17.2 Electric and magnetic fields (full D.2, HL)

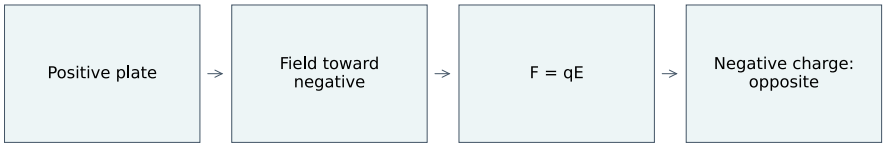
Name: _____ Class: _____ Date: _____ **Total: 30 marks**

KEY WORDS Coulomb's law • electric field strength • quantization of charge • electric potential • equipotential surface • electronvolt

Objective

Practise the full guide D.2 toolkit including AHL: Coulomb's law $F = kq_1q_2/r^2$, force directions between charges, charge conservation and Millikan's quantization evidence, charging by friction, contact and induction with grounding, $E = F/q$ with field-line density, the uniform field $E = V/d$ between parallel plates, and magnetic field-line patterns for a bar magnet, straight wire, coil and solenoid; at higher level also potential $V_e = kQ/r$, energy $E_p = kq_1q_2/r$, the potential gradient, equipotential surfaces, and work in joules and electronvolts. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The D.2 rule set (HL)**

$$F = \frac{kq_1q_2}{r^2} \qquad E = \frac{F}{q} \qquad E = \frac{V}{d} \qquad V_e = \frac{kQ}{r} \qquad E_p = \frac{kq_1q_2}{r} \qquad W = q\Delta V_e$$

Field lines run positive to negative and denser means stronger; magnetic field lines close on themselves. Charge is conserved and quantized – Millikan balanced $qE = mg$ on oil drops and found only whole multiples of e.

■ **Worked example: the Millikan balance**

A drop of mass 3.2×10^{-15} kg carrying three excess electrons floats between plates: $qE = mg$ gives $E = (3.2 \times 10^{-15} \times 9.8)/(4.8 \times 10^{-19}) = 6.5 \times 10^4$ V/m. Every other drop balances at a field making its charge some whole number of e – that staircase is the quantization evidence. Two habits: keep the signs of charges in the force direction but use magnitudes in the formula, and check plate fields with $E = V/d$ before using $F = qE$.

2 Practice

2.1 State Coulomb's law and the direction of the force between two negative charges. [2]

2.2 Two charges of $+2.0\ \mu$C and $-3.0\ \mu$C sit 0.060 m apart. Calculate the magnitude of the force between them. [3]

2.3 State what Millikan's oil-drop experiment showed about electric charge. [2]

2.4 A charged rod is brought near (not touching) an isolated conducting sphere, which is then grounded briefly. Describe the sphere's net charge after the ground is removed and the rod taken away. [3]

2.5 Calculate the electric potential at 0.30 m from a point charge of $+2.0\ \mu$C. [2]

3 Exam-style questions

3.1 Two parallel plates 5.0 mm apart hold 250 V across them. Calculate the field strength between them and the force on an electron placed there, and state one assumption about the field. [4]

3.2 Describe the magnetic field-line pattern around a long straight current-carrying wire, and state how the pattern changes if the current direction reverses. [3]

3.3 Sketch in words: the electric field-line pattern for two equal opposite point charges, giving two rules the pattern obeys. [4]

3.4 Explain how a balloon rubbed on hair can attract small neutral pieces of paper, naming the process that acts on the paper. [3]

3.5 An electron is accelerated from rest through a potential difference of 500 V. Calculate the work done on it in electronvolts and in joules, and the speed it reaches ($m_e = 9.1 \times 10^{-31}$ kg). [4]

Solutions

Original-task marking: M1 method, A1 accuracy, B1 reasoning.

2.1 $F = kq_1q_2/r^2$, proportional to the product of the charges and the inverse square of their separation; two negative charges repel – forces point away from each other along the joining line.

2.2 $F = (9.0 \times 10^9 \times 2.0 \times 10^{-6} \times 3.0 \times 10^{-6})/(0.060)^2 = (5.4 \times 10^{-2})/(3.6 \times 10^{-3}) = 15$ N, attractive since the signs are opposite.

2.3 Charge is quantized: every drop carried a whole-number multiple of the electron charge $e = 1.6 \times 10^{-19}$ C, never a fraction of it.

2.4 The rod's field separates the sphere's charges – near side opposite, far side like the rod; grounding drains the like charge away to Earth; after the ground is removed first and the rod leaves, the sphere keeps a net charge opposite to the rod – charging by induction.

2.5 $V_e = kQ/r = (9.0 \times 10^9 \times 2.0 \times 10^{-6})/0.30 = 6.0 \times 10^4$ V.

3.1 $E = V/d = 250/5.0 \times 10^{-3} = 5.0 \times 10^4$ V/m; $F = eE = 1.6 \times 10^{-19} \times 5.0 \times 10^4 = 8.0 \times 10^{-15}$ N; assumes a uniform field – ignoring edge effects.

3.2 Concentric circles centred on the wire, lying in the plane perpendicular to it; direction given by the right-hand grip rule with the thumb along the current; reversing the current reverses the sense of every circle.

3.3 Lines run from the positive charge to the negative, curving so pairs meet the charges symmetrically; the straight line joins the two charges through the middle; rules: lines start on positive and end on negative charge, never cross, and their local density represents the field strength – dense near each charge, weakest in the far field.

3.4 Rubbing transfers electrons, leaving the balloon charged; the charged balloon polarizes the neutral paper – induction separates its charges, opposite sign nearer the balloon; the nearer opposite charge feels the stronger attraction (inverse-square), so the paper is pulled to the balloon.

3.5 $W = q\Delta V_e = 500$ eV $= 500 \times 1.6 \times 10^{-19} = 8.0 \times 10^{-17}$ J; $\frac{1}{2}mv^2 = W$ so $v = \sqrt{2W/m_e} = \sqrt{(1.6 \times 10^{-16})/(9.1 \times 10^{-31})} = 1.3 \times 10^7$ m/s.