Week 44

A-Level Physics

Homework bundle for this week

本周作业合集

exercises.lol

Contents 目录

A-Level Physics Name: ____________ Score: ______

1. A magnetic field is a region where:
   - ☐ a moving charge or current feels a force
   - ☐ any mass feels a force
   - ☐ light always bends
   - ☐ sound travels faster

2. The force on a current-carrying wire in a magnetic field is:
   - ☐ $BIL\sin\theta$
   - ☐ $\frac{BI}{L}$
   - ☐ BIL^2
   - ☐ $\frac{BL}{I}$

3. A 2.0 C charge moves at 3.0 $\frac{\text{m}}{\text{s}}$ at right angles to a 0.50 T field. What is the force?

   ____________ N

4. The magnetic field around a long straight wire forms:
   - ☐ circles around the wire
   - ☐ straight lines along the wire
   - ☐ a single point
   - ☐ no field at all

5. The magnetic flux through an area A at right angles to a field B is:
   - ☐ BA
   - ☐ $\frac{B}{A}$
   - ☐ BA^2
   - ☐ $B + A$

6. A magnetic field is a region in which a force acts on which of these? Select **all** that apply.
   - ☐ a moving charge
   - ☐ a current-carrying conductor
   - ☐ a magnetic material

☐ a stationary charge

Tick every correct option.

7. The force on the wire is zero when it lies along the field.

☐ True ☐ False

8. For motion at right angles, the magnetic force on a moving charge is $F = BQ$______.

____

9. The right-hand grip rule gives the direction of the field around a current-carrying wire.

☐ True ☐ False

10. A 0.50 m^2 coil sits at right angles to a 0.20 T field. What is the flux?

________________ Wb

A-Level Physics

1. **a moving charge or current feels a force**

   Magnetic forces act only on **moving** charges (and currents) — a charge at rest feels nothing.

2. $BIL\sin\theta$

   Largest when the wire is perpendicular to the field ($\sin 90° = 1$, so $F = BIL$).

3. **3 N**

   $F = BQv = 0.50 \times 2.0 \times 3.0 = 3.0$ N.

4. **circles around the wire**

   Concentric circles, with the direction given by the right-hand grip rule.

5. BA

   $\Phi = BA$ (weber). For a coil of N turns the flux linkage is $N\Phi$.

6. **a moving charge; a current-carrying conductor; a magnetic material**

   A stationary charge feels no magnetic force at all, which is exactly what distinguishes a magnetic field from an electric one.

7. **True**

   With the wire parallel to the field, $\theta = 0$ and $\sin\theta = 0$, so there is no force.

8. **v**

   $F = BQv$ — proportional to the charge's speed.

9. **True**

   Thumb along the current, curled fingers show the way the circular field points.

10. **0.1 Wb**

   $\Phi = BA = 0.20 \times 0.50 = 0.10$ Wb.

A-LEVEL PHYSICS • EXERCISE SHEET

20.1 Concept of a magnetic field

Name: ____________ Class: ________ Date: __________ **Total: 20 marks**

KEY WORDS magnetic field 磁场 • field line 场线 • force 力 • bar magnet 条形磁铁 • permanent magnet 永磁体

Objective

Build the skills to answer exam questions on the **magnetic field** — its sources and field lines.

You must be able to:

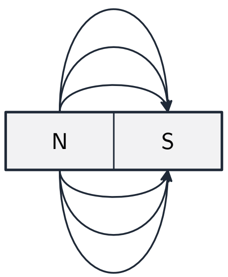
- state what produces a magnetic field
- represent a magnetic field with **field lines**

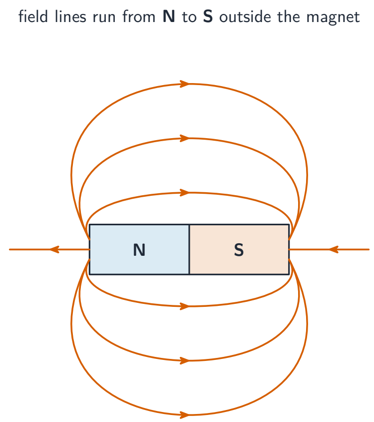
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ Magnetic fields

A **magnetic field** is a region where a moving charge or current feels a force. It is produced by **moving charges (currents)** or **permanent magnets**.





The field of a bar magnet

- field lines run **N to S** outside a magnet (closed loops);
- they **never cross**; **closer lines** → **stronger field**.

2 Practice

Now apply the methods above.

