Additional higher level topics

Essential idea: Chemical energy from redox reactions can be used as a portable source of electrical energy.

C.6 Electrochemistry, rechargeable batteries and fuel cells	
Nature of science: Environmental problems—redox reactions can be used as a source of electricity but disposal of batteries has environmental consequences. (4.8)	
Understandings: • An electrochemical cell has internal resistance due to the finite time it takes for ions to diffuse. The maximum current of a cell is limited by its internal resistance. • The voltage of a battery depends primarily on the nature of the materials used while the total work that can be obtained from it depends on their quantity. • In a primary cell the electrochemical reaction is not reversible. Rechargeable cells involve redox reactions that can be reversed using electricity. • A fuel cell can be used to convert chemical energy, contained in a fuel that is consumed, directly to electrical energy. • Microbial fuel cells (MFCs) are a possible sustainable energy source using different carbohydrates or substrates present in waste waters as the fuel. • The Nernst equation, $E = E^0 - \left(\frac{RT}{nF}\right) \ln Q$, can be used to calculate the potential of a half-cell in an electrochemical cell, under non-standard conditions. • The electrodes in a concentration cell are the same but the concentration of the electrolyte solutions at the cathode and anode are different. **Applications and skills:** • Distinction between fuel cells and primary cells. • Deduction of half equations for the electrode reactions in a fuel cell.	**International-mindedness:** • Are battery recycling programmes equivalent in different areas of the globe? **Theory of knowledge:** • Does scientific language and vocabulary have primarily a descriptive or an interpretative function? Are the terms “electric current” and “internal resistance” accurate descriptions of reality or metaphors? **Utilization:** Syllabus and cross-curricular links: Topic 9.1—redox reactions Topic 19.1—electrochemical cells Biology topic 6.5—muscle and nerve cells discussed in biology are concentration cells Physics topic 5.3—the relationship between electrical power, voltage, resistance and current **Aims:** • **Aim 2**: The conversion of chemical energy to electricity is important in a number of different technologies. • **Aim 6**: The factors that affect the voltage of a cell and the lead–acid battery could be investigated experimentally.

C.6 Electrochemistry, rechargeable batteries and fuel cells	
• Comparison between fuel cells and rechargeable batteries. • Discussion of the advantages of different types of cells in terms of size, mass and voltage. • Solution of problems using the Nernst equation. • Calculation of the thermodynamic efficiency ($\Delta G/\Delta H$) of a fuel cell. • Explanation of the workings of rechargeable and fuel cells including diagrams and relevant half-equations. **Guidance:** • A battery should be considered as a portable electrochemical source made up of one or more voltaic (galvanic) cells connected in series. • The Nernst equation is given in the data booklet in section 1. • Hydrogen and methanol should be considered as fuels for fuel cells. The operation of the cells under acid and alkaline conditions should be considered. Students should be familiar with proton-exchange membrane (PEM) fuel cells. • The *Geobacter* species of bacteria, for example, can be used in some cells to oxidize the ethanoate ions (CH_3COO^-) under anaerobic conditions. • The lead–acid storage battery, the nickel–cadmium (NiCad) battery and the lithium–ion battery should be considered. • Students should be familiar with the anode and cathode half-equations and uses of the different cells.	• **Aim 8**: Consideration of the advantages and disadvantages of the different energy sources shows the economic and environmental implications of using science and technology. The environmental aspects of fuel cells, especially with regard to methanol, could be discussed. • **Aim 8**: Disposal of primary batteries and the chemicals they use can introduce land and water pollution problems. Appreciation of the environmental impact of cadmium and lead pollution. • **Aim 8**: Bacterial fuel cells use substrates found in waste water as the fuel and so can be used to clean up the environment.

Essential idea: Large quantities of energy can be obtained from small quantities of matter.

C.7 Nuclear fusion and nuclear fission

Nature of science:

Trends and discrepancies—our understanding of nuclear processes came from both theoretical and experimental advances. Intermolecular forces in UF_6 are anomalous and do not follow the normal trends. (3.1)

Understandings:

Nuclear fusion:

- The mass defect (Δm) is the difference between the mass of the nucleus and the sum of the masses of its individual nucleons.
- The nuclear binding energy (ΔE) is the energy required to separate a nucleus into protons and neutrons.

Nuclear fission:

- The energy produced in a fission reaction can be calculated from the mass difference between the products and reactants using the Einstein mass–energy equivalence relationship $E = mc^2$.
- The different isotopes of uranium in uranium hexafluoride can be separated, using diffusion or centrifugation causing fuel enrichment.
- The effusion rate of a gas is inversely proportional to the square root of the molar mass (Graham's Law).
- Radioactive decay is kinetically a first order process with the half-life related to the decay constant by the equation $\lambda = \frac{\ln 2}{t_{\frac{1}{2}}}$.
- The dangers of nuclear energy are due to the ionizing nature of the radiation it produces which leads to the production of oxygen free radicals such as superoxide ($O_2^{\cdot}$), and hydroxyl ($HO^{\cdot}$). These free radicals can initiate chain reactions that can damage DNA and enzymes in living cells.

