

Exercise walk-through

# 18.2

## Motion in electromagnetic fields (full D.3)

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International Baccalaureate · IB Diploma · Physics · HL

## Charged Motion · 2.1

### Reasoning

The magnetic force magnitude is  $F = |q|vB \sin\theta$ . It is perpendicular to velocity and magnetic field, with direction determined by charge sign. For perpendicular entry into a uniform field, it can provide the centripetal force for circular motion. magnetic force: Force due to a magnetic field on a moving charge or current. momentum : Mass multiplied by velocity in the classical model.

## Charged Motion · 5.2

### Reasoning

Not true: A magnetic force alone continuously increases the kinetic energy of a charged particle. A force perpendicular to the velocity does no work (work = force  $\times$  distance ALONG the force), so a magnetic field alone cannot change a particle's kinetic energy - only its direction. Speeding up needs a field component along the motion, which only an electric field provides.

## Exercises 2.1·2.3

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

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**2.2** An electron moves at  $1.0 \times 10^6$  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]

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

## Exercises 2.1-2.3

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

**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.

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**2.2** An electron moves at  $1.0 \times 10^6$  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]

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

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

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

## Exercises 2.4·3.2

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

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**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]

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**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]

## Exercises 2.4·3.2

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

**2.4** Attraction.

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**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]

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

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

**3.2**  $v = E/B = 1.5 \times 10^4 / 0.050 = 3.0 \times 10^5 \text{ m/s}$ ; 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).

## Exercises 3.3-3.4

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**3.3** An alpha particle ( $q = 3.2 \times 10^{-19}$  C,  $m = 6.6 \times 10^{-27}$  kg) moves at  $1.0 \times 10^6$  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]

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**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]

## Exercises 3.3-3.4

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**3.3** An alpha particle ( $q = 3.2 \times 10^{-19}$  C,  $m = 6.6 \times 10^{-27}$  kg) moves at  $1.0 \times 10^6$  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]

**3.3**  $r = mv/qB = (6.6 \times 10^{-27} \times 1.0 \times 10^6)/(3.2 \times 10^{-19} \times 0.40) = 6.6 \times 10^{-21}/1.28 \times 10^{-19} = 5.2 \times 10^{-2}$  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 ( $9.6 \times 10^7$  C/kg) is twice the alpha's, so its radius is half:  $r_p \approx 2.6 \times 10^{-2}$  m.

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**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]

**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.