# 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]

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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 $1.296 \times 10^{13}$ C. Use sections 2 and 6 of the data booklet.

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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:

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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]

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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 and sections 2 and 6 of the data booklet. [3]

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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]

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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]

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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]

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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.

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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]

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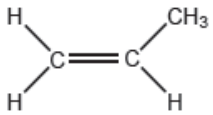
Propene can polymerize to form polypropene.

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.

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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]

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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]

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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]

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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]

---

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.

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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:

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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]

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

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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]

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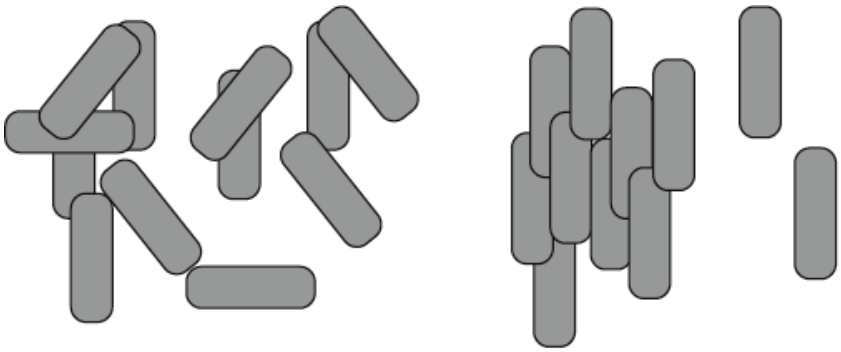
Liquid crystals are widely used in electrically controlled liquid crystal display (LCD) devices such as calculators, computers and watches.

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]



I II

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]

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]

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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]

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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]

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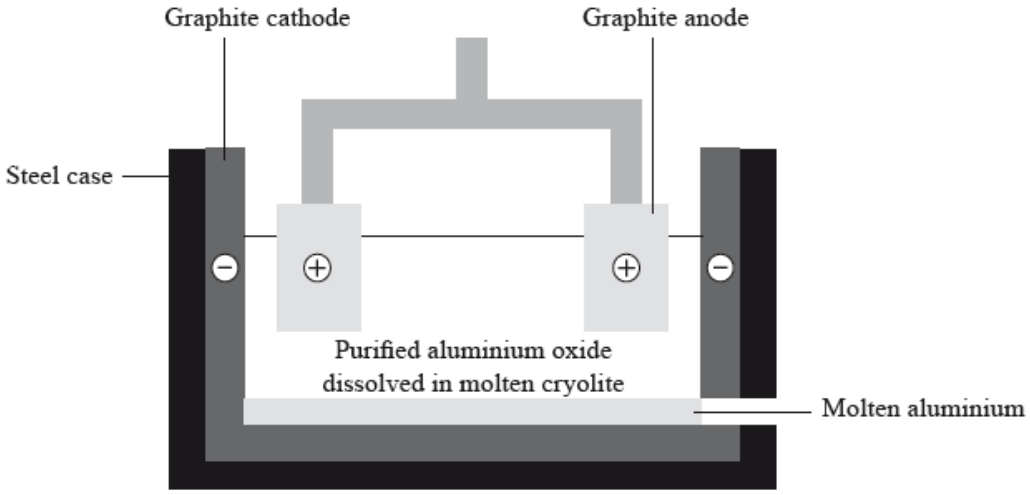
Aluminium is chemically reactive so it has to be extracted by the electrolysis of aluminium oxide dissolved in molten cryolite.




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.

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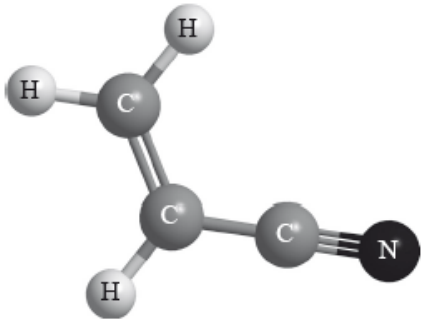
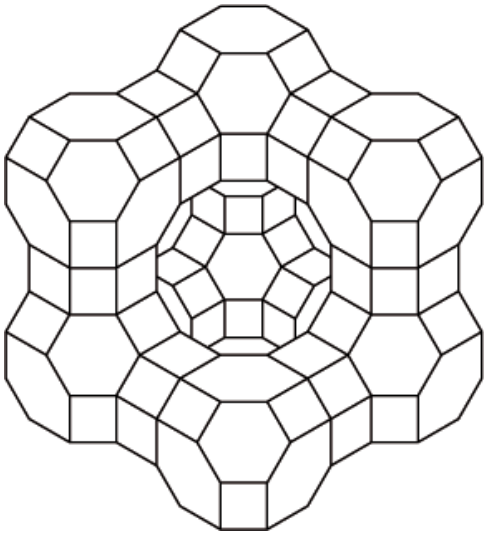
Polyacrylonitrile is an important polymer used in the manufacture of carbon fibres. The monomer has the structure below.




