Option C: Chemistry in industry and technology

As one of the most important roles of chemistry is to make forms of matter that have never existed before, it plays a central role in any material revolution. The Industrial Revolution of the 18th century was the result of the large-scale extraction of iron, but the material revolution continues the development of new materials with structures and properties that serve the technologies of today. The consideration of how the materials benefit society makes this option particularly relevant to aim 8. When teaching this option, the relation between the structure of materials and their properties should be emphasized.

Core material: C1–C7 are core material for SL and HL (15 hours).

Extension material: C8–C12 are extension material for HL only (7 hours).

C1 Iron, steel and aluminium

3.5 hours

	Assessment statement	Obj	Teacher's notes
C.1.1	State the main sources of iron.	1	
C.1.2	Describe and explain the reactions that occur in the blast furnace.	3	
C.1.3	Describe and explain the conversion of iron into steel using the basic oxygen converter.	3	
C.1.4	Describe alloys as a homogeneous mixture of metals or a mixture of a metal and non-metal.	2	
C.1.5	Explain how alloying can modify the properties of metals.	3	
C.1.6	Describe the effects of heat treatment of steel.	2	Effects should include tempering, annealing and quenching.
C.1.7	Describe the properties and uses of iron and steel.	2	
C.1.8	Describe and explain the production of aluminium by electrolysis of alumina in molten cryolite.	3	Include the use of cryolite as a solvent because of the very high melting point of Al_2O_3 and the type of materials used for the construction of the cell and choice of electrodes.
C1.9	Describe the main properties and uses of aluminium and its alloys.	2	
C.1.10	Discuss the environmental impact of iron and aluminium production.	3	**Aim 8**

C2 The oil industry

2 hours

	Assessment statement	Obj	Teacher's notes
C.2.1	Compare the use of oil as an energy source and as a chemical feedstock	3	
C.2.2	Compare catalytic cracking, thermal cracking and steam cracking.	3	**Aim 8:** Students should include the environmental impact of the processes and their products.

C3 Addition polymers

2 hours

	Assessment statement	Obj	Teacher's notes
C.3.1	Describe and explain how the properties of polymers depend on their structural features.	3	Students should consider: • different amounts of branching in low- and high-density polyethene • different positions of the methyl groups in isotactic and atactic polypropene.

	Assessment statement	Obj	Teacher's notes
C.3.2	Describe the ways of modifying the properties of addition polymers.	2	Examples include plasticizers in polyvinyl chloride and volatile hydrocarbons in the formation of expanded polystyrene.
C.3.3	Discuss the advantages and disadvantages of polymer use.	3	Include strength, density, insulation, lack of reactivity, use of natural resources, disposal and biodegradability. Use polyethene (both LDPE and HDPE), polystyrene and polyvinyl chloride plastics as examples.

C4 Catalysts

1.5 hours

	Assessment statement	Obj	Teacher's notes
C.4.1	Compare the modes of action of homogeneous and heterogeneous catalysts.	3	Relate the modes of action of catalysts to their ability to form a range of oxidation states (transition metals), their shape and the availability of active sites.
C.4.2	Outline the advantages and disadvantages of homogeneous and heterogeneous catalysts.	2	Advantages include: • homogeneous catalysts—all the catalyst is exposed to the reactants • heterogeneous catalysts—easily removed from products by filtration. Disadvantages include: • homogeneous catalysts—can be difficult to remove from the products for reuse • heterogeneous catalysts—only effective on the surface.
C.4.3	Discuss the factors in choosing a catalyst for a process.	3	Factors could include: • selectivity (produce only the desired product) • efficiency • ability to work under mild/severe conditions • environmental impact • problems caused by catalysts becoming poisoned by impurities.

