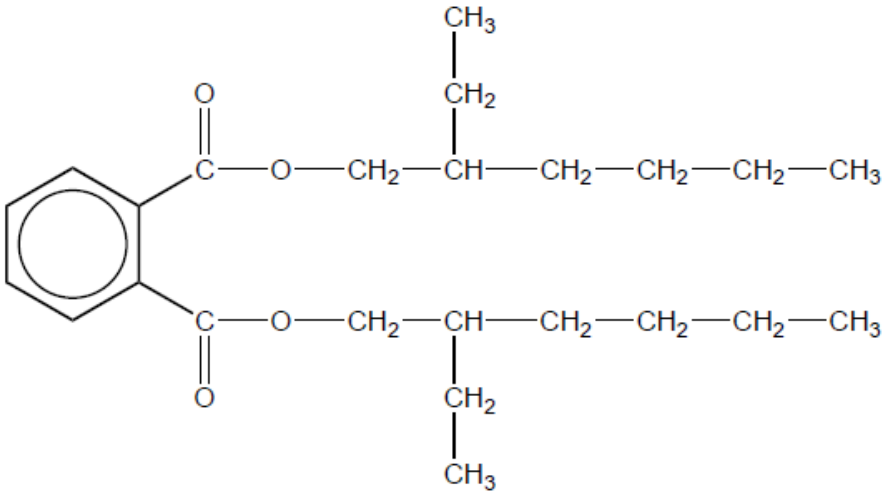
a. (i) Draw the structure of 2-methylpropene. [2]

(ii) Deduce the repeating unit of poly(2-methylpropene).

b. Deduce the percentage atom economy for polymerization of 2-methylpropene. [1]

c. (i) Suggest why incomplete combustion of plastic, such as polyvinyl chloride, is common in industrial and house fires. [2]

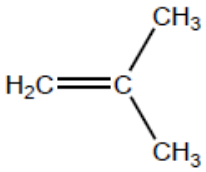
(ii) Phthalate plasticizers such as DEHP, shown below, are frequently used in polyvinyl chloride.



With reference to bonding, suggest a reason why many adults have measurable levels of phthalates in their bodies.

Markscheme

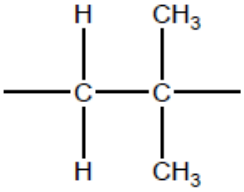
a. i



OR

$H_2C=C(CH_3)_2$

ii



OR

$-CH_2C(CH_3)_2-$

Continuation bonds needed for mark.
No penalty if square brackets present or "n" appears after the bracket/formula.

b. «same mass of product as reactant, thus» 100«%»

Accept "less than 100%" only if a reason is given (eg, the catalyst is not converted into the product, or other reasonable answer).

c. i

due to stability of plastics/strong covalent bonds
OR
low volatility preventing good mixing with oxygen «gas»
OR
lack of/insufficient oxygen
OR

plastics are often parts of devices with non-combustible components «which mechanically prevent the combustion of plastic components»
OR
PVC already partly oxidised «because some C–H bonds are replaced with C–Cl bonds», so it cannot produce enough heat for complete combustion
OR
many industrial/household materials contain additives that reduce their flammability/act as flame retardants

ii

weakly bound to the PVC/no covalent bonds to PVC/only London/dispersion/instantaneous induced dipole-induced dipole forces between DEHP and PVC ***AND*** leach/evaporate «from PVC» to atmosphere/food chain
OR
has low polarity/contains non-polar hydrocarbon chains ***AND*** fat-soluble/deposits in the fatty tissues
OR
has unusual structural fragments/is a xenobiotic/difficult to metabolise ***AND*** stays in the body for a long time

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]

Liquid crystals have many applications.

a. Outline how a lyotropic liquid crystal differs from a thermotropic liquid crystal. [2]

b. Explain the effect of increasing the temperature of a nematic liquid crystal on its directional order. [1]

Markscheme

a.

