B15 · The generator effect and Lenz’s law

Completed notes

Explain how motion in a field separates charge, use ΔV = Blv, and apply Lenz’s law.

Slide 1 of 8 · A moving rod separates charge

The generator effect runs the motor effect backward: **motion in, electricity out**. Pulling a rod through a field pulls its **electrons** through the field too. Each feels a force.

Right hand: fingers along the **field**, thumb along the rod’s **velocity** (in B14 the thumb pointed along the current). The palm shows the force on a **positive** charge. **Reverse** it for electrons.

The electrons gather at one end, so that end is **negative**. The other end is **positive**.

Reverse the velocity or the field, and the polarity **flips**.

Example. A horizontal metal rod is pulled straight down the page through a magnetic field that points into the page. Which end of the rod, left or right, becomes positive?

1. For a positive charge: thumb down (velocity), fingers into the page (field), so the force is to the right.

2. Electrons are negative, so they are pushed to the left and gather at the left end.

3. The right end is positive.

Try it. A vertical rod is pulled to the right through a magnetic field that points out of the page. Which end, top or bottom, becomes positive, and how does this compare with the field into the page?

1. Fingers out of the page, thumb right: the palm faces down, so a positive charge is pushed down.

2. The electrons are pushed up, so the top end is negative and the bottom end is positive.

3. This is the opposite of the case with the field into the page.

Slide 2 of 8 · How large is the potential difference?

ΔV is the potential difference between the **two ends** of the rod. ΔV = **Blv**. B is the field (T), l is the rod length (m), v is the speed (m/s).

Faster rod, longer rod or stronger field: a **bigger** ΔV. 1 T × 1 m × 1 m/s = **1 V**. Example: (0.250 T)(0.40 m)(3.0 m/s) = **0.300 V**.

The equation is **not** on the data sheet. Write the rearranged form, such as v = **ΔV/(Bl)**, before the numbers.

For ratio questions, **multiply** the change factors. Never add them.

Example. A rod of length 0.60 m moves at right angles to a magnetic field of 0.150 T and to its own length. The potential difference between its ends is 0.90 V. What is the speed of the rod? (ΔV = Blv)

1. ΔV = Blv, so v = ΔV/(Bl).

2. v = 0.90 V ÷ [(0.150 T)(0.60 m)] = 10.0 m/s.

Try it. A rod moving through a field produces a potential difference ΔV. A second rod has twice the length, moves at half the speed, and is in a field three times as strong. What is its potential difference? A. ΔV/3 B. ΔV C. 3ΔV D. 6ΔV

1. ΔV is proportional to Blv. The factors are 2 for the length, ½ for the speed and 3 for the field.

2. 2 × ½ × 3 = 3, so the new potential difference is 3ΔV.

3. Answer C.

Slide 3 of 8 · Closing the circuit

The rod slides on two **rails** (parallel metal bars) with a **resistor** (a part that uses electrical energy, like a lamp) joining the ends. The rod acts like a **battery**.

Conventional current leaves the **positive** end, goes round the circuit and returns to the **negative** end. Inside the rod it goes from negative to positive.

Find the ends first (right hand, then reverse). Then **follow** the current: clockwise or counterclockwise.

Reverse the velocity or the field, and the current **reverses**.

Example. A rod slides on two rails. A resistor joins the right-hand ends of the rails, and the magnetic field points into the page. When the rod is pulled to the right the top end is positive and the current is clockwise. Now the rod is pulled to the left. Does conventional current go clockwise or counterclockwise?

1. With the rod moving left, the force on the electrons is up, so they gather at the top: the bottom end is positive.

2. Conventional current leaves the bottom end and goes the opposite way round from the earlier case: counterclockwise.

Try it. Same rails and rod, but the field now points out of the page and the rod is pulled to the right. Does conventional current go clockwise or counterclockwise, and which end of the rod is positive?

1. Fingers out of the page, thumb right: the palm faces down, so a positive charge is pushed down and the electrons are pushed up.