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]

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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]

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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 $9.00 \times 10^3$ 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]

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]

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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]

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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).

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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]

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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]

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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]

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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]

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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]

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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]

–[– –]–

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.

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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 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]

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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.

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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]

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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]

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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 , 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]

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]

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, , to produce **two** products with similar masses. [1]

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]

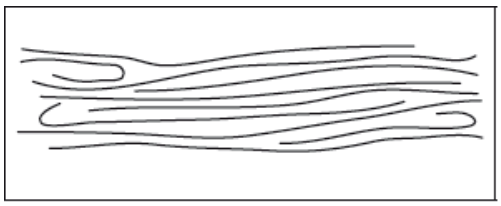
b. Predict the magnetic properties of $Fe_2O_3$ and $Al_2O_3$ in terms of the electron structure of the metal ion, giving your reasons. [2]

$Fe_2O_3$:

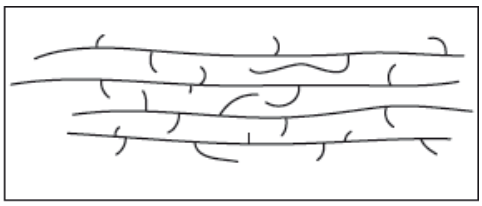
$Al_2O_3$:

c. Molten alumina, $Al_2O_3(l)$, was electrolysed by passing $2.00\times10^6$ C through the cell. Calculate the mass of aluminium produced, using sections 2 and 6 of the data booklet. [2]

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, how adding a plasticizer to PVC modifies the properties of the polymer. [3]

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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]

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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, , (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. [1]

Suggest **one** way in which it was achieved.

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]

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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]

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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]

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Iron acts as a catalyst in the chemical reactions below.

Reaction I, catalysed by :

Reaction II, catalysed by Fe(s):

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 |
|---|---|---|
| $Fe^{2+}(aq)$ | ..... ..... | ..... ..... |
| Fe (s) | ..... ..... | ..... ..... |

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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.

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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]

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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:

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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, , is able to remove mercury(II) ions, , when it is bubbled through a water sample.

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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]

---

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, . [2]

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

:

:

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

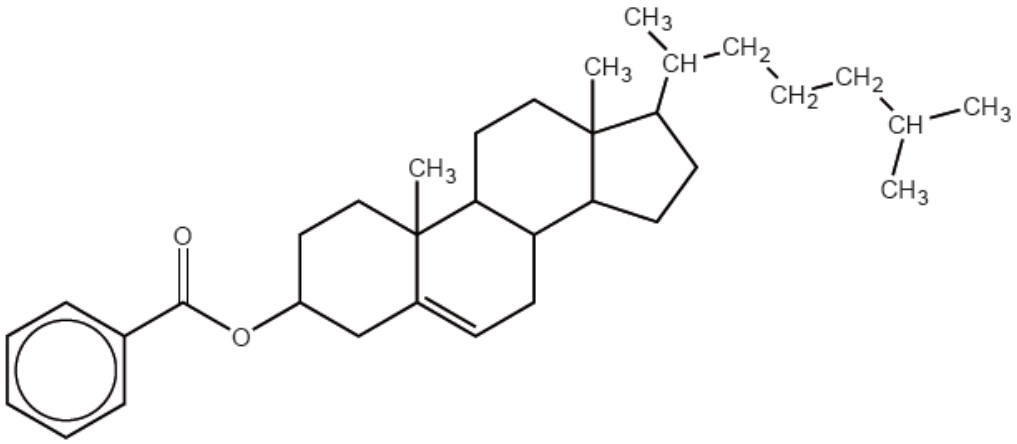
c. Catalytic cracking uses silica as a heterogeneous catalyst. Explain the mode of action of a heterogeneous catalyst. [2]