International-mindedness:

- There are only a very small number of countries that have developed nuclear weapons and the International Atomic Energy Agency strives to limit the spread of this technology. There are disputes about whether some countries are developing nuclear energy for peaceful or non-peaceful purposes.
- Nuclear incidents have a global effect; the accidents at Three Mile Island and Chernobyl and the problems at Fukushima caused by a tsunami could be discussed to illustrate the potential dangers.

Theory of knowledge:

- "There is no likelihood that humans will ever tap the power of the atom." (Robert Millikan, Nobel Laureate Physics 1923 quoted in 1928). How can the impact of new technologies be predicted? How reliable are these predictions? How important are the opinions of experts in the search for knowledge?
- The release of energy during fission reactions can be used in times of peace to generate energy, but also can lead to destruction in time of war. Should scientists be held morally responsible for the applications of their discoveries? Is there any area of scientific knowledge the pursuit of which is morally unacceptable?

Utilization:

Syllabus and cross-curricular links:
Topics 4.1 and 4.3—structure and bonding
Topic 16.1—first order reactions
Physics topic 7.2—nuclear fusion
Geography—the different polices and attitudes to nuclear energy are discussed in resources sections in the guide

C.7 Nuclear fusion and nuclear fission	
Applications and skills: *Nuclear fusion:* • Calculation of the mass defect and binding energy of a nucleus. • Application of the Einstein mass–energy equivalence relationship, $E = mc^2$, to determine the energy produced in a fusion reaction. *Nuclear fission:* • Application of the Einstein mass–energy equivalence relationship to determine the energy produced in a fission reaction. • Discussion of the different properties of UO_2 and UF_6 in terms of bonding and structure. • Solution of problems involving radioactive half-life. • Explanation of the relationship between Graham's law of effusion and the kinetic theory. • Solution of problems on the relative rate of effusion using Graham's law. **Guidance:** • Students are not expected to recall specific fission reactions. • The workings of a nuclear power plant are not required. • Safety and risk issues include: health, problems associated with nuclear waste, and the possibility that nuclear fuels may be used in nuclear weapons. • Graham's law of effusion is given in the data booklet in section 1. • Decay relationships are given in the data booklet in section 1. • A binding energy curve is given in the data booklet in section 36.	**Aims**: • **Aim 7**: Computer animations and simulations of radioactive decay, and nuclear fusion and fission reactions. • **Aim 8**: Consideration of the advantages and disadvantages of nuclear fusion illustrates the economic and environmental implications of using science and technology. The use of fusion reactions in the hydrogen bomb can also be discussed.

Essential idea: When solar energy is converted to electrical energy the light must be absorbed and charges must be separated. In a photovoltaic cell both of these processes occur in the silicon semiconductor, whereas these processes occur in separate locations in a dye-sensitized solar cell (DSSC).

C.8 Photovoltaic cells and dye-sensitized solar cells (DSSC)

Nature of science:

Transdisciplinary—a dye-sensitized solar cell, whose operation mimics photosynthesis and makes use of TiO_2 nanoparticles, illustrates the transdisciplinary nature of science and the link between chemistry and biology. (4.1)

Funding—the level of funding and the source of the funding is crucial in decisions regarding the type of research to be conducted. The first voltaic cells were produced by NASA for space probes and were only later used on Earth. (4.7)

Understandings:

- Molecules with longer conjugated systems absorb light of longer wavelength.
- The electrical conductivity of a semiconductor increases with an increase in temperature whereas the conductivity of metals decreases.
- The conductivity of silicon can be increased by doping to produce n-type and p-type semiconductors.
- Solar energy can be converted to electricity in a photovoltaic cell.
- DSSCs imitate the way in which plants harness solar energy. Electrons are "injected" from an excited molecule directly into the TiO_2 semiconductor.
- The use of nanoparticles coated with light-absorbing dye increases the effective surface area and allows more light over a wider range of the visible spectrum to be absorbed.

Applications and skills:

- Relation between the degree of conjugation in the molecular structure and the wavelength of the light absorbed.
- Explanation of the operation of the photovoltaic and dye-sensitized solar cell.
- Explanation of how nanoparticles increase the efficiency of DSSCs.
- Discussion of the advantages of the DSSC compared to the silicon-based

International-mindedness:

- The harnessing of solar energy could change the economic fortunes of countries with good supplies of sunlight and unused land.

Theory of knowledge:

- A conjugated system has some similarities with a violin string. How useful is this metaphor? What are the underlying reasons for these similarities? What role do models and metaphors play in the acquisition of knowledge?

Utilization:

Syllabus and cross-curricular links:
Topic 3.2—patterns in ionization energy
Topic 9.1—redox reactions
Biology topic 2.9—photosynthesis

Aims:

- **Aim 6**: Students could build an inexpensive dye-sensitized solar cell and investigate their photovoltaic properties.
- **Aim 7**: The properties of DSSCs can be best investigated using data loggers.

C.8 Photovoltaic cells and dye-sensitized solar cells (DSSC)	
photovoltaic cell. **Guidance:** • The relative conductivity of metals and semiconductors should be related to ionization energies. • Only a simple treatment of the operation of the cells is needed. 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. • In a photovoltaic cell the light is absorbed and the charges separated in the silicon semiconductor. The processes of absorption and charge separation are separated in a dye-sensitized solar cell. • Specific redox and electrode reactions in the newer Grätzel DSSC should be covered. An example is the reduction of I_2/I_3^- ions to I^-.	