Additional higher level topics

Essential idea: Superconductivity is zero electrical resistance and expulsion of magnetic fields. X-ray crystallography can be used to analyse structures.

A.8 Superconducting metals and X-ray crystallography

Nature of science:

Importance of theories—superconducting materials, with zero electrical resistance below a certain temperature, provide a good example of theories needing to be modified to fit new data. It is important to understand the basic scientific principles behind modern instruments. (2.2)

Understandings:

- Superconductors are materials that offer no resistance to electric currents below a critical temperature.
- The Meissner effect is the ability of a superconductor to create a mirror image magnetic field of an external field, thus expelling it.
- Resistance in metallic conductors is caused by collisions between electrons and positive ions of the lattice.
- The Bardeen–Cooper–Schrieffer (BCS) theory explains that below the critical temperature electrons in superconductors form Cooper pairs which move freely through the superconductor.
- Type 1 superconductors have sharp transitions to superconductivity whereas Type 2 superconductors have more gradual transitions.
- X-ray diffraction can be used to analyse structures of metallic and ionic compounds.
- Crystal lattices contain simple repeating unit cells.
- Atoms on faces and edges of unit cells are shared.
- The number of nearest neighbours of an atom/ion is its coordination number.

International-mindedness:

- Analytical techniques have applications in forensics, mineral exploration, medicine and elsewhere. How does the unequal access to advanced technology affect world economies?

Theory of knowledge:

- X-ray diffraction has allowed us to probe the world beyond the biological limits of our senses. How reliable is our knowledge of the microscopic world compared to what we know at the macroscopic level?

Utilization:

Syllabus and cross-curricular links:
Topic 2.2—Pauli exclusion principle
Topic 3.2—atomic radius and periodicity
Topic 21.1—X-ray crystallography
Physics topic 4.2—travelling waves

Aims:

- **Aim 7**: Animations and simulations would be very useful to explain superconductivity and X-ray crystallography.

A.8 Superconducting metals and X-ray crystallography	
Applications and skills: • Analysis of resistance versus temperature data for Type 1 and Type 2 superconductors. • Explanation of superconductivity in terms of Cooper pairs moving through a positive ion lattice. • Deduction or construction of unit cell structures from crystal structure information. • Application of the Bragg equation, $n\lambda = 2dsin\theta$, in metallic structures. • Determination of the density of a pure metal from its atomic radii and crystal packing structure. **Guidance:** • Only a simple explanation of BCS theory with Cooper pairs is required. At low temperatures the positive ions in the lattice are distorted slightly by a passing electron. A second electron is attracted to this slight positive deformation and a coupling of these two electrons occurs. • Operating principles of X-ray crystallography are not required. • Only pure metals with simple cubic cells, body centred cubic cells (BCC) and face centred cubic cells (FCC) should be covered. • Perovskite crystalline structures of many superconductors can be analysed by X-ray crystallography but these will not be assessed. • Bragg's equation will only be applied to simple cubic structures.	

Essential idea: Condensation polymers are formed by the loss of small molecules as functional groups from monomers join.

A.9 Condensation polymers

Nature of science:

Speculation—we have had the Stone Age, Iron Age and Bronze Age. Is it possible that today's age is the Age of Polymers, as science continues to manipulate matter for desired purposes? (1.5)

Understandings:

- Condensation polymers require two functional groups on each monomer.
- NH_3, HCl and H_2O are possible products of condensation reactions.
- Kevlar® is a polyamide with a strong and ordered structure. The hydrogen bonds between O and N can be broken with the use of concentrated sulfuric acid.

Applications and skills:

- Distinguishing between addition and condensation polymers.
- Completion and descriptions of equations to show how condensation polymers are formed.
- Deduction of the structures of polyamides and polyesters from their respective monomers.
- Explanation of Kevlar®'s strength and its solubility in concentrated sulfuric acid.

Guidance:

- Consider green chemistry polymers.

International-mindedness:

- Does science, economics or politics play the most essential role in research, such as the development of new polymers?

Utilization:

Syllabus and cross-curricular links:
Topic 10.2—addition and condensation reactions
Topic 20.2—synthesis techniques
Option A.5—polymers

Aims:

- **Aim 6**: Synthesis of nylon could be performed.

Essential idea: Toxicity and carcinogenic properties of heavy metals are the result of their ability to form coordinated compounds, have various oxidation states and act as catalysts in the human body.

A.10 Environmental impact—heavy metals

Nature of science:

Risks and problems—scientific research often proceeds with perceived benefits in mind, but the risks and implications also need to be considered. (4.8)

Understandings:

- Toxic doses of transition metals can disturb the normal oxidation/reduction balance in cells through various mechanisms.
- Some methods of removing heavy metals are precipitation, adsorption, and chelation.
- Polydentate ligands form more stable complexes than similar monodentate ligands due to the chelate effect, which can be explained by considering entropy changes.

Applications and skills:

- Explanation of how chelating substances can be used to remove heavy metals.
- Deduction of the number of coordinate bonds a ligand can form with a central metal ion.
- Calculations involving K_{sp} as an application of removing metals in solution.
- Compare and contrast the Fenton and Haber–Weiss reaction mechanism.

Guidance:

- Ethane-1,2-diamine acts as a bidentate ligand and $EDTA^{4-}$ acts as hexadentate ligand.
- The Haber–Weiss reaction generates free radicals naturally in biological processes. Transition metals can catalyse the reaction with the iron-catalysed (Fenton) reaction being the mechanism for generating reactive hydroxyl radicals.
- K_{sp} values are in the data booklet in section 32.

Theory of knowledge:

- What responsibility do scientists have for the impact of their endeavours on the planet?

Utilization:

Syllabus and cross-curricular links:
Topic 9.1—redox reactions
Topic 13.2—transition metal complexes
Biology option C.3—impact of humans on ecosystems

Aims:

- **Aims 1** and **8**: Investigations of waste water treatment.
- **Aim 6**: Experiments could include investigations of K_{sp}.