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]

---

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]

---

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

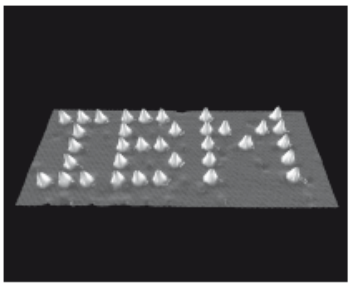
a. Define the term *nanotechnology*. [2]

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

---

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 . Estimate the approximate length, in m, of the "I" in the original IBM image. [1]

---

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]

---

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:

---

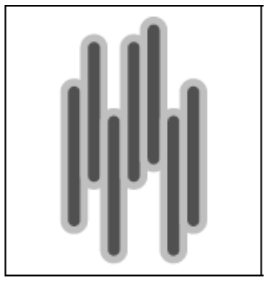
Steel is a vital structural material in modern society. Some of it is obtained from recycled iron and steel, but much of it is produced from iron ore using a blast furnace.

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

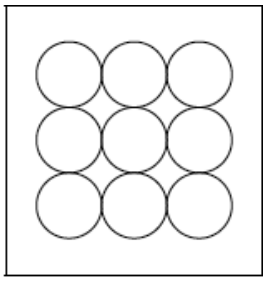
State **three** factors which need to be considered when an industrial catalyst is chosen. In **each** case explain why they are important.

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]

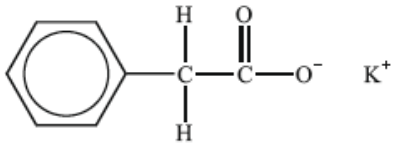
A. 

B. 

C. 

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

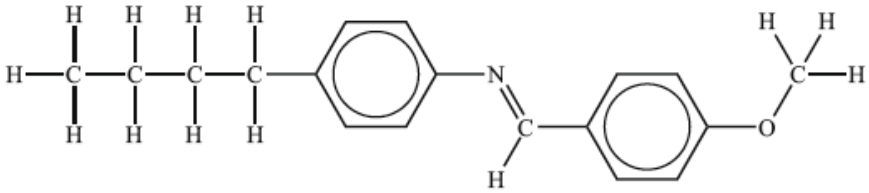
Substance I:



Liquid-crystalline behaviour (yes/no):

Reasoning:

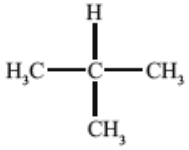
Substance II:



Liquid-crystalline behaviour (yes/no):

Reasoning:

Substance III:



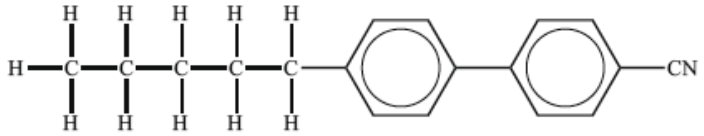
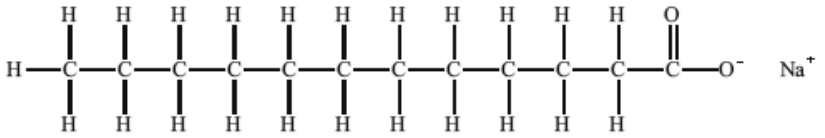
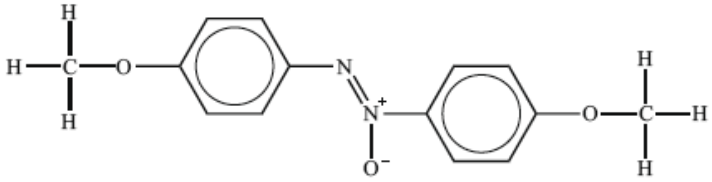
Liquid-crystalline behaviour (yes/no):

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:  | |

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]

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

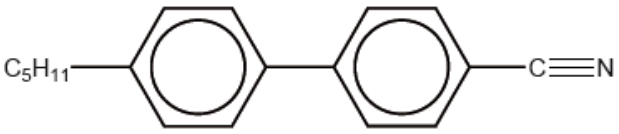
a. Explain why PVC is less flexible than polyethene. [2]

