Electricity and magnetism

Subtopic 2.1: Electric fields

This uses the concepts of force developed in Stage 1, Subtopic 1.2: Forces and charge in Subtopic 2.1: Potential difference and electric current.

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| Electrostatically charged objects exert forces upon one another; the magnitude of these forces can be calculated using Coulomb’s Law.   * Solve problems involving the use of: * Using proportionality, discuss changes in the magnitude of the force on each of the charges as a result of a change in one or both of the charges and/or a change in the distance between them. * Explain that the electric forces are consistent with Newton’s Third Law. |
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| When more than two point charges are present, the force on any one of them is equal to the vector sum of the forces due to each of the other point charges.   * Use vector addition in one dimension or two dimensions with right-angled, isosceles, or equilateral triangles to calculate the magnitude and direction of the force on a point charge due to two other point charges. |
| Point charges and charged objects produce electric fields in the space that surrounds them. A charged object in an electric field experiences an electric force.  The direction and number of electric field lines per unit area represent the direction and magnitude of the electric field.   * Sketch the electric field lines: * for an isolated positive or negative point charge and for two point charges * between and near the edges of two finite oppositely charged parallel plates. |
| A positively charged body placed in an electric field will experience a force in the direction of the field; the strength of the electric field is defined as the force per unit charge.   * Solve problems involving the use of: * Using Coulomb’s Law, derive the formula: * Solve problems using:   for one or two point charges in one or two dimensions. |
| There is no electric field inside a hollow conductor of any shape, provided that there is no charge in the cavity.   * Sketch the electric field produced by a hollow spherical charged conductor. |
| Electric fields are strongest near sharp points on conductors. These fields may be large enough to ionise molecules in the air near the sharp points, resulting in charge movement away from the conductor. This is called a ‘corona discharge’.   * Sketch the electric field produced by charged conductors of an irregular shape. * Explain how the electric field near sharp points may ionise the air. |
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Subtopic 2.2: Motion of charged particles in electric fields

This uses the concepts of force developed in Stage 1, Subtopic 1.2: Forces and energy in Stage 1, Subtopic 4.1: Energy.

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| When a charged body moves or is moved from one point to another in an electric field, work is done on or by the field.  The electric potential difference, between two points is the work done per unit charge on a small positive test charge moved between the points, provided that all other charges remain undisturbed.  The electronvolt  is a unit of measurement which describes the energy carried by a particle. It is the work done when an electron moves through a potential difference of 1 volt.   * Solve problems involving the use of . * Convert energy from joules into electronvolts and vice versa.   The magnitude of the electric field (away from the edges) between two oppositely charged parallel plates a distance d apart, where is the potential difference between the plates, is given by the formula: .   * Solve problems involving the use of . |
| The force on a charged particle moving in a uniform electric field is constant in magnitude and direction, thus producing a constant acceleration.   * Derive the formula  for the acceleration of a charged particle in an electric field. * Solve problems using  and the motion formulae for the movement of charged particles parallel or antiparallel to a uniform electric field. * Describe the motion of charged particles parallel or antiparallel to a uniform electric field.   In a cyclotron, the electric field in the gap between the dees increases the speed of the charged particles.   * Describe how an electric field between the dees can transfer energy to an ion passing between them. * Describe how ions could be accelerated to high energies if they could be made to repeatedly move across an electric field. * Calculate the energy transferred to an ion each time it passes between the dees. * Explain why the ions do not gain kinetic energy when inside the dees. |
| A charged particle moving at an angle to a uniform electric field experiences a force which affects both components of its velocity differently. The component of the velocity parallel to the electric field changes due the electric force and the component perpendicular to the field remains constant.   * Compare the motion of a projectile in the absence of air resistance with the motion of a charged particle in a uniform electric field. * Solve problems for the motion of charged particles that enter a uniform electric field perpendicular to the field. * Solve problems for the motion of charged particles that enter a uniform electric field at an angle to the field where the displacement of the charged particle parallel to the field is zero. |
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Subtopic 2.3: Magnetic fields

This uses the concept of electric current developed in Stage 1, Subtopic 2.1: Potential difference and electric current.

