B14 · The motor effect

Completed notes

Find the direction and size of the magnetic force on a current-carrying wire, F = ILB.

Slide 1 of 7 · Why a wire in a field is pushed

A wire carries a huge number of moving charges, all moving the **same** way, so each feels the force in the same direction and the whole wire is pushed. This is the motor effect: **current in, force out**.

Conventional current is the way **positive** charge would move, so it points **opposite** to the electron flow. Every hand rule in this course uses conventional current.

Right-hand rule for a wire (the same rule as for one charge in B11): fingers along the **magnetic field**, thumb along the **conventional current**, **palm** shows the force. For electron flow, point the thumb along the **electrons** and the force comes out of the **back of the hand**.

Example: fingers into the page, thumb right, palm faces **up**, so the force on the wire is up the page. Reversing the field or the current flips the force; reversing both flips it **twice**.

Example. A wire carries conventional current from left to right through a magnetic field that points out of the page. In which direction is the magnetic force on the wire?

1. Fingers point out of the page (along B) and the thumb points right (along the current).

2. The palm faces down the page, so the force on the wire is down the page.

3. This is opposite to the case with the field into the page, as expected when the field is reversed.

Try it. A vertical wire in the plane of the page carries electrons moving down the page. The magnetic field points to the right across the page. Which way is the force on the wire: into the page, out of the page, left or right?

1. Electrons move down, so conventional current is up the page.

2. Fingers point right (along B) and the thumb points up (along the current).

3. The palm faces into the page, so the force on the wire is into the page.

Slide 2 of 7 · The size of the force: F = I L B

More current, more length in the field and a stronger field each give more force. They multiply: F = **I L⊥ B**, where L⊥ is the length **across the field**. Only the length **inside the field** counts.

Current is charge per time: I = **q ÷ t**, in amperes, where one ampere is **one coulomb per second**. Units: 1 T = **1 N/(A·m)**, so A × m × T gives **newtons**.

θ is the angle between the **wire** and the **field**, and L⊥ = **L sin θ**. As for velocity in B11, only the part across the field counts. At 90°, L⊥ = **L**.

Numerical questions often hide a step, such as finding I from **q and t**. Check that the angle is measured from the **field**, then decide sine or cosine. A picture settles it.

Example. 18 C of charge pass a point in a wire in 4.0 s. A 0.120 m length of the wire lies at right angles to a uniform magnetic field of 0.450 T. What is the current, and what is the size of the magnetic force on the wire?

1. I = q/t = 18 C ÷ 4.0 s = 4.5 A.

2. F = ILB = (4.5 A)(0.120 m)(0.450 T) = 0.243 N.

Try it. A straight wire of length 0.20 m carries 6.0 A through a magnetic field of 0.500 T, at 30° to the field direction. What is the size of the magnetic force on the wire?

1. The part of the length across the field is L sin 30° = (0.20 m)(0.500) = 0.10 m.

2. F = I(L sin θ)B = (6.0 A)(0.10 m)(0.500 T) = 0.300 N.

3. Check: at 90° the force would be 0.600 N, so 0.300 N at 30° is smaller, as it should be.

Slide 3 of 7 · Magnetic force against gravity

A wire in a field can feel the magnetic force and gravity at once. Gravity is **mg** downward; convert the mass from **grams** to kilograms. g = 9.81 **N/kg**, the same as 9.81 m/s².

If the two forces point opposite ways, **subtract** the sizes; the net force points the way of the larger force.

A wire that hangs still has net force **zero**, so ILB = **mg** and I = **mg ÷ (L B)**. “Suspended” and “hangs motionless” both mean net force zero. Size check: a weaker field needs a **larger** current.

Equal in size and opposite in direction is not the same as equal as **vectors**. A stationary wire can still have forces on it; they just **balance**.

Example. A horizontal wire of mass 1.40 g has 0.0900 m of its length in a horizontal magnetic field of 0.0500 T. The north pole is on the left, the south pole on the right, and the current is 4.00 A toward you. What are the magnetic force, the weight, and the net force on the wire?

