

Forces on currents and moving charges in magnetic fields

Physics grades 11-12 (A Level · IB · Class 11-12) · Worksheet answers

Check your method as well as the final number: each answer shows the formula, the substitution and the result with its unit. Directions come from the left-hand rule for conventional current. Small rounding differences in the last digit are acceptable.

Level: Physics grades 11-12 (A Level · IB · Class 11-12) · **Curriculum:** IB D.3

Problem 1 Force on a lab wire

$$F = BIL = 0.40 \times 3.0 \times 0.50 = \mathbf{0.60 \text{ N}}.$$

Problem 2 Direction of the force

1. Current north, field down: the force is perpendicular to both, so it is horizontal. By the left-hand rule (or the cross product $\mathbf{I} \times \mathbf{B}$) it points **west**.
2. Reversing the current reverses the force: **east**.

Problem 3 Electron in a field

$$F = Bqv = 0.20 \times 1.60 \times 10^{-19} \times 5.0 \times 10^6 = \mathbf{1.6 \times 10^{-13} \text{ N}}.$$

Problem 4 Finding the field

$$B = F / (IL) = 0.054 / (6.0 \times 0.15) = 0.054 / 0.90 = \mathbf{0.060 \text{ T}}.$$

Problem 5 Wire at an angle

1. $F = BIL \sin \theta = 0.25 \times 2.0 \times 0.40 \times \sin 30^\circ = 0.20 \times 0.50 = \mathbf{0.10 \text{ N}}.$
2. $\sin 0^\circ = 0$, so the force is **zero**.

Problem 6 Power cable and Earth's field

1. $45 \mu\text{T} = 45 \times 10^{-6} \text{ T} = \mathbf{4.5 \times 10^{-5} \text{ T}}.$
2. $F = BIL = 4.5 \times 10^{-5} \times 250 \times 80 = \mathbf{0.90 \text{ N}}$, small for a cable of that length.

Problem 7 Speed unchanged

1. The magnetic force is always perpendicular to the velocity, so it has no component along the motion and does no work.

2. Because no work is done, the kinetic energy is **constant**; only the direction of the velocity changes.

Problem 8 Proton orbit radius

$$r = mv/(qB) = (1.67 \times 10^{-27} \times 4.0 \times 10^6) / (1.60 \times 10^{-19} \times 0.80) = 6.68 \times 10^{-21} / 1.28 \times 10^{-19} = \mathbf{5.2 \text{ cm}}.$$

Problem 9 Cyclotron frequency of an electron

$$1. T = 2\pi m/(qB) = 2\pi \times 9.11 \times 10^{-31} / (1.60 \times 10^{-19} \times 1.5 \times 10^{-3}) = \mathbf{2.4 \times 10^{-8} \text{ s}}.$$

$$2. f = 1/T = \mathbf{4.2 \times 10^7 \text{ Hz}}.$$

3. Neither changes: the period does not depend on speed, because the radius doubles with the speed.

Problem 10 Selecting a speed

$$1. v = E/B = 2.4 \times 10^4 / 0.080 = \mathbf{3.0 \times 10^5 \text{ m/s}}.$$

2. The magnetic force qvB grows with v while qE stays the same, so the magnetic force wins and the faster particle is deflected out of the straight line, towards the magnetic-force side.

Problem 11 Electron gun then field

$$1. eV = \frac{1}{2}mv^2, \text{ so } v = \sqrt{(2eV/m)} = \sqrt{(2 \times 1.60 \times 10^{-19} \times 150 / 9.11 \times 10^{-31})} = \mathbf{7.3 \times 10^6 \text{ m/s}}.$$

$$2. r = mv/(qB) = 9.11 \times 10^{-31} \times 7.3 \times 10^6 / (1.60 \times 10^{-19} \times 1.0 \times 10^{-3}) = \mathbf{4.1 \text{ cm}}.$$

Problem 12 Floating wire

1. The upward magnetic force must equal the weight: $BIL = mg$, so $BI = (m/L)g$.

$$2. I = (m/L)g / B = 4.0 \times 10^{-3} \times 9.81 / 0.050 = \mathbf{0.78 \text{ A}}.$$

Problem 13 Reading a force graph

1. The line passes through (5.0 A, 0.100 N): gradient = $0.100 / 5.0 = \mathbf{0.020 \text{ N/A}}$.

2. $F = (BL) I$, so gradient = BL and $B = 0.020 / 0.25 = \mathbf{0.080 \text{ T}}$.

