Teaching ideas for Topic 10: Fields (HL)

The main point of this topic is to bring together the ideas that students have been introduced to in Topic **5**: Electricity and magnetism and Topic **6**: Circular motion and gravitation and explore the quantitative aspects of fields using mathematics and mathematical relationships.

Some useful points to consider are:

- Students should understand what a field is, for example; that it is 'a region, or volume, in space in which a force acts on a body because of some property the body has'.
- Students need to understand that in a uniform field, the field strength is, at all points, constant. Both uniform electrical fields (such as those between two parallel charged plates) and uniform gravitational fields (such as the gravitational field at small heights from the surface of the Earth) are examples that are used frequently in questions about fields.
- Teaching students what the main terms are and how they relate to each other is the key to success in this topic. (See lesson ideas for a way of going about this.)
- Students should appreciate that the symmetry involved in radial fields produces equations that are mathematically identical – it is only the letters representing quantities in the equations that are different.
- The relative sizes of gravitational forces and electrical forces are the result of a big difference in the constants involved in the two equations as well as the sizes of charge and mass involved.

Ideas for teaching the topic

- It is to be expected that students will have covered Topics **5** and **6** by the time they get on to this topic. Of course, it is possible to combine teaching Topics **5**, **6** and **10** all at the same time, but this is not recommended because the amount of material in these topics is too much for students to cope with in one big hit. There is also considerable evidence from teaching studies that going back to a topic and revising its earlier points increases the overall understanding of students in the long term. For these reasons, it is probably best to teach Topic **10** a while after students have done Topics **5** and **6**.
- It is the mathematical relationships between the four quantities involved with fields that form the focus of teaching for this topic. These relationships should build on understanding that students already have as well as on new ideas they are introduced to. This will make the learning of the material so much more meaningful and coherent in the picture students are trying to build up. Most teachers will teach this topic in one of three ways:

  (i) Begin with electrical fields. Teach students what a uniform electrical field is, how it is produced and what effect it has on a charged body. Introduce the terms 'force', 'field strength', 'potential' and 'electrical potential energy' and show how these four terms are related to each other. Then move on to gravitational fields and repeat the method, expecting that students will be able to gain a growing realisation that the two fields are essentially the same mathematically.

  (ii) Begin with gravitational fields (because humans live in one and may feel that they already have an understanding of them) and follow a similar scheme to the one in method (i) above, moving from gravitational to electrical fields.

  (iii) Teach both fields at the same time by teaching students about another, made up or imaginary, field that explores the mathematical form of the equations for force, field strength, potential and potential energy. Only when students understand what the mathematical form of these equations is, and the mathematical links between them, do they then move on to the two actual fields: gravitational and electrical. This might sound a strange way to do it, but it has been shown to produce an excellent understanding of the nature of a field.

It is a teacher's choice to find which way of teaching this topic works best for their students. If you have not tried teaching this topic using method (iii) before, have a go and see how successful it is! This links directly with aims 3 and 4 of the group 4 aims.

- The energy considerations of bodies in orbit can be applied to:

  (i) Gravitational fields: combining the potential energy (negative) with the kinetic energy (positive) will produce an overall negative total, showing that the body is in the field. Equating the potential at the surface of a planet with the kinetic energy given to a projectile fired upwards (and ignoring any effects of air friction) will allow students to find an escape velocity for the planet. (It is fun at this point to get students to find out how 'big' a black hole might be (i.e. the radius of its event horizon) by giving the escape velocity to be the speed of light and making the mass of the black hole at least twice the solar mass, the revised Oppenheimer–Volkov limit. Students will like doing this!)

  (ii) Electrical fields: the classical picture of an electron orbiting around a positively charged nucleus and the energy considerations of this (again, the total energy of the electron will have to be negative) will help to set the scene for some of the work in Topic **7**: Atomic, nuclear and particle physics and Topic **12**: Quantum and nuclear physics (HL).

Practical activities

- Electric fields are used to accelerate charged particles. An old CRT TV or a disused oscilloscope can be dismantled so that students can see inside and identify: where electrons are produced (thermionic emission from a heated cathode); the anode that accelerates them; the (usually magnetic) fields that deflect them; and the screen (fluorescent) that shows where they go.

- If students have understood what a voltmeter measures, it might be a good idea to ask them what **one** of the leads from the voltmeter might measure. Introducing the gold-leaf electroscope as a way of measuring potential will be a good idea at this point, and students might like to produce their own calibration graph for an electroscope. They can then use this later to measure the potential in any electrical field.