1. Field points north to south, to the right. Fingers right, thumb toward you, palm faces up: the magnetic force is up.

2. Fm = ILB = (4.00)(0.0900)(0.0500) = 0.01800 N, up. Weight = mg = $(1.40 \times 10^{-3})(9.81)$ = 0.01373 N, down.

3. Forces are opposite: Fnet = 0.01800 − 0.01373 = 4.27×10^{-3} N, up.

Try it. The same wire (1.40 g, 0.0900 m in a 0.0500 T field) hangs still between the magnets with the current toward you. What current is needed to suspend it? Use g = 9.81 N/kg.

1. A wire at rest has Fnet = 0, so ILB = mg.

2. I = mg/(LB) = $(1.40 \times 10^{-3}$ kg)(9.81 N/kg)/[(0.0900 m)(0.0500 T)] = 3.05 A.

Slide 4 of 7 · Method: how to choose the tool for a wire in a field

Step 1: write what is **asked** and every **given**. Note if the wire is at **rest**.

Step 2: a current in a wire uses F = **ILB**. One moving charge uses F = **qvB**, from lesson B11.

Step 3: use only the length **in the field**, and L sin θ if the wire is **slanted**. Change grams to **kilograms**.

Step 4: right hand: fingers along the **field**, thumb along **conventional** current, palm shows the **force**. Electron flow? **Reverse** it first.

Step 5: gravity pulls **down** with mg. A wire at rest has Fnet = **0**, so ILB = **mg**. Otherwise subtract the smaller force from the larger.

Check: units A·m·T give **N**. Do the two forces point **opposite** ways? On the diploma: a wire at rest is **balanced**, not “without force”.

Example. A horizontal wire of mass 1.40 g hangs still between a north pole on the left and a south pole on the right. 0.0900 m of its length is in the field, the field is 0.0500 T and the current is toward you. What current holds the wire still, and which way is the magnetic force?

1. Step 1: asked I. Given m = 1.40 g, L = 0.0900 m, B = 0.0500 T. The wire is at rest.

2. Step 2: a current in a wire, so F = ILB, not qvB.

3. Step 3: the wire is at right angles to the field, so L = 0.0900 m. Change the mass: 1.40 g = 1.40×10^{-3} kg.

4. Step 4: the field points right, north to south. Fingers right, thumb toward you, palm up: the magnetic force is up and gravity is down.

5. Step 5: at rest, so Fnet = 0 and ILB = mg. mg = $(1.40 \times 10^{-3})(9.81) = 1.3734 \times 10^{-2}$ N. I = $1.3734 \times 10^{-2} \div [(0.0900)(0.0500)] = 3.052$ A, so I = 3.05 A.

Try it. NEW, for teacher review. A horizontal wire of mass 2.40 g has 0.150 m of its length in a horizontal field of 0.0800 T. The north pole is on the right, the south pole is on the left and the current is away from you. The wire hangs still. What is the current, and is the magnetic force up or down?

1. Step 1: asked I. Given m = 2.40 g, L = 0.150 m, B = 0.0800 T. The wire is at rest.

2. Steps 2 and 3: a current in a wire, so F = ILB. L = 0.150 m and 2.40 g = 2.40×10^{-3} kg.

3. Step 4: the field points left, north to south. Fingers left, thumb away from you, palm up: the magnetic force is up.

4. Step 5: at rest, so ILB = mg. mg = $(2.40 \times 10^{-3})(9.81) = 2.3544 \times 10^{-2}$ N.

5. I = $2.3544 \times 10^{-2} \div [(0.150)(0.0800)] = 1.962$ A, so I = 1.96 A.

Slide 5 of 7 · Reading a force graph

A wire rests on a balance and carries a current in a magnet’s field, so the magnetic force pushes **down**. The balance reads F = **I L B + mg**. Plot F against I and match it to y = (slope)x + (intercept), as in B5.

The slope is **L B** and the vertical intercept is **mg**, the force of gravity when the current is zero. The line does not start at zero because gravity always pulls **down**.

From the line: B = **slope ÷ L** and m = **intercept ÷ g**. Use kilograms for mass and tesla for field.

Pick two points **far apart**, not data points. Show the slope and intercept steps with **units**. To predict a reading use the equation of the line, because ILB alone leaves out the weight.