2. The bottom end is positive.

3. Conventional current leaves the bottom end and flows counterclockwise.

Slide 4 of 8 · A magnet and a coil

A coil can do it too. When a magnet and a coil move **relative** to each other, the electrons in the coil feel a force. This is electromagnetic **induction**. Michael **Faraday** discovered it in 1831.

Current flows only **while** they move. A magnet held still gives **zero** current.

Reverse the motion or the pole, and the current **reverses**.

Faster, a stronger magnet or more turns gives **more** current. Four times the turns gives about **four times** the current.

Example. Pushing the south pole of a bar magnet into a coil at a steady speed deflects the meter needle to the right. Predict the needle for (a) pulling the same pole out at the same speed, (b) pushing the north pole in at the same speed, (c) pushing the south pole in twice as fast, and (d) holding the magnet still inside the coil.

1. (a) Pulling out reverses the motion, so the needle goes left.

2. (b) Pushing the north pole in reverses the pole, so the needle goes left.

3. (c) Twice as fast: same direction (right) with a larger deflection, about twice.

4. (d) A magnet held still gives no current, so the needle stays at zero.

Try it. Pushing the south pole into a coil at a steady speed gives a deflection of 2 divisions to the right. Predict the needle if the same pole is pushed in at half the speed into a coil with four times as many turns.

1. Same pole and same direction of motion, so the needle goes right.

2. Half the speed gives half the size; four times the turns gives four times the size: 4 × ½ = 2 times.

3. The deflection is about 4 divisions to the right.

Slide 5 of 8 · Motors and generators

A motor and a generator are the same device used both ways. Motor: electricity in, **motion** out. Generator: motion in, **electricity** out.

Name the energy change: motion to **electricity**, or the reverse.

A generator joined to a lamp is **harder** to turn. Its current is in a field, so it feels a force that **resists** the turning.

With nothing connected there is no **current**, so no force. The extra **work** you do goes into the lamp’s energy.

Example. A hand-cranked generator is easy to turn when its wires are not connected to anything, and noticeably harder when it is connected to a lamp that lights. Explain why it is harder when connected, and where the extra energy goes.

1. With the circuit open there is no current, so there is no magnetic force on the coil and it turns easily.

2. With the lamp connected there is a current in a magnetic field, so there is a magnetic force that resists the turning.

3. The extra work you do against that force becomes the lamp’s energy.

Try it. A small toy motor is spun by hand with its two wires joined to a lamp, and the lamp lights. Is the device acting as a motor or a generator? Name the energy change.

1. It is acting as a generator: the coil is turned in a field, so the generator effect gives a voltage and a current.

2. Energy change: motion (kinetic energy from your hand) to electrical energy, which the lamp changes to light and heat.

Slide 6 of 8 · Lenz’s law: the force opposes the motion

A moving magnet makes currents in a conductor. A current made by motion in a field, with no battery, is an **induced** current. It feels a **force**, and the force acts on the magnet.

Lenz’s law: the force from an induced current **opposes** the motion that caused it. A magnet falling feels a force **up**.

Chain: motion → **induced current** → **opposing force** → slower fall. No current means **no** force. A better conductor carries a **larger** current.

The force always opposes the motion. It takes energy **away**.

In air the magnet falls 0.30 m in **0.25 s**. In the aluminium tube it takes **2–3 s**.

Example. Three rods of the same size, one plastic, one aluminium and one copper, each have a ring magnet dropped over them from the same height. Copper conducts better than aluminium; plastic is an insulator. Order the rods from fastest fall to slowest and explain.

1. Plastic is fastest. It is an insulator, so there is no induced current, no force and the magnet falls as if the rod were not there.

2. Aluminium is slower: it carries induced currents that give an opposing force.

3. Copper is slowest: it is the better conductor, so the current and the opposing force are largest.

Try it. A pendulum with a strong magnet at its end swings between two aluminium blocks and is moving to the right through its lowest point. What is the direction of the magnetic force on the magnet right now, what happens to the swing over time, and does this force’s direction change when it swings back to the left?