2.1 State **two** things that can produce a magnetic field. [1]

2.2 State the direction of the field lines **outside** a bar magnet. [1]

2.3 State what **closer** field lines indicate. [1]

3 Exam-style questions

3.1 Magnetic field lines **outside** a bar magnet point from: [1]

- **A** S to N
- **B** N to S
- **C** N to N
- **D** nowhere

3.2 Sketch the magnetic field lines around a bar magnet. [2]

3.3 State **two** ways a magnetic field can be produced. [2]

3.4 A long, straight vertical wire carries a current of 5.0 A **into** the page. A second parallel wire, 0.040 m away, carries 3.0 A in the **same** direction. The flux density produced by the first wire at the position of the second is 2.5×10^{-5} T.

(a) **State** what is meant by a **magnetic field**. [2]

(b) In the space below, **draw** four field lines to represent the magnetic field around the first wire, and **mark** the direction of the field. [3]

(c) **Calculate** the magnetic force per unit length exerted on the second wire. [2]

(d) **State**, with a reason, the direction of that force. [2]

(e) The flux density produced by the **second** wire at the position of the first is 1.5×10^{-5} T. **Determine** the force per unit length on the first wire, and **explain** your reasoning. [3]

Solutions

Each answer shows the steps, then the **result**.

2.1

- **moving charges (currents)** and **permanent magnets**

2.2

- from **N to S**

2.3

- a **stronger** magnetic field

3.1 B

- outside a magnet, field lines run **N to S**

3.2

- curved lines from **N to S** outside the magnet
- closer together near the **poles**

3.3

- a **current** (moving charges) in a wire
- a **permanent magnet**

3.4

(a) a region in which a **force** is experienced by a moving charge, a current-carrying conductor or a magnetic pole

(b) four **concentric circles** centred on the wire

- drawn with the spacing **increasing** with distance, because the field weakens as $1/r$
- arrows **clockwise**, from the right-hand grip rule with the current into the page

(c) $F/L = BI$

$$\frac{F}{L} = (2.5 \times 10^{-5}\ \text{T})(3.0\ \text{A}) = \mathbf{7.5 \times 10^{-5}}\ \text{N m}^{\mathbf{-1}}$$

(d) the force is **towards** the first wire, i.e. the two wires **attract**

- currents in the same direction attract; applying the left-hand rule with the field of one wire and the current in the other gives a force pointing along the line joining them

(e) by **Newton's third law** the forces on the two wires are equal in magnitude and opposite in direction

- so the force per unit length on the first wire is also 7.5×10^{-5} N m^{-1}
- check: $BI = (1.5 \times 10^{-5}\ \text{T})(5.0\ \text{A}) = 7.5 \times 10^{-5}$ N m^{-1} — a smaller field acting on a larger current gives the same product

6 (a) State what is meant by a magnetic field.

....

....

.... [2]

(b) A long, straight wire P carries a current into the page, as shown in Fig. 6.1.

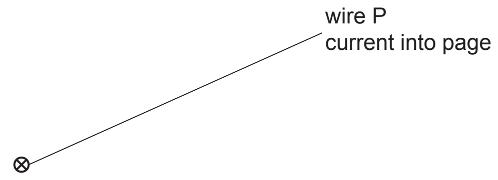


Fig. 6.1

On Fig. 6.1, draw four field lines to represent the magnetic field around wire P due to the current in the wire. [3]

(c) A second long, straight wire Q, carrying a current of 5.0A out of the page, is placed parallel to wire P, as shown in Fig. 6.2.

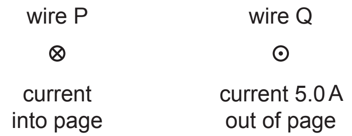


Fig. 6.2

The flux density of the magnetic field at wire Q due to the current in wire P is 2.6 mT.

(i) Calculate the magnetic force per unit length exerted on wire Q by wire P.

force per unit length = ... N m^{-1} [2]

(ii) State the direction of the force exerted on wire Q by wire P.

.... [1]

(iii) The flux density of the magnetic field at wire P due to the current in wire Q is 1.5 mT.

Determine the magnitude of the current in wire P. Explain your reasoning.

current = ... A [2]

[Total: 10]