Example. A balance reading F against current I gives a straight line through P (0.80 A, 0.530 N) and Q (4.00 A, 0.786 N). The length of wire in the field is 0.120 m. Find the field strength B and the mass of the wire and supports.

1. Slope = (0.786 − 0.530)/(4.00 − 0.80) = 0.0800 N per A = LB, so B = 0.0800/0.120 = 0.667 T.

2. Intercept = 0.530 − (0.0800)(0.80) = 0.466 N = mg.

3. m = 0.466/9.81 = 4.75×10^{-2} kg.

Try it. Using the same line, F = (0.0800 N/A)I + 0.466 N, predict the balance reading when the current is 2.50 A.

1. Use the equation of the line, not ILB alone, because the weight is included.

2. F = (0.0800)(2.50) + 0.466 = 0.200 + 0.466 = 0.666 N.

3. Check: it lies between 0.530 N (0.80 A) and 0.786 N (4.00 A), so it is reasonable.

Slide 6 of 7 · Two wires, two forces

Each wire makes a field, and each sits in the other’s field. Do two steps: find the **field** of one wire at the other, then the **force** on the second wire.

Rule 1 (the field of a wire): grip with your right hand, **thumb** along the current; the fingers curl the way the field goes. For current up, the field on the right side of the wire is **into** the page.

Rule 2 (the force on a wire): fingers along the **field**, thumb along the **current**, **palm** shows the force.

Currents in the **same** direction attract; currents in **opposite** directions repel. The two forces are equal in size and opposite in **direction**.

Use the same-direction rule as a **check** on your answer. A slinky with current shrinks because neighbouring turns **attract**.

Example. Wire A carries conventional current up the page. Wire B, to its right, carries conventional current down the page. Do the wires attract or repel, and which way is the force on B?

1. The field of A at B is into the page (thumb up, right side).

2. B’s current is down, so the thumb points down and the fingers point into the page: the palm faces right.

3. The force on B is to the right, away from A, so currents in opposite directions repel.

Try it. Wire A carries conventional current down the page. Wire B, to its right, also carries conventional current down the page. Which way is the force on B, and do the wires attract or repel?

1. Thumb down on A: the field on the right side of A, at B, comes out of the page.

2. B’s current is down (thumb down), fingers out of the page: the palm faces left.

3. The force on B is left, toward A, so the wires attract (same-direction currents attract).

Slide 7 of 7 · How a motor’s coil turns

A motor is a **loop** of wire in a magnetic field. Each side of the loop is a wire in a field, so use the same rule: fingers along the **field**, thumb along the **current**, palm shows the force.

The two sides carry current in **opposite** directions, so the forces on them are **opposite**. One side is pushed into the page and the other out of the page, so the loop **turns**.

The top and bottom sides run **along** the field, so they feel **no** force.

After half a turn the sides swap places. The **commutator** (a split ring) reverses the **current** every half turn, so the loop keeps turning the **same** way.

More **current** or more **turns** of wire gives a larger force. Reverse the current, or the field, and the motor turns the **opposite** way.

Example. A rectangular loop sits between a north pole on the left and a south pole on the right, so the field points to the right. Conventional current goes down the left side of the loop and up the right side. (a) Which way is the force on the left side, and on the right side? (b) Does the loop turn the same way as it does with current up the left side, or the opposite way?

1. (a) Left side: fingers right, thumb down, so the palm faces out of the page. Right side: thumb up, so the palm faces into the page.

2. (b) Both forces have reversed, so the loop turns the opposite way. Reversing the current reverses a motor.

Try it. NEW, for teacher review: The same loop has conventional current up its left side and down its right side. The magnets are swapped, so the field now points to the left. Which way is the force on the left side, and on the right side?

1. Left side: fingers left, thumb up, so the palm faces out of the page.

2. Right side: fingers left, thumb down, so the palm faces into the page.

3. Reversing the field reverses both forces, so the motor turns the opposite way.

B14 · Worked practice

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Constants from the Alberta Physics 30 data sheets: $k = 8.99 \times 10^{9}$ N·m²/C², $e = 1.60 \times 10^{-19}$ C, electron mass $m_e = 9.11 \times 10^{-31}$ kg, proton mass $m_p = 1.67 \times 10^{-27}$ kg, $g = 9.81$ m/s².