Lyotropic LCs		*Thermotropic LCs*
solutions	***AND***	pure substances
LC over certain concentration range	***AND***	LC over a temperature range «between the solid and liquid phases»

*Do **not** award any credit if one type only is described as the question asks how they differ.*

b. decreases ***AND*** as energy «added» overcomes interparticle forces

OR

decreases ***AND*** as energy «added» causes faster movement «of particles»

Examiners report

a. [N/A]
b. [N/A]

Polymer nanocomposites often have better structural performance than conventional materials. Lithographic etching and metal coordination are two methods of assembling these nanocomposites.

Nanoparticles anchor plasticizers in PVC so that they cannot escape from the polymer as easily.

a. State the two distinct phases of a composite. [2]

b. Identify the methods of assembling nanocomposites by completing the table. [2]

	Physical or chemical	Bottom up or top down
Lithography	. . . . .	. . . . .
Metal coordination	. . . . .	. . . . .

c.i. Explain how the structure of plasticizers enables them to soften PVC. [3]

c.ii. Suggest a reason why nanoparticles can better anchor plasticizers in the polymer. [1]

Markscheme

a. reinforcing «phase»

«embedded in» matrix «phase»

[2 marks]

b.

	Physical or chemical	Bottom up or top down
Lithography	physical	top down
Metal coordination	chemical	bottom up

*Award **[2]** for all 4, **[1]** for 2 or 3 correct.*

[2 marks]

c.i. *Any three of:*

contain a polar group «which locks into the polymer»

a non-polar group «which weakens the forces between chains»

embedded between chains of polymers

«plasticizer molecules» fit between chains

«plasticizer molecules» prevent chains from forming crystalline regions

«plasticizer molecules» keeps strands/chains/molecules separated

«plasticizer molecules» increase space/volume between chains

weakens intermolecular/dipole-dipole/London/dispersion/instantaneous induced dipole-induced dipole/van der Waals/vdW forces

Do not accept "«plasticizer molecules» "lower density" or "softer".

[3 marks]

c.ii. more places «for plasticizers» to bond

OR

increased surface area

[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]

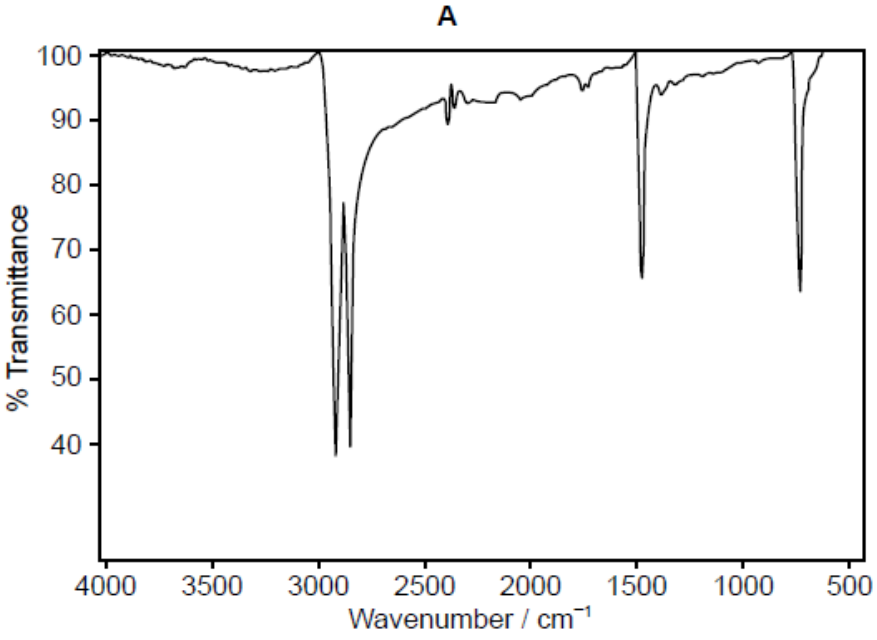
The development of materials with unique properties is critical to advances in industry.