6 A rectangular coil PQRS of wire is free to rotate about its axis XY, as shown in Fig. 6.1.

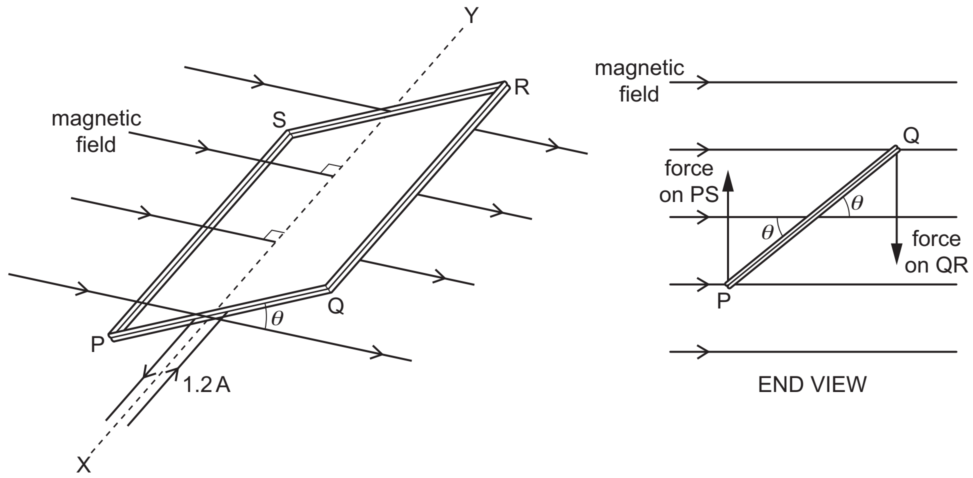


Fig. 6.1 (not to scale)

The coil has length QR of 5.4 cm, width PQ of 2.5 cm and has 190 turns of wire.
The plane of the coil is at an angle θ to a uniform magnetic field of flux density 5.2×10^{-3} T.
The axis XY of the coil is normal to the field.
The current in the coil is 1.2 A.

(a) **(i)** Calculate the magnitude of the force on side QR of the coil.

force = ... N [3]

(ii) Use your answer in **(a)(i)** to show that the torque τ on the coil is given by

$$\tau = 1.6 \times 10^{-3} \cos\theta \text{ N m}.$$

[2]

(iii) Using the expression in **(a)(ii)** sketch, on the axes of Fig. 6.2, a graph to show the variation of the torque τ with angle θ for values of θ between 0 and 360°. Label the τ axis with an appropriate scale.

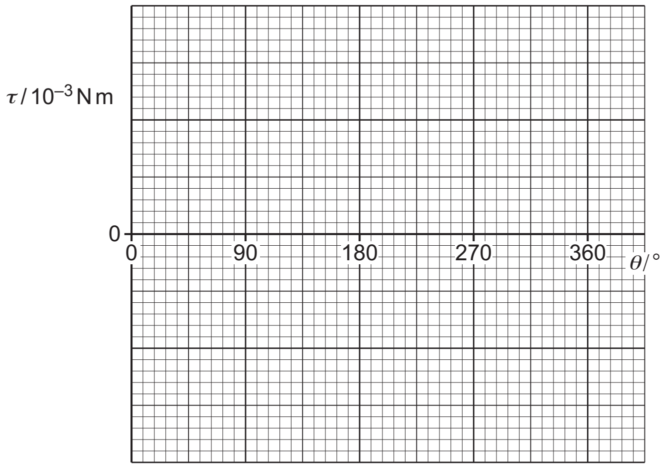


Fig. 6.2

[3]

(b) The coil is now replaced by an identical coil wound on a ferrous core.

Suggest, with a reason, how the torque on this coil compares with the torque on the original coil.

....

....

.... [2]

[Total: 10]

A-LEVEL PHYSICS • EXERCISE SHEET

20.2 Force on a current-carrying conductor

Name: ______________ Class: __________ Date: ____________ **Total: 23 marks**

KEY WORDS magnetic flux density 磁通密度 • magnetic flux 磁通量 • fleming's left-hand rule 弗莱明左手定则 • magnetic field 磁场 • tesla 特斯拉

Objective

Build the skills to answer exam questions on the **force on a current-carrying conductor**.

You must be able to:

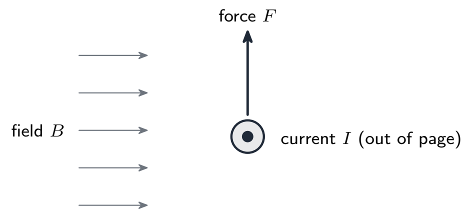
- use $F = BIL\sin\theta$ and **Fleming's left-hand rule**
- define **magnetic flux density**

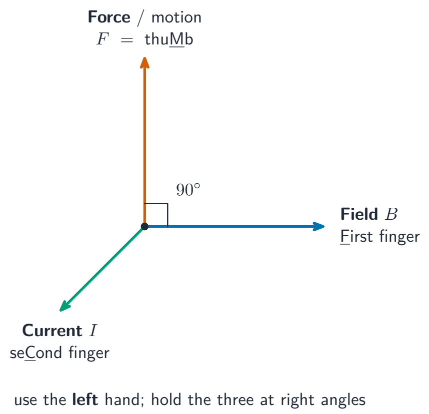
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

■ The motor effect

A current in a wire in a magnetic field feels a force, perpendicular to both:





Fleming left-hand rule for the motor force

$$F = BIL\sin\theta,$$

where θ is the angle between wire and field. The force is **maximum** at 90° ($F = BIL$) and **zero** when the wire is along the field. **Fleming's left-hand rule:** thuMb = Motion/force, First finger = Field, seCond finger = Current.