Easy · B14-N01. A wire carries conventional current to the right through a magnetic field that points up the page. The magnetic force on the wire is

A. into the page
B. out of the page
C. up the page
D. to the right

1. Givens: I to the right; B up the page. Question: direction of the force.

2. Right hand: fingers up the page (along B), thumb right (along I). The palm faces out of the page.

3. Answer: B. out of the page

Easy · B14-N02. A 0.250 m length of wire carries 5.0 A at right angles to a magnetic field of 0.80 T. Find the magnetic force on the wire.

1. Givens: L = 0.250 m; I = 5.0 A; B = 0.80 T. Question: F.

2. F = ILB = (5.0)(0.250)(0.80) = 1.0 N.

3. Answer: 1.00 N

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Easy · B14-N03. 12 C of charge pass through a wire in 3.0 s. A 0.100 m length of the wire is at right angles to a field of 0.50 T. Find the magnetic force on that length.

1. Givens: q = 12 C; t = 3.0 s; L = 0.100 m; B = 0.50 T. Question: F.

2. I = q/t = 12 ÷ 3.0 = 4.0 A.

3. F = ILB = (4.0)(0.100)(0.50) = 0.20 N.

4. Answer: 0.200 N

Medium · B14-N04. A wire of mass 2.4 g has 0.100 m of its length at right angles to a field of 0.250 T. What current makes the magnetic force exactly balance gravity? Use g = 9.81 m/s².

1. Givens: m = 2.4 × 10^{-3} kg; L = 0.100 m; B = 0.250 T; g = 9.81 m/s². Question: I.

2. Balance: ILB = mg.

3. I = mg/(LB) = (2.4 × 10^{-3})(9.81) ÷ ((0.100)(0.250)) = 0.94 A.

4. Answer: 0.942 A

B14 · Worked practice

Medium · B14-N05. A wire of mass 1.40 g has 0.0900 m of its length in a field of 0.0500 T. A current of 4.00 A flows so that the magnetic force points down. Find the size of the net force on the wire.

1. Givens: m = 1.40 × 10^{-3} kg; L = 0.0900 m; B = 0.0500 T; I = 4.00 A; magnetic force down. Question: Fnet.

2. Magnetic: ILB = 0.0180 N down. Gravity: mg = 0.0137 N down.

3. Both point down, so add: 0.0317 N downward.

4. Answer: 0.0317 N

Medium · B14-N06. A graph of scale reading against current for a wire in a field gives the line F = 0.0800 I + 0.466 (F in newtons, I in amperes). What should the scale read at 5.5 A?

1. Givens: F = 0.0800 I + 0.466; I = 5.5 A. Question: F.

2. F = 0.0800(5.5) + 0.466 = 0.906 N.

3. 5.5 A should be within the measured current range for the prediction to be reliable.

4. Answer: 0.906 N

B14 · Worked practice

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Challenging · B14-N07. Two parallel wires carry currents in the same direction. Do they attract or repel? Explain using the field of one wire and the force on the other.

1. Givens: parallel wires, same direction. Question: attract or repel, and why.

2. Wire 1 makes a magnetic field at wire 2 (right-hand rule, thumb along the current).

3. The current in wire 2 is at right angles to that field, so by the right-hand rule the force on wire 2 points toward wire 1. The same argument gives the force on wire 1 toward wire 2: they attract.

Challenging · B14-N08. A horizontal wire of mass 5.00 g has 0.200 m of its length in a horizontal field of 0.150 T at right angles to the wire. What current holds the wire up, and what direction must the force have? Give the current in A. Use g = 9.81 m/s².

1. Givens: $m = 5.00 \times 10^{-3}$ kg; L = 0.200 m; B = 0.150 T; g = 9.81 m/s². Question: I (and the force direction).

2. The magnetic force must be upward and equal in size to the weight: ILB = mg.

3. $I = mg/(LB) = (5.00 \times 10^{-3})(9.81) \div ((0.200)(0.150)) = 1.64$ A.

4. Answer: 1.64 A