- A more advanced investigation, involving students mapping the electric potential in an electrical field can also be done. With an electroscope that has been calibrated to measure potential, connect one end of a lead to the flat plate on the top of the electroscope and the other end to the metal needle of a hypodermic syringe. Then, connect a gas supply to the syringe so that a small flame can be maintained from the end of the needle. The deflection of the gold foil on the electroscope will measure the potential at the end of the needle and the needle point can be moved into various positions within the field. (The small flame will 'burn off' any excess charge, preventing the effect of induction from disturbing the field.) This will allow students to create their own graph of potential against position in the field. For a uniform field, produced with two parallel charged metal plates, students will be able to produce a really good graph of potential against distance between the plates so that the gradient of the graph can be used to find the field strength. This links directly with aim 6 of the group 4 aims.

- If the above idea is extended to the electrical field produced by a small charged ball (a ping-pong ball, suspended from some thin string, covered in conducting paint and charged to a few thousand volts using a high-tension power pack) will produce a surprisingly good inverse relationship of potential against radial distance.

- Newton's law of gravitation can be demonstrated by reproducing the famous experiment performed by Henry Cavendish in 1798. This demonstration is worth making the effort to perform. Specialist equipment may be available in your school, but it is not too difficult to build your own version of this, using two heavy spheres in a torsional balance configuration and two more heavy spheres located near each end of the torsional balance. Cavendish attempted to measure the universal gravitational constant, G; students might like to see if they can reach an answer anywhere near the accepted value.

- For investigating the motion of smaller masses in gravitational fields, a large sheet of rubber that is stretched horizontally can be used. If a fairly heavy mass is placed on the rubber sheet, it will create an indentation in the horizontal plane of the sheet that mimics the behaviour of the gravitational field produced by the mass. Students can then investigate the trajectories of other, smaller, masses within this field and see how the initial kinetic energy and the original direction of the motion of the small mass affect its path. Because the indentation in the rubber sheet is a model for the attractive nature of the gravitational field, students can apply this idea to the passage of light past very heavy stars, as Einstein proposed, to show that it is not only mass that experiences the force of gravity. If you have used the 'witch's' hat' demonstration for modelling the path of alpha particles in the famous alpha particle scattering experiment performed by Geiger and Marsden (under the leadership of Lord Rutherford), as described in Topic **7**, you may notice that the rubber sheet idea is like an inverted version of this; inverted because the alpha particles were being repelled by the positively charged nucleus and the mass in a gravitational field is being attracted.
- Please see the available practical notes for further ideas.

ICT

- An experiment, such as measuring potential in an electric field suggested above, is perhaps best done by getting students to enter their measurements directly into a spreadsheet or graphical analysis software package. This is because of the ease of regression for the graphs produced. It is also another opportunity for students to develop their confidence and ability with such software packages.

Common problems

- Students confuse the concepts of potential, potential energy, field strength and force. A good way to help them with this is to get students to make a poster with each of the four quantities in each corner of the poster. Links between each of the quantities can be added, showing how to derive one quantity from another. Together with a sketch of what the graph of the quantity against radial distance is like, the equations for each quantity can be added to the poster. This will help students to find their way about the various equations and prevent them from becoming too confused by how similar they all appear to be. There is a nice aspect of symmetry in this method that students might find helpful, too.
- The concept of an equipotential, and the 'map' of equipotentials for any field, is something that students frequently confuse with the diagram showing the field lines in a field. It is a good idea to reinforce the relationship between field lines and equipotentials: i.e. that they are always perpendicular. It is also important to get students to appreciate that the spacing of the equipotentials provides an indication of the field strength. Equipotentials are about energy and field lines are about force.

Theory of knowledge (TOK)

- Coulomb's law and Newton's law of gravitation are both inverse-square laws. Mathematically, the field strength approaches zero at radial distances that approach infinity. At what radial distance is it reasonable to make the assumption that field strength is close enough to zero? What other examples are there in physics (or, indeed, in any other academic discipline) when we can make assumptions like this? What factors are likely to influence our decision making?

- Yet again, the use of models to help illustrate physical laws or theories forms a large part in teaching this topic. This allows students to revisit their earlier discussions about the effectiveness of models.

International-mindedness

- The international use of the global positioning system (GPS) requires a global network of satellites and, in turn, a complete understanding of the physics of satellites. Collaboration between the many countries that use GPS has been necessary to produce an acceptable way of using this agreed by all countries.