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| Magnetic fields are associated with permanent magnets and moving charges, such as charges in an electric current.  Current-carrying conductors produce magnetic fields; these fields are utilised in solenoids.  Magnetic field lines can be used to represent the magnetic field. The direction of the magnetic field depends on the direction of the moving charge that is producing the magnetic field.  The magnitude of magnetic field strength, B, at any point is represented by the number of lines crossing a unit area perpendicular to the field in the vicinity of the point.   * Sketch and/or interpret the magnetic field lines produced by a bar magnet, and an electric current flowing in a straight conductor, a loop, and a solenoid. |
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| The magnitude of the magnetic field strength in the vicinity of a current‑carrying conductor is given by  where r is the radial distance to the conductor.   * Solve problems involving the use of * Use vector addition in one dimension or in two dimensions (with right-angled or equilateral triangles) to calculate the magnitude and direction of the magnetic field due to two current-carrying conductors) |
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Subtopic 2.4: Motion of charged particles in magnetic fields

This uses the concept of force developed in Stage 1, Subtopic 1.2: Forces and the concept of circular motion in Stage 2, Subtopic 1.3: Circular motion and gravitation.

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| Magnets, magnetic materials, moving charges, and current-carrying conductors experience a force in a magnetic field.  The magnetic force on a moving charged particle within a uniform magnetic field depends on the velocity of the particle, its charge, the magnetic field, and the angle between the velocity and magnetic field.  The force on a current-carrying conductor within a uniform magnetic field depends on the current in the conductor, the length of the conductor within the magnetic field, the magnetic field strength, and the angle between the conductor and magnetic field.   * Determine the direction of one of: * force * magnetic field * charge movement   given the direction of the other two.   * Solve problems involving the use of  for a current-carrying conductor and  for a moving charged particle.   A charged particle moving at right angles to a uniform magnetic field experiences a force of constant magnitude at right angles to the velocity. The force changes the direction but not the speed of the charged particle, therefore causes centripetal acceleration.   * Explain how the velocity dependence of the magnetic force on a charged particle causes the particle to move with uniform circular motion when it enters a uniform magnetic field at right angles. |
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| * Derive  for the radius r of the circular path of an ion of charge q and mass m that is moving with speed v at right angles to a uniform magnetic field of magnitude B. * Solve problems involving the use of . |
| Cyclotrons are used to accelerate ions to high speed. Radioisotopes used in medicine and industry may be produced from collisions between high-speed ions and nuclei. |
| The magnetic field within the dees of a cyclotron causes the charged particles to travel in a circular path, so that they repeatedly pass through the electric field.   * Describe the nature and direction of the magnetic field needed to deflect ions into a circular path in the dees of a cyclotron. * Derive the formula  for the period T of the circular motion of an ion, and hence show that the period is independent of the speed of the ion. * Use  to relate the period to the frequency of the alternating potential differences. * Derive the formula for the kinetic energy of the ions emerging at radius r from a cyclotron. |
| * Explain why  is independent of the potential difference across the dees and, for given ions, depends only on the magnetic field and the radius of the cyclotron. * Solve problems involving the use of  and |

Subtopic 2.5: Electromagnetic induction

*This uses the concept of electric current developed in Stage 1, Subtopic 2.1: Potential difference and electric current.*

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| Magnetic flux (Φ) is defined as the product of magnetic field strength (B) and the area perpendicular to the magnetic field (). Hence:   * Solve problems involving the use of |
| Electromagnetic induction is the process in which a changing magnetic flux induces a potential difference in a conductor.  The induced potential difference is referred to as an electromotive force .  The changing magnetic flux is due to relative movement of the conductor or variation of the magnetic field strength.  Faraday’s Law states that the induced emf is equal to the rate of change of the magnetic flux.  For N conducting loops the induced  is given by  Lenz’s Law states that the direction of a current created by an induced  is such that it opposes the change in magnetic flux producing the .   * Solve problems involving the induction of an  in a straight conductor. * Solve problems involving the induction of an  in N conducting loops. * Use the law of conservation of energy to explain Lenz's Law. * Use Lenz’s Law to determine the direction of the current produced by the induced . * Use Lenz's Law to explain the production of eddy currents. |
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| Some generators use a fixed magnet to generate  in rotating conducting loops for electricity production.   * Explain how generators can be used to produce an alternating electric current.   Transformers allow generated voltage to be either increased or decreased before it is used. A transformer consists of an input coil (with  turns) with a potential difference  and an output coil (with  turns) with a potential difference .  The relationship between the potential differences is given by the formula:   * Describe the purpose of transformers in electrical circuits. * Explain how a transformer increases or decreases an alternating potential difference. * Compare step-up and step-down transformers. * Solve problems involving the use of: |