Magnetic flux density B is defined as the **force per unit current per unit length** on a wire at right angles to the field (unit: **tesla**, T).

Worked example. 0.20 m wire, 3.0 A, $B = 0.50$ T at 90°: $F = BIL = 0.50 \times 3.0 \times 0.20 = 0.30$ N.

2 Practice

Now apply the methods above.

2.1 Write $F = BIL\sin\theta$ and state what each symbol means. [2]

2.2 A 0.20 m wire carries 3.0 A at right angles to a 0.50 T field. Find the **force**. [2]

2.3 Define **magnetic flux density**. [1]

2.4 State the three quantities in **Fleming's left-hand rule**. [1]

3 Exam-style questions

3.1 The force on a current-carrying wire is **maximum** when the wire is: [1]

- **A** parallel to the field
- **B** at 45° to the field
- **C** at 90° to the field
- **D** removed from the field

3.2 A wire of length 0.15 m carries 4.0 A at right angles to a 0.30 T field. Calculate the **force**. [2]

3.3 State what happens to the force when the wire is **parallel** to the field. [1]

3.4 A wire carries current **out of the page** in a field pointing **to the right**. Use Fleming's left-hand rule to find the **direction of the force**. [2]

3.5 A straight horizontal wire of length 8.0 cm lies on a top-pan balance, at right angles to a uniform horizontal magnetic field. When a current of 2.4 A passes through the wire, the balance reading **increases** by 1.6 g.

(a) **Explain** why the balance reading changes when the current is switched on. [2]

(b) **Determine** the force on the wire. [2]

(c) **Determine** the magnetic flux density of the field. [2]

(d) **State** what happens to the balance reading if (i) the current is reversed, and (ii) the wire is turned so that it lies **along** the field. [2]

(e) The current is now increased in steps and the change in balance reading recorded each time. **State** what a graph of the change in reading against current would look like, and **explain** how its gradient could be used to find the flux density. [3]

Solutions

Each answer shows the steps, then the **result**.

2.1

- $F = BIL\sin\theta$
- F = force, B = flux density, I = current, L = length, θ = angle between wire and field

2.2

- $F = BIL$

$$F = (0.50\ \text{T})(3.0\ \text{A})(0.20\ \text{m}) = \mathbf{0.30}\ \text{N}$$

2.3

- the **force per unit current per unit length** on a wire placed at **right angles** to the field

2.4

- **force (motion)**, **field**, **current**

3.1 C

- F is maximum when the wire is **at** $90°$ **to the field**

3.2

- $F = BIL$

$$F = (0.30\ \text{T})(4.0\ \text{A})(0.15\ \text{m}) = \mathbf{0.18}\ \text{N}$$

3.3

- the force is **zero** ($\sin 0° = 0$)

3.4

- first finger = field (right), second finger = current (out of page)
- the thumb points **upwards**, so the force is **upward**

3.5

(a) the current-carrying wire in a magnetic field experiences a force $F = BIL$

- by Newton's third law the wire pushes back on the magnet with an equal and opposite force, and here that push is **downwards** on the balance, so the reading rises

(b) $F = mg$

$$F = (1.6 \times 10^{-3}\ \text{kg})(9.81\ \text{m s}^{-2}) = \mathbf{1.6 \times 10^{-2}}\ \text{N}$$

(c) $F = BIL$, so $B = F/(IL)$

$$B = \frac{1.57 \times 10^{-2}\ \text{N}}{(2.4\ \text{A})(0.080\ \text{m})} = \mathbf{8.2 \times 10^{-2}}\ \text{T}$$

(d) (i) the force reverses, so the reading **decreases** by the same 1.6 g instead

(ii) with the wire **along** the field the force is **zero** ($\theta = 0$ in $F = BIL\sin\theta$), so the reading returns to its original value

(e) a **straight line through the origin**

- because $F \propto I$ when B and L are fixed
- the gradient of force against current is BL, so dividing the gradient by the length L gives the flux density B

7 **(a)** Define magnetic flux density.

....

....

.... [2]

(b) A particle of mass m and charge $+Q$ moves at speed v into a region where there is a uniform magnetic field, as shown in Fig. 7.1.