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

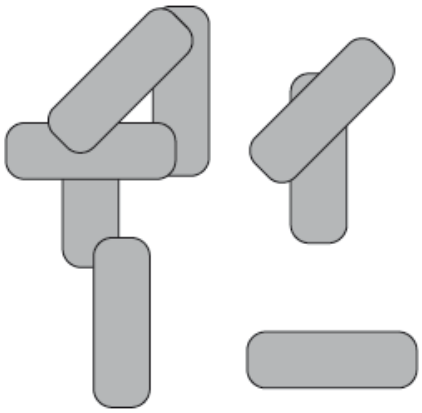
c. PVC can exist in isotactic and atactic forms. Draw the structure of the isotactic form showing a chain of at least six carbon atoms. [1]

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]

---

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]

---

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

---

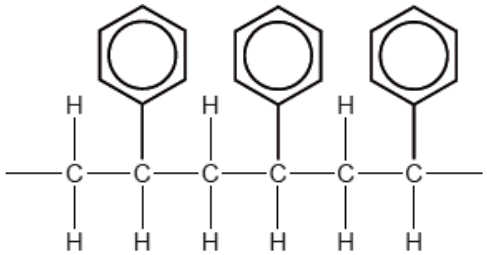
Compare the positional and directional order in a crystalline solid, nematic phase liquid crystal and a pure liquid. Show your answer by stating **yes** or **no** in the table below.

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

---

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:

---

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):

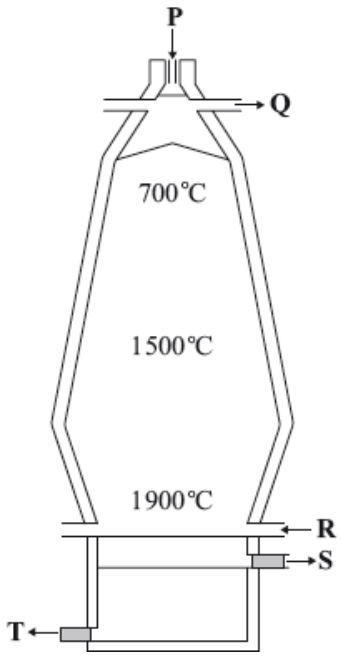
b. Another source of power for portable devices is the fuel cell. Compare fuel cells with lead-acid rechargeable batteries, stating one similarity and two differences. [3]

Similarity:

Differences:

---

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.

---

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.

---

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]

---

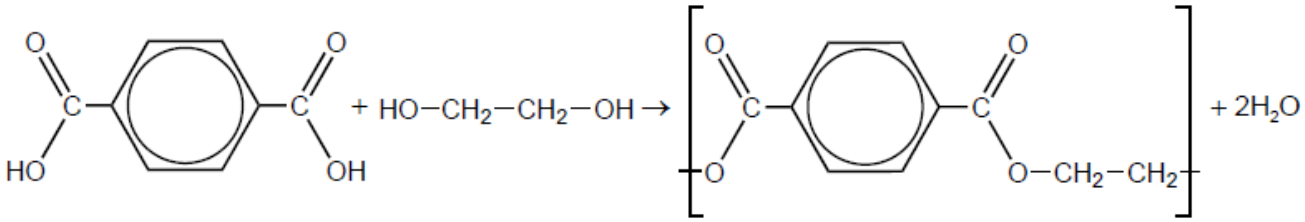
The two major acids that cause acid rain originate from different sources.

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]

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.

Chloroethene undergoes polymerization with a free-radical initiator to produce the atactic form of polychlorethene (PVC).