3. With no current there is no force on the wire, so $F = 0$ when $I = 0$.

Problem 14 Proton against alpha particle

$$1. r = mv/(qB), \text{ so } r(\alpha)/r(p) = (m(\alpha)/m(p)) \times (q(p)/q(\alpha)) = (6.64 \times 10^{-27} / 1.67 \times 10^{-27}) \times (1/2) = 3.98 \times 0.5 = \mathbf{1.99} \text{ (about 2)}.$$

2. The alpha is four times heavier, which widens the circle, but it carries twice the charge, which tightens it. The net effect is a circle twice as large.

Problem 15 Tracks in a bubble chamber

1. For a positive charge moving right with B into the page, $F = qv \times B$ points up, so the track curves upwards: track 1 is **positive**, track 2 is **negative**.
2. $p = mv = qBr$. With equal $|q|$ and the same B , the larger radius means larger momentum: **track 1**.
3. The force is always perpendicular to the velocity and constant in size, so it acts as a centripetal force.

Problem 16 Proton cyclotron

1. $v = qBr/m = 1.60 \times 10^{-19} \times 1.2 \times 0.45 / 1.67 \times 10^{-27} = \mathbf{5.17 \times 10^7 \text{ m/s}}$.
2. $KE = \frac{1}{2}mv^2 = 0.5 \times 1.67 \times 10^{-27} \times (5.17 \times 10^7)^2 = \mathbf{2.24 \times 10^{-12} \text{ J}}$.
3. $2.24 \times 10^{-12} / 1.60 \times 10^{-19} = 1.40 \times 10^7 \text{ eV} = \mathbf{14.0 \text{ MeV}}$.

Problem 17 Spiral path

1. $v_{\perp} = v \sin 60^\circ = \mathbf{3.46 \times 10^6 \text{ m/s}}$, $v_{\parallel} = v \cos 60^\circ = \mathbf{2.00 \times 10^6 \text{ m/s}}$.
2. $r = mv_{\perp}/(eB) = 9.11 \times 10^{-31} \times 3.46 \times 10^6 / (1.60 \times 10^{-19} \times 2.0 \times 10^{-3}) = \mathbf{0.99 \text{ cm}}$.
3. $T = 2\pi m/(eB) = 1.79 \times 10^{-8} \text{ s}$, so pitch $= v_{\parallel}T = 2.00 \times 10^6 \times 1.79 \times 10^{-8} = \mathbf{3.6 \text{ cm}}$.

Problem 18 Coil in a field

1. $F = N B I L = 40 \times 0.15 \times 0.80 \times 0.050 = \mathbf{0.24 \text{ N}}$.
2. The current flows the opposite way in the other side, so its force is **equal and opposite**.
3. Couple $= F \times$ perpendicular distance $= 0.24 \times 0.030 = \mathbf{7.2 \times 10^{-3} \text{ N m}}$.

Problem 19 Separating chlorine ions

1. $qV = \frac{1}{2}mv^2$ gives $v = \sqrt{(2qV/m)}$; substituting into $r = mv/(qB)$ gives $r = (1/B)\sqrt{(2mV/q)}$.
2. For 35 u: $m = 5.81 \times 10^{-26} \text{ kg}$, $r = \mathbf{7.62 \text{ cm}}$. For 37 u: $m = 6.14 \times 10^{-26} \text{ kg}$, $r = \mathbf{7.84 \text{ cm}}$.
3. The landing points are $2r$ from the entry slit, so the separation is $2(r_{37} - r_{35}) = \mathbf{4.3 \text{ mm}}$.

Problem 20 Checking a student's solution

1. $r = 1.67 \times 10^{-27} \times 2.0 \times 10^6 / (1.60 \times 10^{-19} \times 0.40) = 3.34 \times 10^{-21} / 6.4 \times 10^{-20} = \mathbf{5.2 \text{ cm}} = 0.052 \text{ m}$, ten times smaller than claimed.
2. $T = 2\pi r/v = 2\pi \times 0.0522 / 2.0 \times 10^6 = \mathbf{1.6 \times 10^{-7} \text{ s}}$.
3. Estimate $1.7 \times 2 \div (1.6 \times 0.4) \approx 5$, and $10^{-27+6} \div 10^{-19} = 10^{-2}$, so r should be about $5 \times 10^{-2} \text{ m}$, a few centimetres.