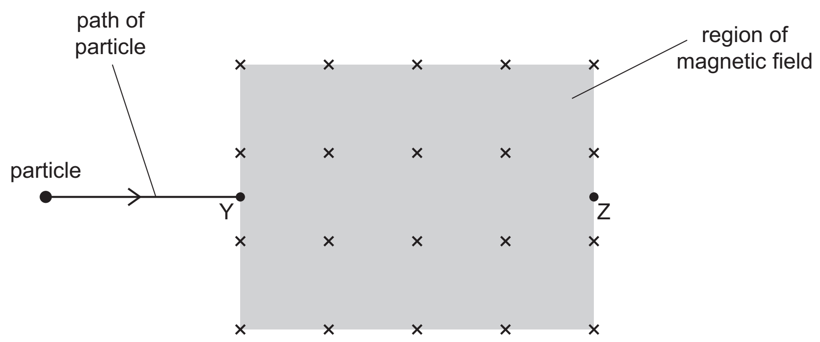


Fig. 7.1

The uniform magnetic field is into the page and has flux density B. The particle enters the region of the field at point Y.

(i) State an expression, in terms of some or all of m, Q, B and v, for the magnetic force F that acts on the particle when it is at point Y.

F = ... [1]

(ii) On Fig. 7.1, draw an arrow at point Y to indicate the direction of the force in **(b)(i)**. [1]

(iii) On Fig. 7.1, draw a line to show a possible path for the particle through the region of the magnetic field. [1]

(c) (i) Explain how an electric field can be used with the magnetic field to ensure that the particle in **(b)** now passes through point Z.

....

....

....

....

.... [3]

(ii) Derive an expression for v in terms of B and the electric field strength E.

v = ... [2]

[Total: 10]

6 A rectangular coil PQRS of wire is free to rotate about its axis XY, as shown in Fig. 6.1.

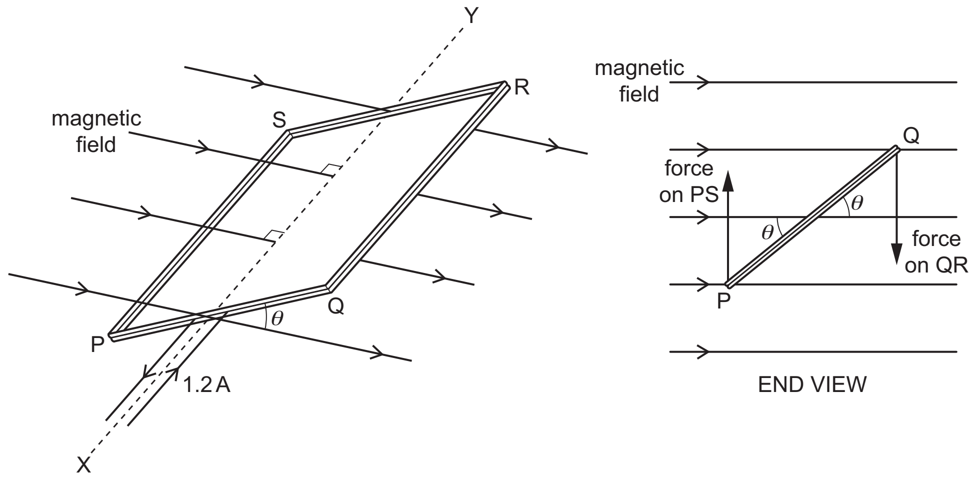


Fig. 6.1 (not to scale)

The coil has length QR of 5.4 cm, width PQ of 2.5 cm and has 190 turns of wire.
The plane of the coil is at an angle θ to a uniform magnetic field of flux density 5.2×10^{-3} T.
The axis XY of the coil is normal to the field.
The current in the coil is 1.2 A.

(a) (i) Calculate the magnitude of the force on side QR of the coil.

force = ... N [3]

(ii) Use your answer in **(a)(i)** to show that the torque τ on the coil is given by

$$\tau = 1.6 \times 10^{-3} \cos\theta \text{ N m}.$$

[2]

(iii) Using the expression in **(a)(ii)** sketch, on the axes of Fig. 6.2, a graph to show the variation of the torque τ with angle θ for values of θ between 0 and 360°. Label the τ axis with an appropriate scale.

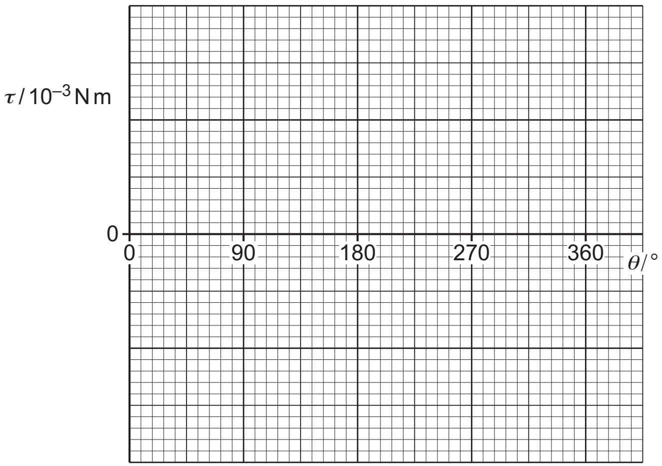


Fig. 6.2

[3]

(b) The coil is now replaced by an identical coil wound on a ferrous core.