C5 Fuel cells and rechargeable batteries

2 hours

	Assessment statement	Obj	Teacher's notes
C.5.1	Describe how a hydrogen–oxygen fuel cell works.	2	Include the relevant half-equations in both acidic and alkaline electrolytes.
C.5.2	Describe the workings of rechargeable batteries.	2	Include the relevant half-equations. **Aim 8:** Examples should include the lead–acid storage battery, the nickel–cadmium (NiCad) battery and the lithium-ion battery.
C.5.3	Discuss the similarities and differences between fuel cells and rechargeable batteries.	3	

C6 Liquid crystals

2 hours

	Assessment statement	Obj	Teacher's notes
C.6.1	Describe the meaning of the term liquid crystals.	2	Liquid crystals are fluids that have physical properties (electrical, optical and elasticity) that are dependent on molecular orientation relative to some fixed axis in the material. Examples should include graphite, cellulose, the solution extruded by a spider to form silk, and DNA. Students should be aware that liquid-crystal materials may not always be in a liquid-crystal phase.
C.6.2	Distinguish between *thermotropic* and *lyotropic* liquid crystals.	2	Thermotropic liquid-crystal materials are pure substances that show liquid-crystal behaviour over a temperature range between the solid and liquid states. The biphenyl nitriles are common examples. Lyotropic liquid crystals are solutions that show the liquid-crystal state at certain concentrations. Examples should include soap and water.
C.6.3	Describe the liquid-crystal state in terms of the arrangement of the molecules and explain thermotropic behaviour.	3	Only the nematic phase will be assessed. Rod-shaped molecules are distributed randomly but, on average, point in the same direction. Increased thermal agitation disrupts this directional order until it is lost when the normal liquid phase is formed.
C.6.4	Outline the principles of the liquid-crystal display device.	2	**Aim 8:** Only a simplified treatment is required. The ability of the liquid-crystal molecules to transmit light depends on the orientation of the molecules. The orientation of the polar molecules can be controlled by the application of a small voltage across a small film of the material. The areas of the display that are light and dark can thus be controlled. Liquid-crystal displays are used in digital watches, calculators and laptops because of their small current requirements.
C.6.5	Discuss the properties needed for a substance to be used in liquid-crystal displays.	3	Properties include: • 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.

C7 Nanotechnology

2 hours

	Assessment statement	Obj	Teacher's notes
C.7.1	Define the term *nanotechnology*.	1	Nanotechnology should be defined as: "Nanotechnology involves research and technology development at the 1 nm - to - 100 nm range. Nanotechnology creates and uses structures that have novel properties because of their small size. Nanotechnology builds on the ability to control or manipulate at the atomic scale." (Quoted from Booker, R and Boysen, E. 2005. *Nanotechnology for dummies*, Wiley Publishing Inc, USA. P 10) **TOK:** The use of the scanning tunnelling microscope has allowed us to "see" individual atoms. Does technology blur the distinction between simulation and reality?
C.7.2	Distinguish between *physical* and *chemical* techniques in manipulating atoms to form molecules.	2	Physical techniques allow atoms to be manipulated and positioned to specific requirements. Chemical techniques position atoms in molecules using chemical reactions.
C.7.3	Describe the structure and properties of carbon nanotubes.	2	Only a simple treatment is required. The main cylinder is made only from carbon hexagons, with pentagons needed 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. A comparison should be made with graphite, which is soft and malleable. The same strong covalent bonding extends along the nanotube. As the behaviour of electrons depends on the length of the tube, some forms are conductors and some are semiconductors. This is a typical nanoscale (quantum) effect, and the differences between the bulk properties and the size-dependent properties on the nanoscale should be emphasized.
C.7.4	Discuss some of the implications of nanotechnology.	3	**Aim 8:** Issues could include the following. • Possible applications • Health concerns • Toxicity regulations are difficult as properties depend on the size of particle • Unknown health effects because new materials have new health risks • Concern that the human immune system will be defenceless against particles on the nanoscale • Responsibilities of the industries • Political issues, such as the need for public education, for informed debate and for public involvement in policy discussions **TOK:** Who should decide whether particular directions in research are pursued? Who should determine priorities in the funding of research?