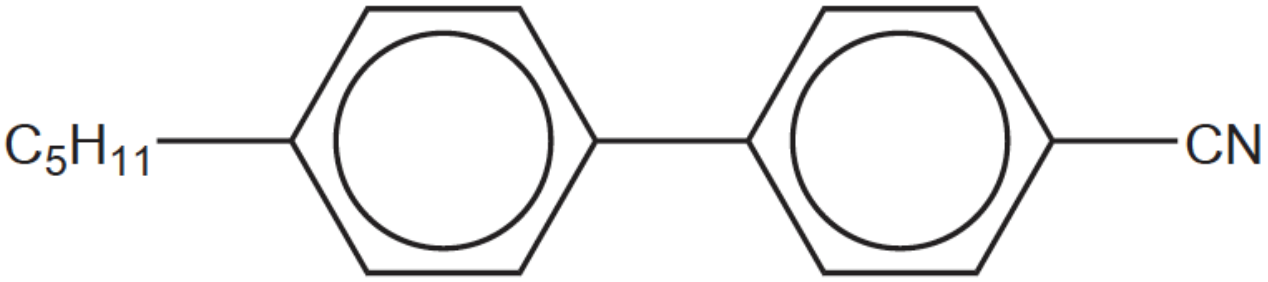
a. Sketch the atactic form of polychloroethene showing **four** units. [1]

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]

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]

---

Polymers are made up of repeating monomer units which can be manipulated in various ways to give structures with desired properties.

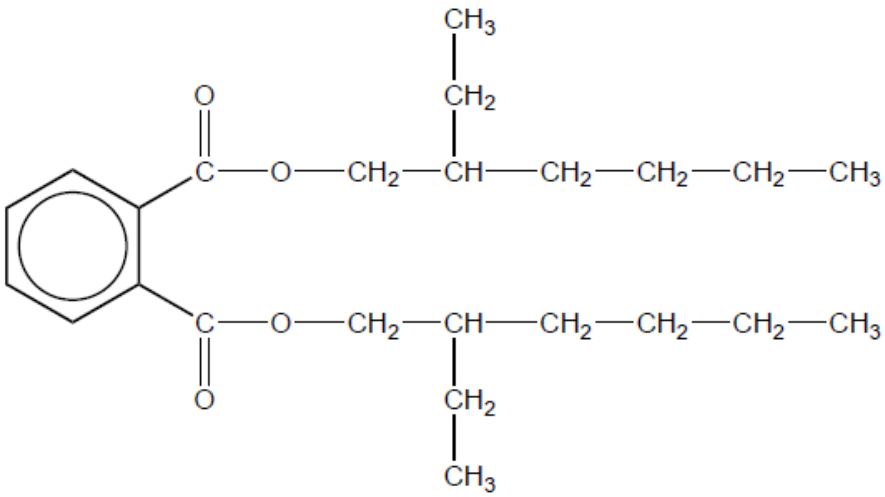
a. (i) Draw the structure of 2-methylpropene. [2]

(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.

---

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]

---

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]