Suggest, with a reason, how the torque on this coil compares with the torque on the original coil.

....

....

.... [2]

[Total: 10]

6 **(a)** Define magnetic flux density.

....

....

....

.... [2]

(b) Electrons are moving in a vacuum with speed 1.7×10^7 m s^{-1}. The electrons enter a uniform magnetic field of flux density 4.8 mT. Fig. 6.1 shows the path of the electrons.

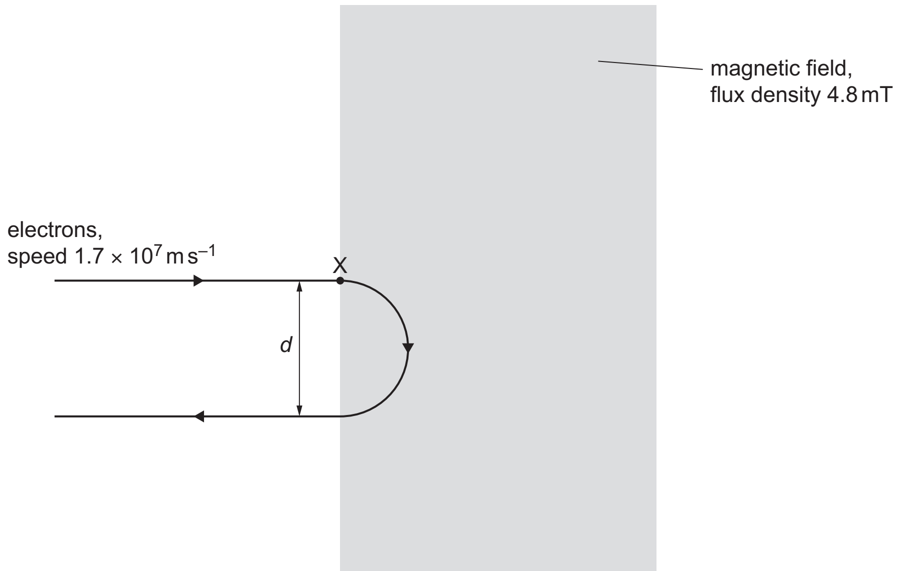


Fig. 6.1

The path of the electrons remains in the plane of the page.

(i) State the direction of the magnetic field.

....

.... [1]

(ii) Show that the magnitude of the force exerted on each electron by the magnetic field is 1.3×10^{-14} N.

[2]

(iii) On Fig. 6.1, draw an arrow to indicate the direction of the centripetal acceleration of the electron where it enters the magnetic field at point X. [1]

(iv) Use the information in **(b)(ii)** to calculate the distance *d* between the path of the electrons entering the magnetic field and the path of the electrons leaving it.

d = ... m [3]

(c) The electrons in **(b)** are replaced with positrons that are moving with speed $3.4 \times 10^{7}\,\mathrm{m\,s^{-1}}$ along the same initial path as the electrons.
The positrons enter the magnetic field at point X on Fig. 6.1.

On Fig. 6.1, draw a line to show the path of the positrons through the magnetic field. [3]

[Total: 12]

A-LEVEL PHYSICS • EXERCISE SHEET

20.3 Force on a moving charge

Name: ____________ Class: ________ Date: __________ **Total: 26 marks**

KEY WORDS velocity 速度 • velocity selector 速度选择器 • uniform field 匀强场 • hall voltage 霍尔电压 • magnetic field 磁场

Objective

Build the skills to answer exam questions on the **force on a moving charge** in a magnetic field.