HL C8 Condensation polymers

1 hour

	Assessment statement	Obj	Teacher's notes
C.8.1	Distinguish between *addition* and *condensation* polymers in terms of their structures.	2	
C.8.2	Describe how condensation polymers are formed from their monomers.	2	Examples should include phenol–methanal plastics, polyurethane and polyethylene terephthalate (PET).
C.8.3	Describe and explain how the properties of polymers depend on their structural features.	3	Examples should include Kevlar and the formation of cross-links in phenol–methanal plastics.
C.8.4	Describe ways of modifying the properties of polymers.	2	Examples should include: • air in the manufacture of polyurethane foams • doping polymer such as polyethyne with I_2 to increase conductivity • blending of polyester fibres to make them dyeable and more comfortable.
C.8.5	Discuss the advantages and disadvantages of polymer use.	3	Consider strength, density, insulation, lack of reactivity, use of natural resources, disposal and biodegradability. Examples should include PET, polyurethane foams and phenol–methanal plastics.

HL C9 Mechanisms in the organic chemicals industry

1 hour

	Assessment statement	Obj	Teacher's notes
C.9.1	Describe the free-radical mechanism involved in the manufacture of low-density polyethene.	2	
C.9.2	Outline the use of Ziegler–Natta catalysts in the manufacture of high-density polyethene.	2	The ionic mechanism will not be assessed.

HL C10 Silicon and photovoltaic cells

1 hour

	Assessment statement	Obj	Teacher's notes
C.10.1	Describe the doping of silicon to produce p-type and n-type semiconductors.	2	In p-type semiconductors, electron holes in the crystal are created by introducing a small percentage of a group 3 element. In n-type semiconductors, inclusion of a group 5 element provides extra electrons.
C.10.2	Describe how sunlight interacts with semiconductors.	2	

HL C11 Liquid crystals

2 hours

	Assessment statement	Obj	Teacher's notes
C.11.1	Identify molecules that are likely to show liquid-crystal properties, and explain their liquid-crystal behaviour on a molecular level.	3	Only the biphenyl nitriles will be assessed. The nitrile group makes the molecules polar, which ensures that the intermolecular forces are strong enough to align in a common direction. The biphenyl groups make the molecules more rigid and rod-shaped. The long alkane chain ensures that the molecules cannot pack together so closely and so maintains the liquid-crystal state.
C.11.2	Describe and explain in molecular terms the workings of a twisted nematic liquid crystal.	3	Each pixel contains a liquid crystal sandwiched between two glass plates. The plates have scratches at 90° to each other. The molecules in contact with the glass line up with the scratches, and molecules form a twisted arrangement between the plates due to intermolecular bonds. Plane-polarized light is rotated with the molecules and so is rotated through 90° as it passes through the film. When the polarizers are aligned with the scratches, light will pass through the film and the pixel will appear bright. As a voltage is applied across the film, the polar molecules will align with the field and so the twisted structure is lost. Plane-polarized light is no longer rotated and so the pixel appears dark.
C.11.3	Describe the liquid-crystal properties of Kevlar, and explain its strength and its solubility in concentrated sulfuric acid.	3	Kevlar is a lyotropic liquid crystal. It has rigid rod-shaped molecules due to the linked benzene rings. The alignment of these molecules depends on the concentration of the solution. Kevlar has strong intermolecular hydrogen bonds between the chains. This gives a very ordered and strong structure. These bonds can be broken with concentrated sulfuric acid, as O and N atoms are protonated, breaking the hydrogen bonds. **Aim 7:** Molecular modelling can be used here.

HL C12 The chlor-alkali industry

2 hours

	Assessment statement	Obj	Teacher's notes
C.12.1	Discuss the production of chlorine and sodium hydroxide by the electrolysis of sodium chloride.	3	Include the mercury, diaphragm and membrane chlor-alkali electrolysis cells.
C.12.2	Outline some important uses of the products of this process.	2	
C.12.3	Discuss the environmental impact of the processes used for the electrolysis of sodium chloride.	3	**Aim 8:** Include reasons why the membrane cell is replacing both the mercury-cathode and diaphragm cells, and reservations on the use of chlorine-containing solvents due to their effect on the ozone layer.