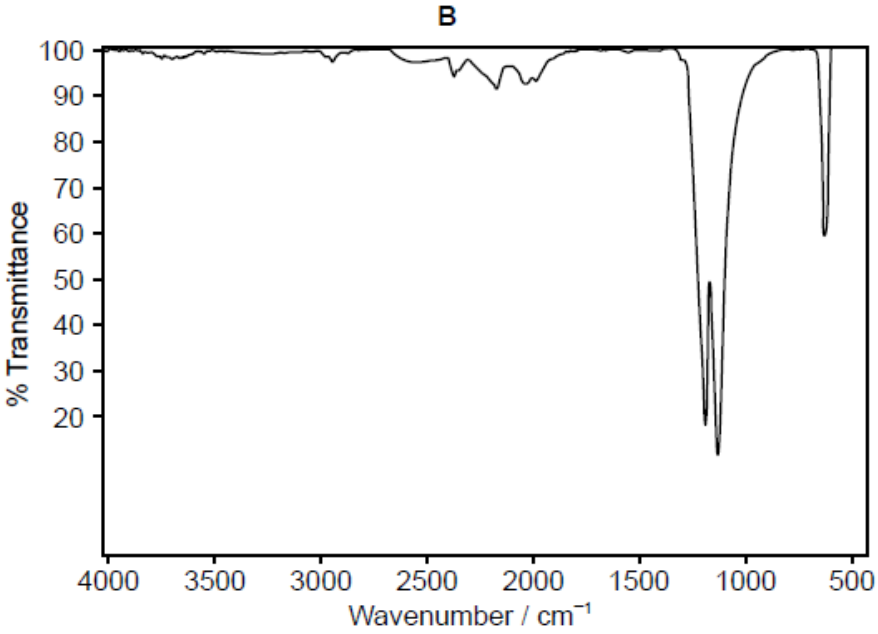
Low density polyethene (LDPE) and high density polyethene (HDPE) are both addition polymers.

a. Outline two properties a substance should have to be used as liquid-crystal in a liquid-crystal display. [2]

b.i. Describe how the structures of LDPE and HDPE affect one mechanical property of the plastics. [2]

b.ii. One of the two infrared (IR) spectra is that of polyethene and the other of polytetrafluoroethene (PTFE). [1]





[Source: www.doitpoms.ac.uk]

Deduce, with a reason, which spectrum is that of PTFE. Infrared data is given in section 26 of the data booklet.

c. Many plastics used to be incinerated. Deduce an equation for the complete combustion of two repeating units of PVC, $(-C_2H_3Cl-)_2$. [2]

Markscheme

a. *Any two of:*

ability to form a LC phase

chemically stable

«LC phase that is» stable over suitable temperature range

polar

OR

being able to change orientation with applied electric field

rapid switching speed «responds to changes of voltage quickly»

Accept "ability of molecules to transmit light under certain conditions" ***OR*** *"rodshaped molecules"* ***OR*** *"stable to light/not light sensitive".*

[Max 2 Marks]

b.i. branching in LDPE prevents close packing «of chains»

LDPE is more flexible/less rigid

OR

LDPE has lower «tensile» strength

Do ***not*** *accept "difference in density".*

Award ***[1 max]*** *for stating "branching in LDPE* ***AND*** *little/no branching in HDPE".*

b.ii. **B** ***AND*** absence «of absorption of» C–H at 2850–3090 «cm^{-1}»

OR

B ***AND*** presence of «absorption of» C–F at 1000–1400 «cm^{-1}»

c. $(–C_2H_3Cl–)_2$ (s) + $5O_2$ (g) → $4CO_2$ (g) + $2H_2O$ (l) + 2HCl (g)

correct species in reactants and products

balanced

Accept "$(–C_2H_3Cl–)_2$ (s) + $5.5O_2$ (g) → $4CO_2$ (g) + $3H_2O$ (l) + Cl_2 (g)".