1. Moving right, the force on the magnet is to the left, opposing the motion.

2. The swing dies away quickly, because the force always opposes the motion and removes energy.

3. When it swings left the force is to the right: the direction changes with the motion, but it always opposes it.

Slide 7 of 8 · Lenz’s law for a coil: which way the current goes

An induced current turns a coil into a **magnet**. By Lenz’s law, that magnet **opposes** the motion that caused the current.

Step 1: which way is the magnet **moving**? Step 2: which pole opposes that? A magnet moving closer must be **repelled**, so the near end is the **same** pole. A magnet moving away must be **attracted**, so the near end is the **opposite** pole.

Step 3: the field inside a coil points toward its **north** end. Grip a wire on the **front** of the coil with the right hand, thumb along the conventional current. The fingers inside the coil show the field.

Thumb up puts the field inside to the **left**. Thumb down puts it to the **right**. Reverse the motion and the pole and the current both **reverse**.

Example. A coil is joined to a meter in a closed circuit. The north pole of a bar magnet is pushed toward the right end of the coil. (a) Which pole does the right end of the coil become? (b) Which way does the conventional current go in the wires on the front of the coil, up or down? (c) The magnet is then pulled back out. What happens to the pole and to the current?

1. (a) The magnet is moving closer, so the coil must repel it. The right end becomes a north pole.

2. (b) The field inside the coil points right, toward the north end. Thumb down on a front wire puts the fingers pointing right inside the coil, so the current in the front wires is down.

3. (c) The coil must now attract the magnet, so the right end becomes a south pole and the current reverses to up.

Try it. NEW, for teacher review: The south pole of a bar magnet is pushed toward the left end of a coil in a closed circuit. Which pole does the left end of the coil become, and which way does the conventional current go in the wires on the front of the coil?

1. The magnet is moving closer, so the coil must repel it. The left end becomes a south pole, so the right end is the north pole.

2. The field inside the coil points right, toward the north end.

3. Thumb down on a front wire puts the fingers pointing right inside the coil, so the current in the front wires is down.

Slide 8 of 8 · Method: how to find an induced voltage and its direction

Step 1: list v, B and l with units: **m/s**, **T**, **m**. All at **right angles**.

Step 2: ΔV = **Blv**. Keep every digit. The unit is **volts**.

Step 3: right hand, then reverse for electrons. They gather at the **negative** end. The other end is **positive**.

Step 4: current leaves the **positive** end. Step 5: **Lenz's law**: the force on the rod **opposes** v. Reverse v or B, and every direction **flips**.

Example. A 0.40 m rod is pulled to the right at 3.0 m/s through a field of 0.250 T that points into the page. The rod is part of a closed circuit with a resistor on the right. Find the potential difference, the positive end, the direction of the current and the direction of the force on the rod.

1. Step 1: v = 3.0 m/s to the right, B = 0.250 T into the page, l = 0.40 m.

2. Step 2: ΔV = Blv = (0.250)(0.40)(3.0) = 0.300 V.

3. Step 3: fingers into the page, thumb right: the palm faces up, so the electrons are pushed down. The bottom end is negative and the top end is positive.

4. Step 4: current leaves the top end, goes along the top rail, down through the resistor and back along the bottom rail: clockwise.

5. Step 5: in the rod the current goes up, so the palm faces left. The force on the rod is to the left, opposite to v. Lenz's law agrees.

Try it. A 0.60 m rod is pulled to the left at 2.0 m/s through a field of 0.500 T that points into the page. The rod is part of a closed circuit with a resistor on the right. Find the potential difference, the positive end, the direction of the current and the direction of the force on the rod. Write each step number beside your work.

1. Step 1: v = 2.0 m/s to the left, B = 0.500 T into the page, l = 0.60 m.

2. Step 2: ΔV = Blv = (0.500)(0.60)(2.0) = 0.600 V.

3. Step 3: fingers into the page, thumb left: the palm faces down, so the electrons are pushed up. The top end is negative and the bottom end is positive.

4. Step 4: current leaves the bottom end, goes right along the bottom rail, up through the resistor and back along the top rail: counterclockwise.

