Teaching ideas for Topic 5: Electricity and magnetism

Like Topic **4**: Waves, this is also a big unit to teach in the suggested time of 15 hours. It does, however, provide lots of opportunity for practical and investigative work for students. Although the history of the physics of electricity and magnetism is a fruitful area of research for students with a special interest in it, this topic concerns itself with three main lines of learning: (1) the nature of electrical charge and its creation of electric fields, (2) the nature of an electrical circuit and what it can do for us and (3) the nature of, and interaction of, magnetic fields with electrical charge and electric currents.

Some useful points to consider are:

- The concept of what a field is may be a good starting point for teaching this topic. It will lend itself well to Topic **6**: Circular motion and gravitation, too. If students can form a good understanding of the terms 'force', 'field strength', 'potential' and 'potential difference', they will be in a strong position to answer problems on all aspects of fields later on. It is worth stressing that the links between each of these quantities is the kind of material that is most useful in solving problems on this topic. This is more important in the additional HL Topic **10**: Fields.
- Analysing and understanding electrical circuits can be accomplished very successfully by considering the concept of energy and its transformation. Terms such as 'electromotive force', 'internal resistance', 'resistance' and 'voltage' can easily be understood through this method of teaching. Considering current as a flow of charge is the classical, and probably still the best, way of students learning this aspect of electricity, although many teachers will use models (such as water circuits) to excellent effect.
- Although the quantitative analysis of magnetic fields is deemed too demanding for students at this level, they are required to learn basic field patterns and how these fields interact with charges and with electrical currents. If students can learn both of these interactions, they will develop a good understanding of basic electromagnetism.

Ideas for teaching the topic

- It may be that teachers prefer to begin this topic with the nature of electrical circuits. It is to be expected that students will have some knowledge and understanding of these already, although considerable work may be needed to overcome misunderstandings. The key is that students should understand the nature of (1) what an electrical current is, (2) what is meant by 'voltage' (or 'potential difference') and (3) what is meant by 'resistance'. These three vital aspects cause many students difficulty, so it is worth spending time on making sure students understand these ideas.
- There are four required experiments in this topic (see the 'Applications and skills' section of the IB Physics guide), all of which are easy for students to investigate and all provide excellent opportunities for students to show off their growing experimental ability. (Practical suggestions for these are outlined in the next section.) These are: investigating combinations of resistors in series and in parallel circuits, investigating the factors that affect **resistivity** (take care with the wording of this investigation!), investigating primary and secondary electric cells, and determining internal resistance.
- Drawing magnetic field patterns is a good starting point for students learning about what magnetic fields do. This approach can help with understanding terms such as 'magnetic flux density' and 'field strength and direction'. The interaction of a magnetic field with a current-carrying wire is a standard lesson for a physics teacher, but this must not allow its importance to be underestimated. Students can arrive at a surprisingly good understanding of the catapult effect (and the use of Fleming's left-hand rule) by investigating the magnetic force as a function of several variables (see below). It should be fairly easy to move from $F = BI\ell\sin\theta$

for a current in a field to $F = Bqv \sin\theta$ for a charged particle in a field by considering I to be q/t and ℓ to be vt. Applications of the former equation are motors and of the latter are mass spectrometers and circular particle accelerators.

- It is worth noting here that if students have already become familiar with the concept of circular motion (i.e. if covered as part of Topic **2**: Mechanics), then the circular paths followed by charged particles in magnetic fields will be easier to teach. For more ideas on this, see Topic **6**.

Practical activities

- A good starting point for students learning about electrical fields is to get some ping-pong balls that have been covered with a conducting paint. Suspending these from thin strings (and hence insulating them) and suspending them a small distance from each other allows students to examine the effect of adding charge to the surface of the balls by using an high-tension power pack, making sure that students understand that it is the movement of electrons that will create a build-up of charge, positive or negative. There is good overlap with the work students did on Topic **2** here, and their revision of free-body force diagrams will be a useful exercise in itself. This will link directly to aim 6 of the group 4 aims.
- The 'shuttling ball' demonstration can then be done with two charged metal plates and one of the balls suspended in between. Students might also like to consider this oscillatory motion in the light of what they have learnt in Topic **4**: Waves.
- Experiments and investigations with electrical circuits are numerous and varied and should be selected carefully according to the ability of the students and the time available. It would be good to start with measuring current and voltage in a variety of circuits involving series and parallel resistors. Not only will this satisfy the first of the required experiments (see 'Applications and skills' section of the IB Physics guide), it will also allow revision of the definition of resistance as the ratio of V to I. At this point it is worth stressing to students that the definition of resistance does not always mean that R is the gradient of the graph of V against I. (This is a special case that applies only when the graph is of an ohmic conductor.) It is much better for students to learn that it is the value of V divided by the value of I that produces the value of R.
- Students should attempt where possible to examine the electrical behaviour of a number of different components, such as an ohmic conductor, a thin filament or light bulb, a thermally sensitive resistor (thermistor), a light-dependent resistor (LDR) and a semiconductor diode. It is a good idea to introduce students to the use of a potential divider as a variable voltage supply in order to do this, rather than allowing students to use a variable resistor in series with each of the components. (Indeed, there is good physics in examining the limitation of each kind of circuit, if there is time.)
- If it is possible to obtain some 'resistivity putty', good investigations can be done by students to see the factors on which resistance depends. An obvious extension to this is to examine the effect of temperature on the resistivity putty. This will satisfy the second of the required experiments.
- Investigating electric cells (both primary and secondary: these are terms that refer to cells that are one-use or rechargeable) is a good way to incorporate a data logger that can measure voltage and current.
- An interesting investigation is to examine whether the claims made by some cell manufacturers are true: Do some cells really last significantly longer than others? With a simple circuit and a data logger, students can record voltage and current against time and with a plot of power against time, integrate their graph by hand to find how much energy had been contained in the cell. This will satisfy the third of the required experiments.