You must be able to:

- use $F = BQv\sin\theta$ and find the force direction
- describe the **circular motion** of a charge in a uniform field
- explain the **Hall voltage** and **velocity selection**

1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

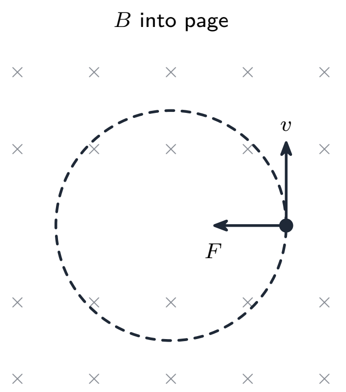
■ **Force on a moving charge**

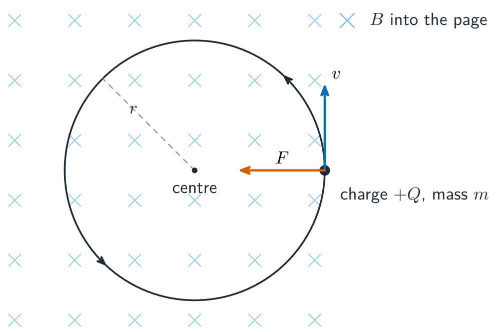
$$F = BQv\sin\theta.$$

Maximum when v is at right angles to B; zero when v is along B.

■ **Circular motion**

A charge moving **perpendicular** to a uniform field feels a force at right angles to v — so it moves in a **circle** at constant speed (the force does **no work**):





$$BQv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{BQ}$$

A moving charge curves in a magnetic field

Set magnetic force = centripetal force: $BQv = \dfrac{mv^2}{r}$, so $r = \dfrac{mv}{BQ}$.

A **velocity selector** uses crossed electric and magnetic fields: only charges with $v = E/B$ (where the forces balance) pass straight through.

2 Practice

Now apply the methods above.

2.1 Write the equation for the force on a moving charge. [1]

2.2 A charge of 1.6×10^{-19} C moves at 2.0×10^{6} m s^{-1} at right angles to a 0.50 T field. Find the force. [2]

2.3 State the **path** of a charge moving perpendicular to a uniform magnetic field. [1]

2.4 State **why** the magnetic force does **no work** on the moving charge. [1]

3 Exam-style questions

3.1 A charged particle moving **perpendicular** to a uniform field follows: [1]

- **A** a straight line
- **B** a parabola
- **C** a circle
- **D** a spreading spiral

3.2 An electron ($m = 9.1 \times 10^{-31}$ kg, $q = 1.6 \times 10^{-19}$ C) moves at 3.0×10^{6} m s^{-1} at right angles to a 0.020 T field. Calculate the **radius** of its circular path. [3]

3.3 Explain why the **speed** of the particle stays constant. [2]

3.4 Describe how a **velocity selector** selects charges of one particular speed. [2]

3.5 A narrow beam of electrons, each of charge -1.60×10^{-19} C and mass 9.11×10^{-31} kg, enters a region of uniform magnetic field of flux density 3.5 mT. The electrons travel at 2.4×10^{7} m s^{-1} **perpendicular** to the field, and follow a circular path.

(a) **Explain** why the magnetic force makes the electrons move in a **circle** rather than speeding them up. [2]

(b) **Determine** the magnitude of the force on one electron. [2]

(c) **Determine** the radius of the circular path. [3]

(d) **Determine** the time for one complete circle, and **state** what happens to that time if the electrons are made to enter at twice the speed. [3]

(e) An electric field is now applied in the same region so that the electrons pass through **undeflected**. **Determine** the magnitude of the electric field strength required, and **state** its direction relative to the magnetic force. [3]

Solutions

Each answer shows the steps, then the **result**.

2.1

- $F = BQv \sin\theta$

2.2

- $F = BQv$

$$F = (0.50\ \mathrm{T})(1.6 \times 10^{-19}\ \mathrm{C})(2.0 \times 10^{6}\ \mathrm{m\ s^{-1}}) = \mathbf{1.6 \times 10^{-13}}\ \mathrm{N}$$

2.3

- a **circle**

2.4

- the force is always **perpendicular** to the velocity, so it does no work (the speed is unchanged)

3.1 C

- a charge moving perpendicular to B follows a **circle**

3.2

- $BQv = mv^2/r \Rightarrow r = mv/(BQ)$

$$r = \frac{(9.1 \times 10^{-31}\ \mathrm{kg})(3.0 \times 10^{6}\ \mathrm{m\ s^{-1}})}{(0.020\ \mathrm{T})(1.6 \times 10^{-19}\ \mathrm{C})} = \mathbf{8.5 \times 10^{-4}}\ \mathrm{m}$$

3.3

- the magnetic force is always **perpendicular** to the velocity
- so it does **no work** — the kinetic energy and hence speed stay constant

3.4

- crossed **electric** and **magnetic** fields exert opposite forces on the charge
- only when they **balance** ($qE = Bqv$, i.e. $v = E/B$) does the charge travel straight through — selecting that speed

3.5

(a) the magnetic force $F = BQv$ is always **perpendicular to the velocity**

- so it does no work on the electron: the speed is unchanged and only the direction turns, which is circular motion