---

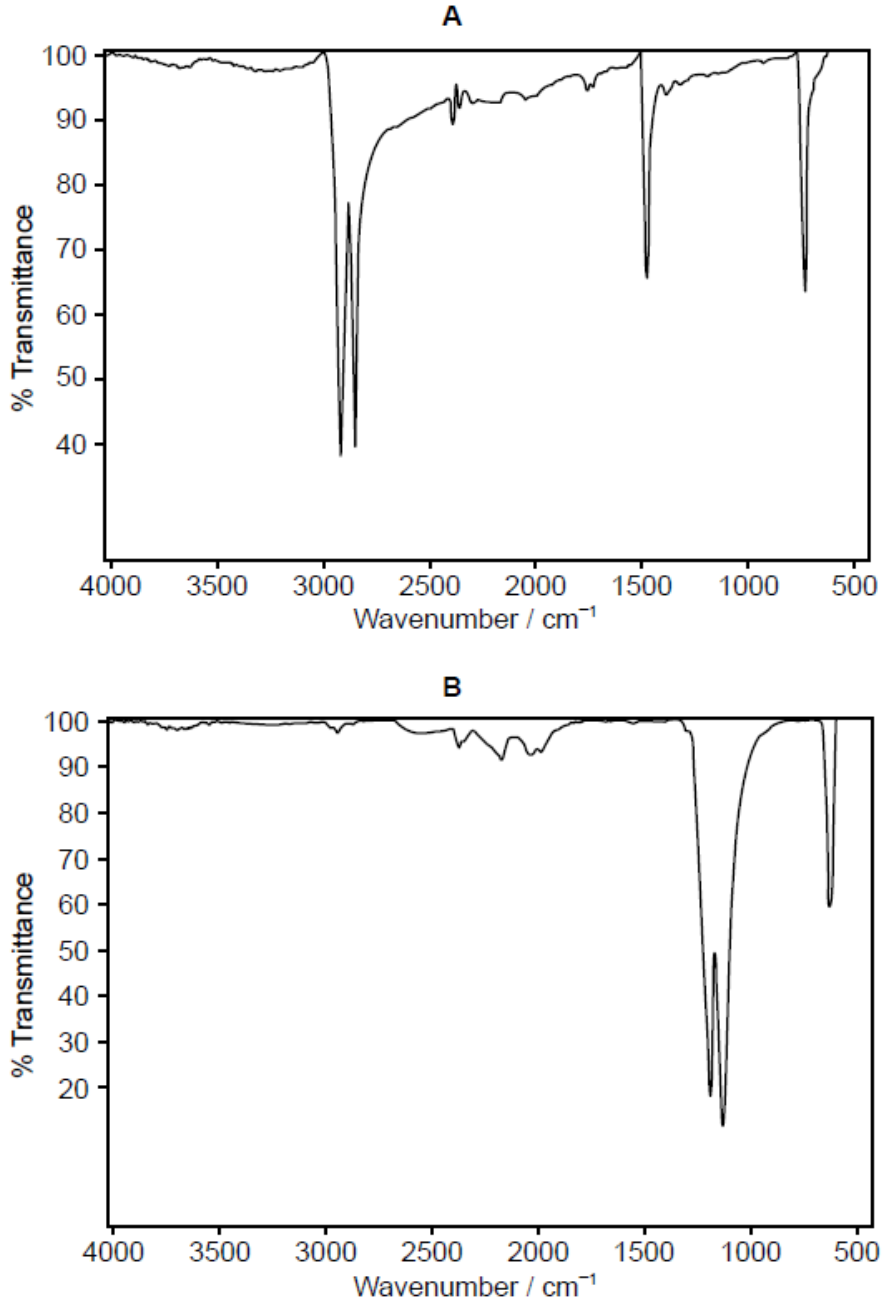
The development of materials with unique properties is critical to advances in industry.

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.

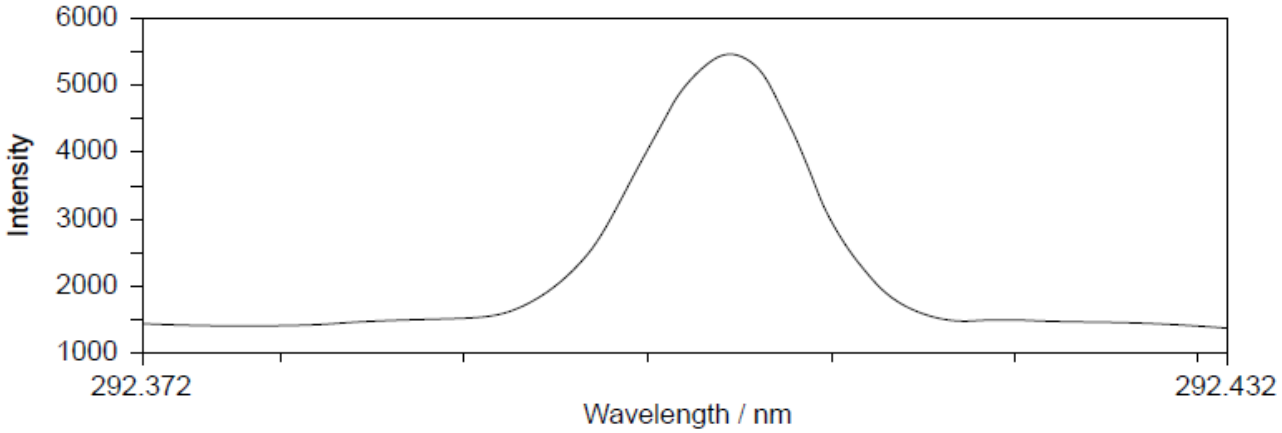
c. Many plastics used to be incinerated. Deduce an equation for the complete combustion of two repeating units of PVC, $(-C_2H_3Cl-)_2$. [2]