- Another good experiment, and the last of the required experiments in this topic, is for students to measure the internal resistance of a cell. If students set up a simple circuit involving a variable resistor, an ammeter and a voltmeter across the terminals of the cell, students can measure the emf of the cell (when there is no current flowing) and the terminal voltage of the cell for a range of currents. A graph of terminal voltage against current will produce a line of negative gradient, the value of which will be the internal resistance of the cell. It is a simple investigation for students to do because it produces excellent reproducible results. It is nice at this point to combine the two required experiments and investigate whether the internal resistance of primary cells is significantly different to that of secondary cells of the same emf. The group 4 aims 2, 3, 6, 8 and 10 are clearly linked to these pieces of experimental work.
- Magnetic field patterns are generally best investigated with a combination of iron filings and paper and with small plotting compasses. Students can examine how the basic magnetic field pattern for a bar magnet becomes distorted when the bar magnet is placed near another magnet. This idea is good, because later on, students should appreciate that things that create magnetic fields (such as wires with currents flowing in them) cause distortion to other magnetic fields. If students can see the magnetic field patterns of various bar magnet configurations (N–N pole and N–S pole are vital), the pattern of the field around a current-carrying wire and the field inside a solenoid, they will be well placed to understand the important features of magnetic fields.
- A demonstration of the catapult effect with a current-carrying wire between the opposing poles of two magnets is a good point for students to start understanding the interaction of electric currents and magnetic fields. This will bring out Fleming's left-hand rule.
- If a current balance is available, students should investigate the factors on which the catapult force depends. Although it is difficult to find magnets with a useable range of magnetic flux densities (in which case students might just do this qualitatively), even a simple current balance can allow students to investigate how F depends on current, length of wire and the angle between the current and the magnetic field lines. These experiments will satisfy aims 2 and 9 of the group 4 aims.
- Please see the available practical notes for further ideas.

ICT

- Once again, the use of simulations to help where equipment may not be available is helped considerably by the University of Colorado website and the 'phet' models (http://phet.colorado.edu). There are good simulations on a variety of the ideas listed above, including making virtual circuits. Such computer-based simulations link directly to aim 7 of the group 4 aims.
- As suggested earlier, the use of data loggers with voltage and current sensors can be used in this topic – particularly if you want to examine the behaviour of a circuit over a period of time.

Common problems

- Understanding that voltage does not flow and that it is a measure of how much energy is transformed per unit charge is, perhaps, one of the major difficulties that students have. It is worthwhile spending time on this: $V = E/q$ is the key idea here.
- The difference between terminal voltage and emf is another idea that students become confused with. The experiment to find the internal resistance of a cell, suggested earlier, should help to overcome this difficulty.
- Whenever magnetic fields are involved, students will become confused about the direction in which forces act. Although Fleming's left-hand rule is a universally accepted aid for students, it is still common to see students make mistakes with this. For example, an electron moving

one way is equivalent to a current moving the other way. Also, it is worth making sure that students correctly identify which quantity is associated with which finger – and that they use their left hand.

Theory of knowledge (TOK)

- Until the discovery of the electron, the micro-scale understanding of the movement of charge was not understood – and yet by this time there had already been considerable progress in the understanding of electrical circuits and their magnetic effects. We might ask the question: In what ways does a paradigm shift in our knowledge force us to change the way we think about what we know?
- Early research on electromagnetism was based on observations of various phenomena. How has our way of learning changed now that we have the ability to model even complex situations with computers?
- Production of electrical circuits and many electrical components that form them use materials that have been shown to be environmentally harmful or directly harmful to humans. To what extent do scientists have to consider the moral or ethical consequences of their research?
- Magnetic field patterns are like maps: they convey information in a visually condensed way. Students also produce mind maps to review their knowledge. What are the advantages and disadvantages of using maps to outline our understanding? To what extent do maps have to be simplified versions of reality?

International-mindedness

- Early civilisations from all over the globe exploited the phenomenon of magnetism for travelling long distances, despite not understanding why such a method of navigation worked. How did different civilisations and cultures view this: magic, religion or science?
- All countries now use batteries of various kinds as portable energy sources. Different countries also vary in the way they deliver electrical mains supplies. Students might like to investigate the similarities and differences between various supplies around the world.
- The view of the Earth from space, especially during night-time hours, is one that is dominated by the effect of electrical energy being transformed into light. What additional information does this provide students with when they examine the industrial, economic and social progress of various countries?