Award M2 only if M1 correct.

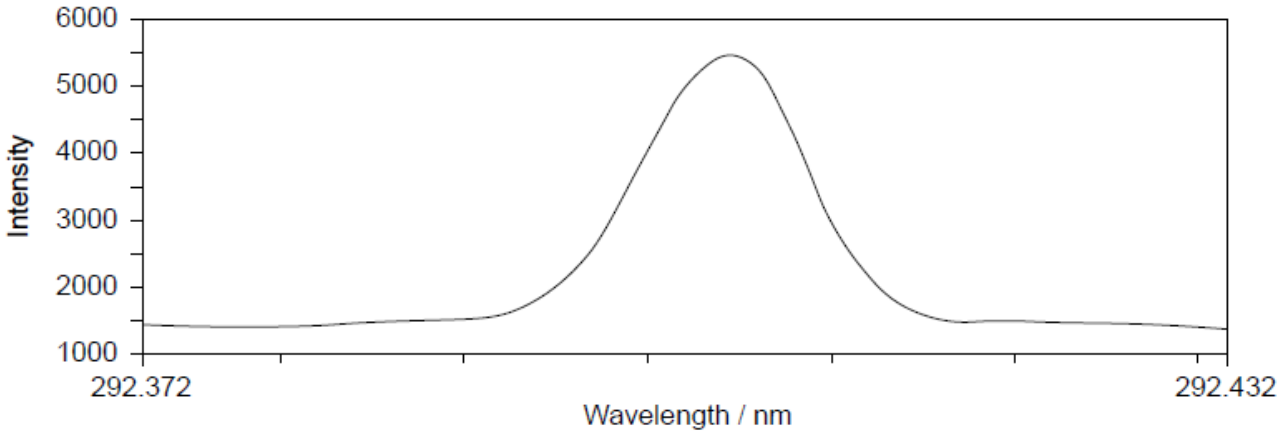
Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c. [N/A]

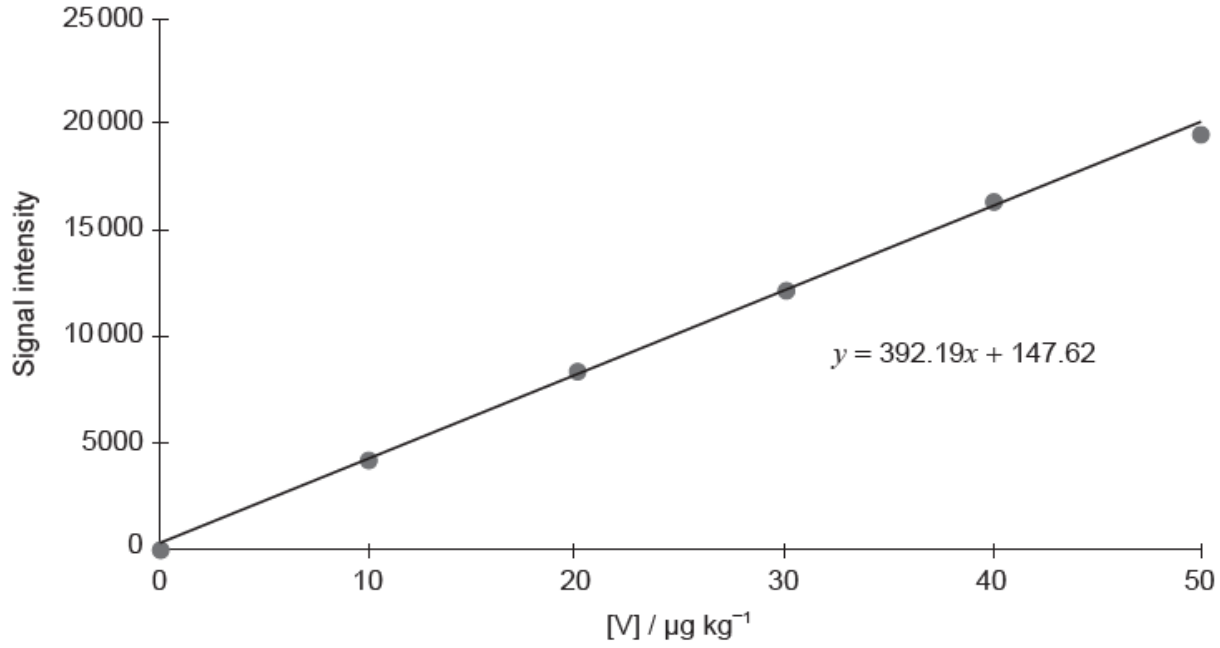
Inductively Coupled Plasma (ICP) used with Mass Spectrometry (MS) or Optical Emission Spectrometry (OES) can be used to identify and quantify elements in a sample.