5. Step 5: in the rod the current goes down, so the palm faces right. The force on the rod is to the right, opposite to v. Lenz's law agrees.

B15 · Worked practice

The generator effect and Lenz’s law | Questions 1-2 of 8

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 · B15-N01. What is the difference between the motor effect and the generator effect?

1. Givens: none. Question: the difference.

2. Motor effect: a current in a magnetic field gives a force (electrical energy into motion).

3. Generator effect: motion in a magnetic field gives a potential difference (motion into electrical energy).

Easy · B15-N02. A vertical rod is pulled to the right through a magnetic field that points into the page. Which end of the rod becomes positive?

A. The top end
B. The bottom end
C. The left end
D. Neither end

1. Givens: rod vertical; v right; B into the page. Question: which end is positive.

2. Treat the charges in the rod as moving right in the field. For a positive charge moving right in a field into the page, the force is up (right-hand rule from B11).

3. Positive charge is pushed to the top, so the top end is positive.

4. Answer: A. The top end

B15 · Worked practice

Easy · B15-N03. A 0.80 m rod moves at 5.0 m/s at right angles to a field of 0.040 T and to its own length. Find the potential difference between its ends.

1. Givens: l = 0.80 m (the length of the rod); v = 5.0 m/s; B = 0.040 T. Question: ΔV.

2. ΔV = Blv = (0.040)(0.80)(5.0) = 0.16 V.

3. Answer: 0.160 V

Medium · B15-N04. A 0.50 m rod moves at 12 m/s at right angles to a 0.25 T field. What potential difference appears between its ends?

1. Givens: l = 0.50 m (the length of the rod); v = 12 m/s; B = 0.25 T. Question: ΔV.

2. ΔV = Blv = (0.25)(0.50)(12) = 1.5 V.

3. Answer: 1.50 V

B15 · Worked practice

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Medium · B15-N05. A magnet is pushed into a coil and the meter shows a current. List three changes that would make the current larger.

1. Givens: magnet and coil with a meter. Question: three ways to increase the current.

2. Push the magnet in faster.

3. Use a stronger magnet.

4. Use a coil with more turns (also: a coil with a smaller resistance).

Medium · B15-N06. Why is a generator harder to turn when it is connected to a lamp?

A. The induced current gives a magnetic force that opposes the motion.
B. The lamp makes the magnet heavier.
C. The lamp removes the magnetic field.
D. The coil stops being a conductor.

1. Givens: generator, with and without a lamp. Question: why harder to turn.

2. With the lamp, there is a closed circuit and a current. The current in the field feels a force that opposes the motion (Lenz’s law).

3. The extra work you do becomes the electrical energy in the lamp.

4. Answer: A. The induced current gives a magnetic force that opposes the motion.

B15 · Worked practice

Challenging · B15-N07. A magnet is dropped from rest through 0.30 m in air. Find the free-fall time. Then compare it with 2–3 s for the same magnet inside a vertical aluminium tube. Use g = 9.81 m/s². Give the free-fall time in seconds.

1. Givens: $\Delta d = 0.30$ m; $v_0 = 0$; $a = 9.81$ m/s². Question: t in free fall; comparison with the tube.

2. $t = \sqrt{(2\Delta d/a)} = \sqrt{(2(0.30) \div 9.81)} = 0.25$ s.

3. In the tube the fall takes about ten times longer. The moving magnet induces currents in the aluminium and their magnetic force opposes the fall (Lenz’s law).

4. Answer: 0.247 s

Challenging · B15-N08. A magnet is dropped through a plastic tube, an aluminium tube and a copper tube of the same size. Rank the fall times from shortest to longest and explain.

1. Givens: three tubes, same size. Question: rank the times and explain.

2. Plastic < aluminium < copper.

3. Plastic is an insulator, so no current is induced and the magnet falls freely. Aluminium and copper are conductors, so currents are induced and the force opposes the fall. Copper is the better conductor (lower resistance), so its current and the opposing force are larger, so the fall is slowest.