Topic 5: Electricity and magnetism

15 hours

Essential idea: When charges move an electric current is created.

5.1 – Electric fields

Nature of science:

Modelling: Electrical theory demonstrates the scientific thought involved in the development of a microscopic model (behaviour of charge carriers) from macroscopic observation. The historical development and refinement of these scientific ideas when the microscopic properties were unknown and unobservable is testament to the deep thinking shown by the scientists of the time. (1.10)

Understandings:

- Charge
- Electric field
- Coulomb's law
- Electric current
- Direct current (dc)
- Potential difference

Applications and skills:

- Identifying two forms of charge and the direction of the forces between them
- Solving problems involving electric fields and Coulomb's law
- Calculating work done in an electric field in both joules and electronvolts
- Identifying sign and nature of charge carriers in a metal
- Identifying drift speed of charge carriers
- Solving problems using the drift speed equation
- Solving problems involving current, potential difference and charge

International-mindedness:

- Electricity and its benefits have an unparalleled power to transform society

Theory of knowledge:

- Early scientists identified positive charges as the charge carriers in metals; however, the discovery of the electron led to the introduction of "conventional" current direction. Was this a suitable solution to a major shift in thinking? What role do paradigm shifts play in the progression of scientific knowledge?

Utilization:

- Transferring energy from one place to another (see *Chemistry* option *C* and *Physics* topic 11)
- Impact on the environment from electricity generation (see *Physics* topic *8* and *Chemistry* option sub-topic *C2*)
- The comparison between the treatment of electric fields and gravitational fields (see *Physics* topic *10*)

5.1 – Electric fields	
Guidance: • Students will be expected to apply Coulomb's law for a range of permittivity values **Data booklet reference:** • $I = \frac{\Delta q}{\Delta t}$ • $F = k\frac{q_1 q_2}{r^2}$ • $k = \frac{1}{4\pi\varepsilon_0}$ • $V = \frac{W}{q}$ • $E = \frac{F}{q}$ • $I = nAvq$	**Aims:** • **Aim 2:** electrical theory lies at the heart of much modern science and engineering • **Aim 3:** advances in electrical theory have brought immense change to all societies • **Aim 6:** experiments could include (but are not limited to): demonstrations showing the effect of an electric field (eg. using semolina); simulations involving the placement of one or more point charges and determining the resultant field • **Aim 7:** use of computer simulations would enable students to measure microscopic interactions that are typically very difficult in a school laboratory situation

Essential idea: One of the earliest uses for electricity was to produce light and heat. This technology continues to have a major impact on the lives of people around the world.

5.2 – Heating effect of electric currents

Nature of science:

Peer review: Although Ohm and Barlow published their findings on the nature of electric current around the same time, little credence was given to Ohm. Barlow's incorrect law was not initially criticized or investigated further. This is a reflection of the nature of academia of the time, with physics in Germany being largely non-mathematical and Barlow held in high respect in England. It indicates the need for the publication and peer review of research findings in recognized scientific journals. (4.4)

Understandings:

- Circuit diagrams
- Kirchhoff's circuit laws
- Heating effect of current and its consequences
- Resistance expressed as $R = \frac{V}{I}$
- Ohm's law
- Resistivity
- Power dissipation

Applications and skills:

- Drawing and interpreting circuit diagrams
- Identifying ohmic and non-ohmic conductors through a consideration of the *V/I* characteristic graph
- Solving problems involving potential difference, current, charge, Kirchhoff's circuit laws, power, resistance and resistivity
- Investigating combinations of resistors in parallel and series circuits
- Describing ideal and non-ideal ammeters and voltmeters
- Describing practical uses of potential divider circuits, including the advantages of a potential divider over a series resistor in controlling a simple circuit
- Investigating one or more of the factors that affect resistance experimentally

International-mindedness:

- A set of universal symbols is needed so that physicists in different cultures can readily communicate ideas in science and engineering

Theory of knowledge:

- Sense perception in early electrical investigations was key to classifying the effect of various power sources; however, this is fraught with possible irreversible consequences for the scientists involved. Can we still ethically and safely use sense perception in science research?

Utilization:

- Although there are nearly limitless ways that we use electrical circuits, heating and lighting are two of the most widespread
- Sensitive devices can employ detectors capable of measuring small variations in potential difference and/or current, requiring carefully planned circuits and high precision components

5.2 – Heating effect of electric currents

Guidance:

- The filament lamp should be described as a non-ohmic device; a metal wire at a constant temperature is an ohmic device
- The use of non-ideal voltmeters is confined to voltmeters with a constant but finite resistance
- The use of non-ideal ammeters is confined to ammeters with a constant but non-zero resistance
- Application of Kirchhoff's circuit laws will be limited to circuits with a maximum number of two source-carrying loops

Data book reference:

- Kirchoff's circuit laws:
  - $\Sigma V = 0$ (loop)
  - $\Sigma I = 0$ (junction)
- $R = \frac{V}{I}$
- $P = VI = I^2R = \frac{V^2}{R}$
- $R_{total} = R_1 + R_2 + \cdots$
- $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$
- $\rho = \frac{RA}{L}$
- *Refer to electrical symbols on page 4 of the physics data booklet*

Aims:

- **Aim 2:** electrical theory and its approach to macro and micro effects characterizes much of the physical approach taken in the analysis of the universe
- **Aim 3:** electrical techniques, both practical and theoretical, provide a relatively simple opportunity for students to develop a feeling for the arguments of physics
- **Aim 6:** experiments could include (but are not limited to): use of a hot-wire ammeter as an historically important device; comparison of resistivity of a variety of conductors such as a wire at constant temperature, a filament lamp, or a graphite pencil; determination of thickness of a pencil mark on paper; investigation of ohmic and non-ohmic conductor characteristics; using a resistive wire wound and taped around the reservoir of a thermometer to relate wire resistance to current in the wire and temperature of wire
- **Aim 7:** there are many software and online options for constructing simple and complex circuits quickly to investigate the effect of using different components within a circuit

Essential idea: Electric cells allow us to store energy in a chemical form.

5.3 – Electric cells

Nature of science:

Long-term risks: Scientists need to balance the research into electric cells that can store energy with greater energy density to provide longer device lifetimes with the long-term risks associated with the disposal of the chemicals involved when batteries are discarded. (4.8)

Understandings:

- Cells
- Internal resistance
- Secondary cells
- Terminal potential difference
- Electromotive force (emf)

Applications and skills:

- Investigating practical electric cells (both primary and secondary)
- Describing the discharge characteristic of a simple cell (variation of terminal potential difference with time)
- Identifying the direction of current flow required to recharge a cell
- Determining internal resistance experimentally
- Solving problems involving emf, internal resistance and other electrical quantities

Guidance:

- Students should recognize that the terminal potential difference of a typical practical electric cell loses its initial value quickly, has a stable and constant value for most of its lifetime, followed by a rapid decrease to zero as the cell discharges completely

Data booklet reference:

- $\varepsilon = I(R + r)$

International-mindedness:

- Battery storage is important to society for use in areas such as portable devices, transportation options and back-up power supplies for medical facilities

Theory of knowledge:

- Battery storage is seen as useful to society despite the potential environmental issues surrounding their disposal. Should scientists be held morally responsible for the long-term consequences of their inventions and discoveries?

Utilization:

- The chemistry of electric cells (see *Chemistry* sub-topics *9.2* and *C.6*)

Aims:

- **Aim 6:** experiments could include (but are not limited to): investigation of simple electrolytic cells using various materials for the cathode, anode and electrolyte; software-based investigations of electrical cell design; comparison of the life expectancy of various batteries
- **Aim 8:** although cell technology can supply electricity without direct contribution from national grid systems (and the inherent carbon output issues), safe disposal of batteries and the chemicals they use can introduce land and water pollution problems
- **Aim 10:** improvements in cell technology has been through collaboration with chemists

Essential idea: The effect scientists call magnetism arises when one charge moves in the vicinity of another moving charge.

5.4 – Magnetic effects of electric currents

Nature of science:

Models and visualization: Magnetic field lines provide a powerful visualization of a magnetic field. Historically, the field lines helped scientists and engineers to understand a link that begins with the influence of one moving charge on another and leads onto relativity. (1.10)

Understandings:

- Magnetic fields
- Magnetic force

Applications and skills:

- Determining the direction of force on a charge moving in a magnetic field
- Determining the direction of force on a current-carrying conductor in a magnetic field
- Sketching and interpreting magnetic field patterns
- Determining the direction of the magnetic field based on current direction
- Solving problems involving magnetic forces, fields, current and charges

Guidance:

- Magnetic field patterns will be restricted to long straight conductors, solenoids, and bar magnets

Data booklet reference:

- $F = qvB \sin \theta$
- $F = BIL \sin \theta$

International-mindedness:

- The investigation of magnetism is one of the oldest studies by man and was used extensively by voyagers in the Mediterranean and beyond thousands of years ago

Theory of knowledge:

- Field patterns provide a visualization of a complex phenomenon, essential to an understanding of this topic. Why might it be useful to regard knowledge in a similar way, using the metaphor of knowledge as a map – a simplified representation of reality?

Utilization:

- Only comparatively recently has the magnetic compass been superseded by different technologies after hundreds of years of our dependence on it
- Modern medical scanners rely heavily on the strong, uniform magnetic fields produced by devices that utilize superconductors
- Particle accelerators such as the Large Hadron Collider at CERN rely on a variety of precise magnets for aligning the particle beams

Aims:

- **Aims 2 and 9:** visualizations frequently provide us with insights into the action of magnetic fields; however, the visualizations themselves have their own limitations
- **Aim 7:** computer-based simulations enable the visualization of electromagnetic fields in three-dimensional space