The following graphs represent data collected by ICP-OES on trace amounts of vanadium in oil.

Graph 1: Calibration graph and signal for 10 μg kg^{-1} of vanadium in oil



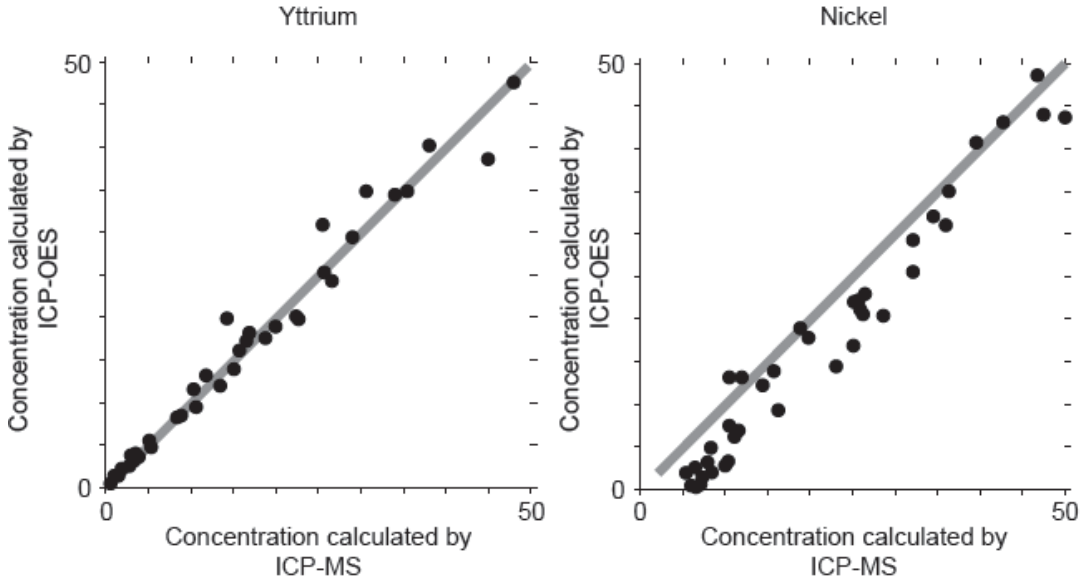
Graph 2: Calibration of vanadium in μg kg^{-1}



[Source: © Agilent Technologies, Inc.1998. Reproduced with Permission, Courtesy of Agilent Technologies, Inc.]

a. ICP-OES/MS can be used to analyse alloys and composites. Distinguish between alloys and composites. [2]

b. ICP-MS is a reference mode for analysis. The following correlation graphs between ICP-OES and ICP-MS were produced for yttrium and nickel. [2]



[Source: http://www.emse.fr/~moutte/kola/report/cmp_icpms.htm © Jacques Moutte]

Each *y*-axis shows concentrations calculated by ICP-OES; each *x*-axis shows concentrations for the same sample as found by ICP-MS.

The line in each graph is $y = x$.