---

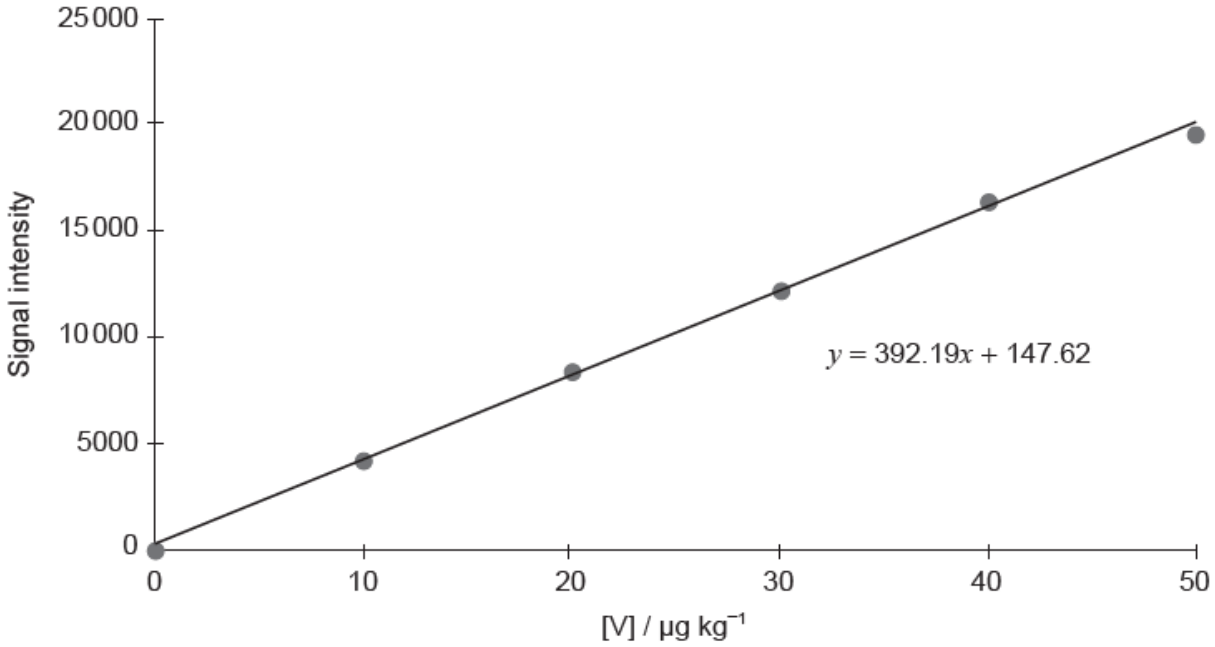
Inductively Coupled Plasma (ICP) used with Mass Spectrometry (MS) or Optical Emission Spectrometry (OES) can be used to identify and quantify elements in a sample.

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



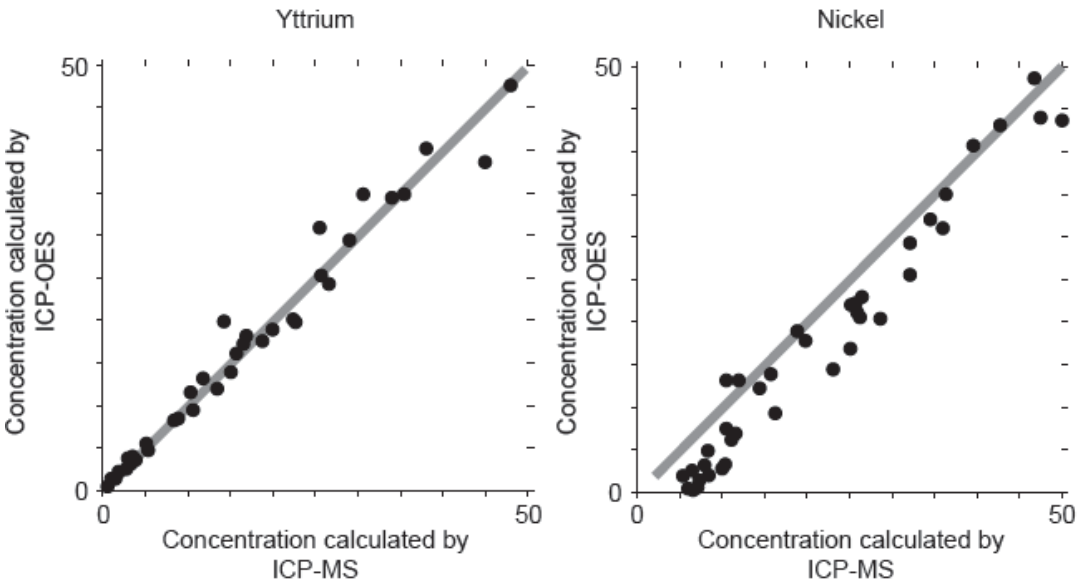

**Graph 2:** Calibration of vanadium in μg $kg^{-1}$




[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]

