18.2 Motion in electromagnetic fields (full D.3)

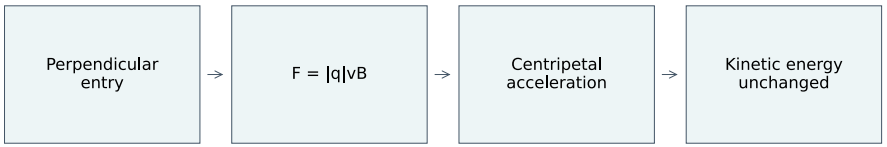
Name: _____ Class: _____ Date: _____ **Total: 23 marks**

KEY WORDS magnetic force • charge-to-mass ratio • velocity selector

Objective

Practise the full guide D.3 toolkit: motion of a charged particle in a uniform electric field (parabolic path), in a uniform magnetic field ($F = qvB\sin\theta$, circular path at constant kinetic energy, $r = mv/qB$ and the charge-to-mass ratio), crossed perpendicular fields as a velocity selector $v = E/B$, the wire force $F = BIL\sin\theta$, and the force per unit length between parallel wires. Original practice; not an official IB paper.

1 Key knowledge and worked examples



■ **The D.3 rule set**

$$F = qvB\sin\theta \qquad r = \frac{mv}{qB} \qquad v = \frac{E}{B} \qquad F = BIL\sin\theta \qquad \frac{F}{L} = \frac{\mu_0 I_1 I_2}{2\pi r}$$

Electric field: constant force, parabolic path. Magnetic field: force perpendicular to velocity, circular path, speed unchanged. Crossed fields: balance selects one speed.

■ **Worked example: reading a proton's track**

A proton moves at 2.0×10^6 m/s perpendicular to a 0.50 T field. $r = mv/qB = (1.67 \times 10^{-27} \times 2.0 \times 10^6)/(1.6 \times 10^{-19} \times 0.50) = 4.2 \times 10^{-2}$ m, and inverting gives $q/m = v/(rB) = 9.5 \times 10^7$ C/kg. Two habits: check the angle – $\sin\theta$ is 1 only when velocity is perpendicular to the field – and remember the magnetic force never changes a particle's speed, only its direction.

2 Practice

2.1 Explain why a magnetic field cannot change a charged particle's kinetic energy. [2]

2.2 An electron moves at 1.0×10^6 m/s perpendicular to a 0.20 T field. Calculate the radius of its circular path ($m_e = 9.1 \times 10^{-31}$ kg). [3]

2.3 State the condition for a charged particle to pass undeflected through perpendicular electric and magnetic fields. [2]

2.4 Two long parallel wires carry currents in the same direction. State the direction of the force between them. [1]

3 Exam-style questions

3.1 A 0.30 m wire carries 5.0 A at right angles to a 0.20 T field. Calculate the force on it, and state what happens to the force when the wire runs parallel to the field. [3]

3.2 In a velocity selector, $E = 1.5 \times 10^4$ V/m and $B = 0.050$ T. Calculate the speed that passes straight through, and describe the deflection of a faster particle. [4]

3.3 An alpha particle ($q = 3.2 \times 10^{-19}$ C, $m = 6.6 \times 10^{-27}$ kg) moves at 1.0×10^6 m/s perpendicular to a 0.40 T field. Calculate the radius of its path and its charge-to-mass ratio from that radius, and compare the radius with a proton at the same speed in the same field. [5]

3.4 Two long parallel wires 0.050 m apart each carry 10 A. Calculate the force per unit length between them, and state whether it is attraction or repulsion when one current is reversed. [3]

Solutions

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

2.1 The magnetic force always acts perpendicular to the velocity; a perpendicular force does no work, so the speed and hence kinetic energy stay constant.

2.2 $r = m_e v/qB = (9.1 \times 10^{-31} \times 1.0 \times 10^6)/(1.6 \times 10^{-19} \times 0.20) = 9.1 \times 10^{-25}/3.2 \times 10^{-20} = 2.8 \times 10^{-5}$ m.

2.3 The electric and magnetic forces must balance: $qE = qvB$, so only $v = E/B$ passes undeflected.

2.4 Attraction.

3.1 $F = BIL \sin\theta = 0.20 \times 5.0 \times 0.30 \times 1 = 0.30$ N; parallel to the field, $\theta = 0$ so $\sin\theta = 0$ – the force falls to zero.

3.2 $v = E/B = 1.5 \times 10^4/0.050 = 3.0 \times 10^5$ m/s; for a faster particle the magnetic force qvB exceeds the electric force qE, so it deflects along the magnetic-force direction (the same side regardless of sign, since both forces flip with charge).

3.3 $r = mv/qB = (6.6 \times 10^{-27} \times 1.0 \times 10^6)/(3.2 \times 10^{-19} \times 0.40) = 6.6 \times 10^{-21}/1.28 \times 10^{-19} = 5.2 \times 10^{-2}$ m; $q/m = v/(rB) = 1.0 \times 10^6/(5.2 \times 10^{-2} \times 0.40) = 4.8 \times 10^7$ C/kg; a proton's charge-to-mass ratio (9.6×10^7 C/kg) is twice the alpha's, so its radius is half: $r_p \approx 2.6 \times 10^{-2}$ m.

3.4 $F/L = \mu_0 I_1 I_2/2\pi r = (4\pi \times 10^{-7} \times 10 \times 10)/(2\pi \times 0.050) = 4.0 \times 10^{-4}$ N/m; same-direction currents attract, so reversing one current turns it into repulsion.