Discuss the effectiveness of ICP-OES for yttrium and nickel.

c.i. Identify the purpose of each graph. [2]

Graph 1:

. . . . . .

. . . . . .

Graph 2:

. . . . . .

. . . . . .

c.ii. Calculate, to four significant figures, the concentration, in μg kg^{-1}, of vanadium in oil giving a signal intensity of 14 950. [1]

c.iii. Vanadium(V) oxide is used as the catalyst in the conversion of sulfur dioxide to sulfur trioxide. [2]

$SO_2(g) + V_2O_5(s) \rightarrow SO_3(g) + 2VO_2(s)$

$\frac{1}{2}O_2(g) + 2VO_2(s) \rightarrow V_2O_5(s)$

Outline how vanadium(V) oxide acts as a catalyst.

Markscheme

a. *Alloy:*

mixture of metal with other metals/non-metals

OR

mixture of elements that retains the properties of a metal

Composite:

reinforcing phase embedded in matrix phase

*Award **[1 max]** for implying "composites only have heterogeneous/nonhomogeneous compositions".*

[2 marks]

b. effective for yttrium «but less/not for nickel»

points on nickel graph do not lie on «*y* = *x*» line

OR

cannot be used for low concentrations of nickel

OR

concentration of nickel is lower than recorded value

Accept "ICP-OES is more accurate for lower yttrium concentrations than higher concentrations" for M1.

Accept [Ni] and [Y] for concentrations of nickel and yttrium.

Accept "detection limit for yttrium is lower than for nickel" for M2.

*Award **[1 max]** for "more accurate for yttrium at lower concentrations **AND** nickel at higher concentrations".*

[2 marks]

c.i. *Graph 1:* determines wavelength of maximum absorption/maximum intensity «for vanadium»

Graph 2: determines absorption of known concentrations «at that wavelength»

OR

estimates [V]/concentration in a sample using «the signal» intensity

*Do **not** accept just "determines maximum wavelength/λ_{max}" for M1.*

*Do **not** accept "calibration curve" for M2.*

[2 marks]

c.ii. «14 950 = 392.19x + 147.62»

x = 37.74 «μg kg^{-1}»

*Answer must be given to **four significant figures**.*

*Do **not** accept values obtained directly from the graph.*

[1 mark]

c.iii. vanadium reduced in first reaction ***AND*** oxidized in second reaction

OR

V_2O_5 oxidizes SO_2 in first reaction ***AND*** VO_2 reduces O_2 in second reaction

OR

vanadium returns to original oxidation state «after reaction»

provides an alternative reaction pathway/mechanism «with a lower activation energy» ✔

*Do **not** accept "reactants adsorb onto surface **AND** products desorb".*

Accept "oxidation number" for "oxidation state".

[2 marks]

Examiners report

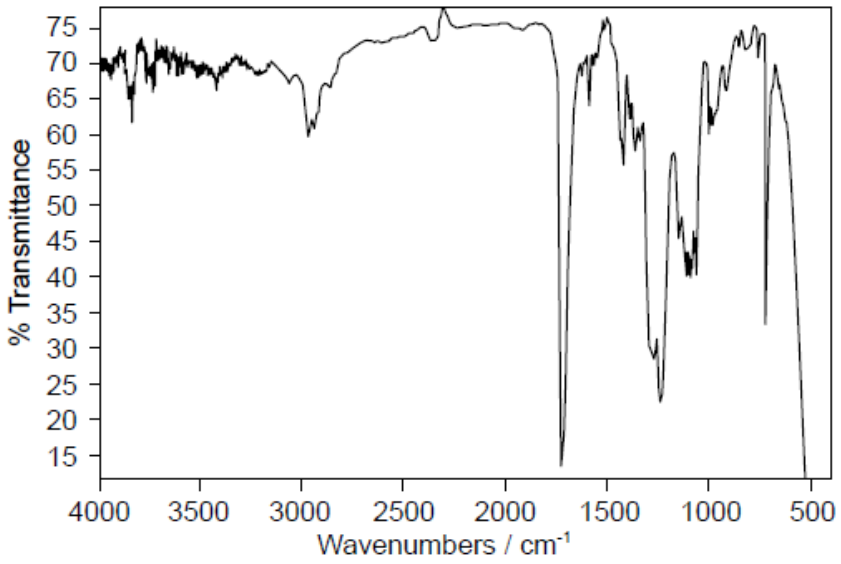
a. [N/A]
b. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]

