Topic 11: Electromagnetic induction 16 hours

Essential idea: The majority of electricity generated throughout the world is generated by machines that were designed to operate using the principles of electromagnetic induction.

11.1 – Electromagnetic induction

Nature of science:

Experimentation: In 1831 Michael Faraday, using primitive equipment, observed a minute pulse of current in one coil of wire only when the current in a second coil of wire was switched on or off but nothing while a constant current was established. Faraday's observation of these small transient currents led him to perform experiments that led to his law of electromagnetic induction. (1.8)

Understandings:

- Electromotive force (emf)
- Magnetic flux and magnetic flux linkage
- Faraday's law of induction
- Lenz's law

Applications and skills:

- Describing the production of an induced emf by a changing magnetic flux and within a uniform magnetic field
- Solving problems involving magnetic flux, magnetic flux linkage and Faraday's law
- Explaining Lenz's law through the conservation of energy

Theory of knowledge:

- Terminology used in electromagnetic field theory is extensive and can confuse people who are not directly involved. What effect can lack of clarity in terminology have on communicating scientific concepts to the public?

Utilization:

- Applications of electromagnetic induction can be found in many places including transformers, electromagnetic braking, geophones used in seismology, and metal detectors

Aims:

- **Aim 2:** the simple principles of electromagnetic induction are a powerful aspect of the physicist's or technologist's armoury when designing systems that transfer energy from one form to another

11.1 – Electromagnetic induction

Guidance:

- Quantitative treatments will be expected for straight conductors moving at right angles to magnetic fields and rectangular coils moving in and out of fields and rotating in fields
- Qualitative treatments only will be expected for fixed coils in a changing magnetic field and ac generators

Data booklet reference:

- $\Phi = BA\cos\theta$
- $\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$
- $\varepsilon = Bv\ell$
- $\varepsilon = Bv\ell N$

Essential idea: Generation and transmission of alternating current (ac) electricity has transformed the world.

11.2 – Power generation and transmission

Nature of science:

Bias: In the late 19th century Edison was a proponent of direct current electrical energy transmission while Westinghouse and Tesla favoured alternating current transmission. The so called "battle of currents" had a significant impact on today's society. (3.5)

Understandings:

- Alternating current (ac) generators
- Average power and root mean square (rms) values of current and voltage
- Transformers
- Diode bridges
- Half-wave and full-wave rectification

Applications and skills:

- Explaining the operation of a basic ac generator, including the effect of changing the generator frequency
- Solving problems involving the average power in an ac circuit
- Solving problems involving step-up and step-down transformers
- Describing the use of transformers in ac electrical power distribution
- Investigating a diode bridge rectification circuit experimentally
- Qualitatively describing the effect of adding a capacitor to a diode bridge rectification circuit

Guidance:

- Calculations will be restricted to ideal transformers but students should be aware of some of the reasons why real transformers are not ideal (for example: flux leakage, joule heating, eddy current heating, magnetic hysteresis)
- Proof of the relationship between the peak and rms values will not be expected

International-mindedness:

- The ability to maintain a reliable power grid has been the aim of all governments since the widespread use of electricity started

Theory of knowledge:

- There is continued debate of the effect of electromagnetic waves on the health of humans, especially children. Is it justifiable to make use of scientific advances even if we do not know what their long-term consequences may be?

Aims:

- **Aim 6:** experiments could include (but are not limited to): construction of a basic ac generator; investigation of variation of input and output coils on a transformer; observing Wheatstone and Wien bridge circuits
- **Aim 7:** construction and observation of the adjustments made in very large electricity distribution systems are best carried out using computer-modelling software and websites
- **Aim 9:** power transmission is modelled using perfectly efficient systems but no such system truly exists. Although the model is imperfect, it renders the maximum power transmission. Recognition of, and accounting for, the differences between the "perfect" system and the practical system is one of the main functions of professional scientists

11.2 – Power generation and transmission

Data booklet reference:

- $I_{rms} = \frac{I_0}{\sqrt{2}}$
- $V_{rms} = \frac{V_0}{\sqrt{2}}$
- $R = \frac{V_0}{I_0} = \frac{V_{rms}}{I_{rms}}$
- $P_{max} = I_0 V_0$
- $\bar{P} = \frac{1}{2} I_0 V_0$
- $\frac{\varepsilon_p}{\varepsilon_s} = \frac{N_p}{N_s} = \frac{I_s}{I_p}$

Essential idea: Capacitors can be used to store electrical energy for later use.

11.3 – Capacitance

Nature of science:

Relationships: Examples of exponential growth and decay pervade the whole of science. It is a clear example of the way that scientists use mathematics to model reality. This topic can be used to create links between physics topics but also to uses in chemistry, biology, medicine and economics. (3.1)

Understandings:

- Capacitance
- Dielectric materials
- Capacitors in series and parallel
- Resistor-capacitor (RC) series circuits
- Time constant

Applications and skills:

- Describing the effect of different dielectric materials on capacitance
- Solving problems involving parallel-plate capacitors
- Investigating combinations of capacitors in series or parallel circuits
- Determining the energy stored in a charged capacitor
- Describing the nature of the exponential discharge of a capacitor
- Solving problems involving the discharge of a capacitor through a fixed resistor
- Solving problems involving the time constant of an RC circuit for charge, voltage and current

International-mindedness:

- Lightning is a phenomenon that has fascinated physicists from Pliny through Newton to Franklin. The charged clouds form one plate of a capacitor with other clouds or Earth forming the second plate. The frequency of lightning strikes varies globally, being particularly prevalent in equatorial regions. The impact of lightning strikes is significant, with many humans and animals being killed annually and huge financial costs to industry from damage to buildings, communication and power transmission systems, and delays or the need to reroute air transport.

Utilization:

- The charge and discharge of capacitors obeys rules that have parallels in other branches of physics including radioactivity (see *Physics* sub-topic *7.1*)

Aims:

- **Aim 3:** the treatment of exponential growth and decay by graphical and algebraic methods offers both the visual and rigorous approach so often characteristic of science and technology
- **Aim 6:** experiments could include (but are not limited to): investigating basic RC circuits; using a capacitor in a bridge circuit; examining other types of capacitors; verifying time constant

11.3 – Capacitance

Guidance:

- Only single parallel-plate capacitors providing a uniform electric field, in series with a load, need to be considered (edge effect will be neglected)
- Problems involving the discharge of capacitors through fixed resistors need to be treated both graphically and algebraically
- Problems involving the charging of a capacitor will only be treated graphically
- Derivation of the charge, voltage and current equations as a function of time is not required

Data booklet reference:

- $C = \frac{q}{V}$
- $C_{\text{parallel}} = C_1 + C_2 + \cdots$
- $\frac{1}{C_{\text{series}}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots$
- $C = \varepsilon \frac{A}{d}$
- $E = \frac{1}{2} C V^2$
- $\tau = RC$
- $q = q_0 e^{-\frac{t}{\tau}}$
- $I = I_0 e^{-\frac{t}{\tau}}$
- $V = V_0 e^{-\frac{t}{\tau}}$