$SO_2(g) + V_2O_5(s) \rightarrow SO_3(g) + 2VO_2(s)$

$-O_2(g) + 2VO_2(s) \rightarrow V_2O_5(s)$

Outline how vanadium(V) oxide acts as a catalyst.

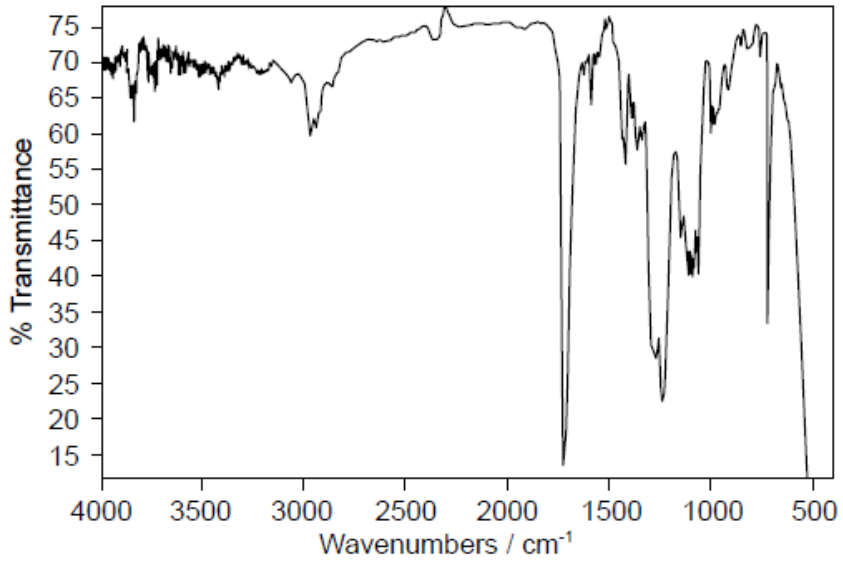
---

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.

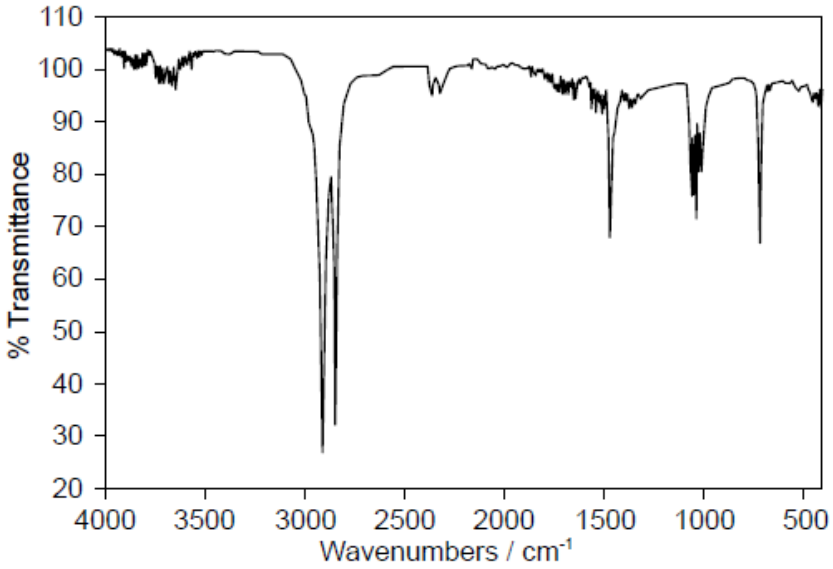
a. Below are the IR spectra of two plastics (**A** and **B**); one is PETE, the other is low density polyethene (LDPE). [3]

**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]