Infrared (IR) spectroscopy is often used for the identification of polymers, such as PETE, for recycling.

LDPE and high density polyethene (HDPE) have very similar IR spectra even though they have rather different structures and physical properties.

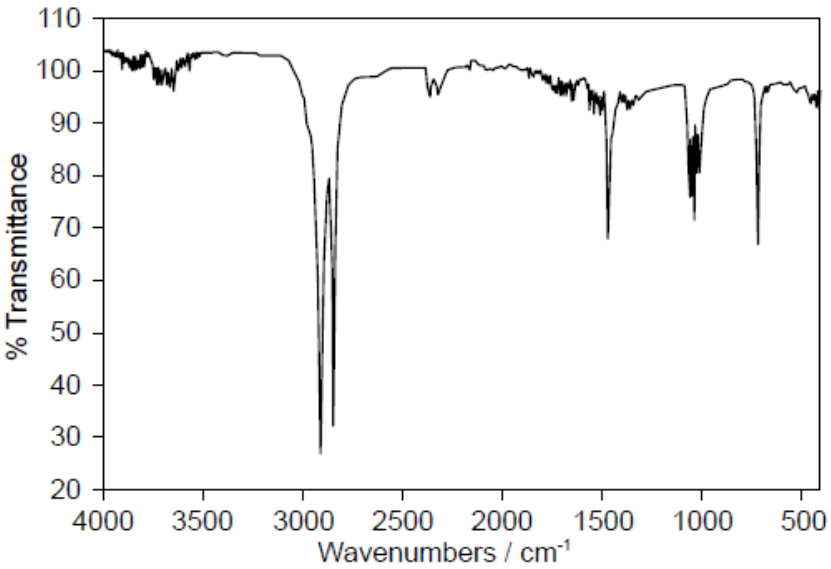
a. Below are the IR spectra of two plastics (**A** and **B**); one is PETE, the other is low density polyethene (LDPE). [3]

A



[Source: www.intechopen.com]

B



[Source: www.andersonmaterials.com]

Deduce, giving your reasons, the identity and resin identification code (RIC) of **A** and **B** using sections 26 and 30 of the data booklet.

A RIC:

. . . . . .

. . . . . .

. . . . . .

B RIC:

. . . . . .

. . . . . .

. . . . . .

b.i. Describe the difference in their structures. [1]

b.ii. Explain why the difference in their structures affects their melting points. [2]

Markscheme

a. *A RIC:* 1 ***AND*** *B RIC:* 4

ALTERNATIVE 1:
«only» PETE contains carbonyl/C=O/ester/COO groups
carbonyl groups absorb at 1700–1750 «cm^{-1}»

ALTERNATIVE 2:
LDPE contains more C–H bonds «than PETE»
C–H bonds absorb at 2850–3090 «cm^{-1}»

For either, accept specific frequencies in these ranges (eg 1735 «cm^{-1}» or 2900 «cm^{-1}»).

[3 marks]

b.i. HDPE less branched

OR

LDPE more branched

*Accept "no branching in HDPE **AND** branching in LDPE".*

[1 mark]

b.ii. HDPE «polymer» chains/molecules can pack together more closely «than LDPE chains»

OR

HDPE «polymer» chains/molecules have a higher contact surface area «than LDPE chains»

stronger intermolecular/dispersion/London/van der Waals' forces in HDPE ***AND*** higher melting point

Accept converse arguments.

[2 marks]

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]