

Magnetic fields of wires and forces on moving charges

AP Physics 2 (algebra-based) · Worksheet answers

Each answer shows the relationship, the substitution and the result in bold. Check the direction as well as the size, because AP free-response questions award marks for the right-hand rule reasoning.

Level: AP Physics 2 (algebra-based) · **Curriculum:** AP P2 Unit 12

Problem 1 Field of a cable

- $B = \mu_0 I / 2\pi r = (4\pi \times 10^{-7})(10) / (2\pi \times 0.020) = \mathbf{1.0 \times 10^{-4} \text{ T}}$.
- B is proportional to $1/r$, so doubling r **halves the field** to $5.0 \times 10^{-5} \text{ T}$.

Problem 2 Field direction

- The field lines are circles, directed **counterclockwise** seen from the front.
- Right-hand grip rule: thumb along the current, fingers curl in the field direction.

Problem 3 Force on a proton

- $F = qvB = (1.6 \times 10^{-19})(3.0 \times 10^5)(0.20) = \mathbf{9.6 \times 10^{-15} \text{ N}}$.
- The force is perpendicular to the velocity, so it does no work: the speed is **constant**.

Problem 4 Force on a wire

- $F = BIL = 0.50 \times 4.0 \times 0.25 = \mathbf{0.50 \text{ N}}$.
- F is proportional to I , so it doubles to **1.0 N**.

Problem 5 When is the force zero?

The force is zero when **(1) the charge is at rest**, **(2) the velocity is parallel or antiparallel to the field** ($\sin \theta = 0$), and **(3) the particle is neutral** ($q = 0$).

Problem 6 Which way?

- Fingers right (v), curl into the page (B): the thumb points **up the page**.

- The electron is negative, so the force is reversed: **down the page**.

Problem 7 Unit conversions

- $250 \text{ mT} = \mathbf{0.25 \text{ T}}$.
- $45 \text{ } \mu\text{T} = \mathbf{4.5 \times 10^{-5} \text{ T}}$.
- From $F = BIL$, $\mathbf{1 \text{ T} = 1 \text{ N/(A}\cdot\text{m)}}$.

Problem 8 Matching the Earth's field

$$r = \mu_0 I / 2\pi B = (4\pi \times 10^{-7})(30) / (2\pi \times 5.0 \times 10^{-5}) = \mathbf{0.12 \text{ m}}$$
, so 12 cm.

Problem 9 Proton in a field

- $r = mv/(qB) = (1.67 \times 10^{-27})(4.0 \times 10^5) / [(1.6 \times 10^{-19})(0.50)] = \mathbf{8.4 \text{ mm}}$.
- $T = 2\pi m/(qB) = 2\pi(1.67 \times 10^{-27}) / (8.0 \times 10^{-20}) = \mathbf{1.3 \times 10^{-7} \text{ s}}$.

Problem 10 Wire at an angle

- $F = BIL \sin \theta = 0.25 \times 8.0 \times 0.60 \times \sin 30^\circ = \mathbf{0.60 \text{ N}}$.
- The greatest force occurs at **90°**.

Problem 11 Velocity selector

- The electric and magnetic forces cancel: $qE = qvB$.
- $v = E/B = 4.0 \times 10^3 / 0.020 = \mathbf{2.0 \times 10^5 \text{ m/s}}$.

Problem 12 Two parallel wires

- $F/L = \mu_0 I_1 I_2 / 2\pi d = (4\pi \times 10^{-7})(5.0)(5.0) / (2\pi \times 0.020) = \mathbf{2.5 \times 10^{-4} \text{ N/m}}$.
- Parallel currents **attract**.

Problem 13 Radius and field data

- r is **inversely proportional** to B : doubling B halves r .
- $r \times B = 11.4 \times 10^{-3} \times 1.0 \times 10^{-3} = 1.14 \times 10^{-5} \text{ T}\cdot\text{m}$; the other rows give 1.14×10^{-5} and $1.14 \times 10^{-5} \text{ T}\cdot\text{m}$. It is **constant**.
- $r = mv/(eB)$, so $v = e(rB)/m = (1.6 \times 10^{-19})(1.14 \times 10^{-5}) / (9.11 \times 10^{-31}) = \mathbf{2.0 \times 10^6 \text{ m/s}}$.

Problem 14 Accelerating a bar

1. $F = BIL = 0.40 \times 12 \times 0.15 = \mathbf{0.72 \text{ N}}$.
2. $a = F/m = 0.72 / 0.050 = \mathbf{14 \text{ m/s}^2}$.

Problem 15 Electron versus proton

1. $r = mv/(qB)$, and the charge magnitudes are equal, so r is proportional to mass: $r_p / r_e = m_p / m_e = 1.67 \times 10^{-27} / 9.11 \times 10^{-31} = \mathbf{1.8 \times 10^3}$.
2. The charges are opposite, so they circulate in **opposite directions**.

Problem 16 Field between two wires

1. Each wire gives $B = (4\pi \times 10^{-7})(6.0) / (2\pi \times 0.050) = 2.4 \times 10^{-5} \text{ T}$ at P. For opposite currents the two fields point the same way at P, so the total is $\mathbf{4.8 \times 10^{-5} \text{ T}}$.
2. For currents in the same direction the two fields are equal and opposite at P, so the total is **zero**.

Problem 17 Levitating a wire

1. $mg = BIL$, so $I = mg / (BL) = (0.012)(9.81) / (0.060 \times 0.50) = \mathbf{3.9 \text{ A}}$.
2. With B to the right and an upward force, the right-hand rule needs the current **out of the page**, as drawn.

Problem 18 Mass spectrometer

1. $qV = \frac{1}{2}mv^2$, so $v = \sqrt{(2qV/m)} = \sqrt{[2(1.6 \times 10^{-19})(500) / 6.5 \times 10^{-26}]} = \mathbf{5.0 \times 10^4 \text{ m/s}}$.
2. $r = mv/(qB) = (6.5 \times 10^{-26})(4.96 \times 10^4) / [(1.6 \times 10^{-19})(0.100)] = \mathbf{0.20 \text{ m}}$.

Problem 19 Spiral path

1. $F = qvB \sin \theta = (1.6 \times 10^{-19})(5.0 \times 10^5)(0.30) \sin 60^\circ = \mathbf{2.1 \times 10^{-14} \text{ N}}$.
2. $v_\perp = 5.0 \times 10^5 \sin 60^\circ = 4.33 \times 10^5 \text{ m/s}$. $r = mv_\perp/(qB) = (1.67 \times 10^{-27})(4.33 \times 10^5) / (1.6 \times 10^{-19} \times 0.30) = \mathbf{1.5 \text{ cm}}$.
3. $T = 2\pi m/(qB) = 2.19 \times 10^{-7} \text{ s}$. $v_\parallel = 5.0 \times 10^5 \cos 60^\circ = 2.5 \times 10^5 \text{ m/s}$. Distance = $v_\parallel T = \mathbf{5.5 \text{ cm}}$.

Problem 20 Spot the errors

1. The magnetic force is always perpendicular to the velocity, so it changes the direction but

does no work. The speed and kinetic energy are **unchanged**.

2. $F = BIL \sin \theta$, and $\sin 0^\circ = 0$, so a wire parallel to the field feels **no force**. $F = 0.20 \times 3.0 \times 0.50 \times 0 = \mathbf{0\ N}$.