(b) $F = BQv$

$$F = (3.5 \times 10^{-3}\ \mathrm{T})(1.60 \times 10^{-19}\ \mathrm{C})(2.4 \times 10^{7}\ \mathrm{m\ s^{-1}}) = \mathbf{1.3 \times 10^{-14}}\ \mathrm{N}$$

(c) $BQv = mv^2/r$, so $r = mv/(BQ)$

$$r = \frac{(9.11 \times 10^{-31}\ \mathrm{kg})(2.4 \times 10^{7}\ \mathrm{m\ s^{-1}})}{(3.5 \times 10^{-3}\ \mathrm{T})(1.60 \times 10^{-19}\ \mathrm{C})} = \mathbf{3.9 \times 10^{-2}}\ \mathrm{m}$$

(d) $T = 2\pi r/v$

$$T = \frac{2\pi(0.039\ \mathrm{m})}{2.4 \times 10^{7}\ \mathrm{m\ s^{-1}}} = \mathbf{1.0 \times 10^{-8}}\ \mathrm{s}$$

- doubling the speed doubles the radius as well, so the time is **unchanged** — the period does not depend on the speed

(e) undeflected means $QE = BQv$

$$E = Bv = (3.5 \times 10^{-3}\ \mathrm{T})(2.4 \times 10^{7}\ \mathrm{m\ s^{-1}}) = \mathbf{8.4 \times 10^{4}}\ \mathrm{V\ m^{-1}}$$

- the electric force must act **opposite** to the magnetic force

7 **(a)** Define magnetic flux density.

....

....

.... [2]

(b) A particle of mass m and charge $+Q$ moves at speed v into a region where there is a uniform magnetic field, as shown in Fig. 7.1.

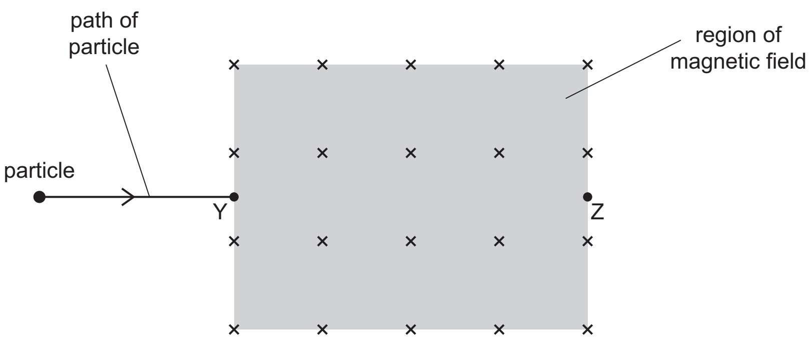


Fig. 7.1

The uniform magnetic field is into the page and has flux density B. The particle enters the region of the field at point Y.

(i) State an expression, in terms of some or all of m, Q, B and v, for the magnetic force F that acts on the particle when it is at point Y.

F = ... [1]

(ii) On Fig. 7.1, draw an arrow at point Y to indicate the direction of the force in **(b)(i)**. [1]

(iii) On Fig. 7.1, draw a line to show a possible path for the particle through the region of the magnetic field. [1]

(c) **(i)** Explain how an electric field can be used with the magnetic field to ensure that the particle in **(b)** now passes through point Z.

....

....

....

....

.... [3]

(ii) Derive an expression for v in terms of B and the electric field strength E.

v = ... [2]

[Total: 10]

6 An electric field and a magnetic field are used to form a velocity selector. Charged particles, called ions, pass into a region of uniform electric and magnetic fields that is between parallel plates, as shown in Fig. 6.1.

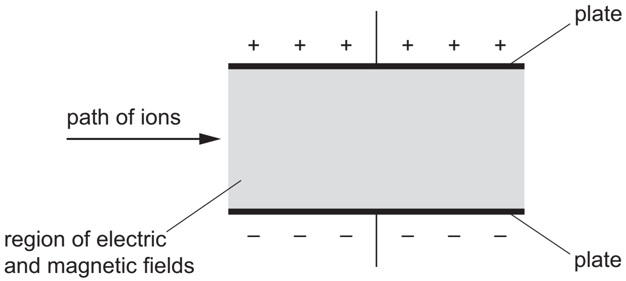


Fig. 6.1

(a) The potential difference (p.d.) between the plates of the velocity selector is V. The separation of the plates is d and the magnetic flux density is B.

Show that the speed u of ions that pass undeviated through the velocity selector is given by

$$u = \frac{V}{Bd}.$$

[2]

(b) Positive ions with kinetic energy 4.1×10^{-17} J and mass 3.2×10^{-27} kg pass undeviated through the velocity selector when V is equal to 980 V and d is equal to 3.6×10^{-2} m.

Determine B.

B = ... T [3]

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(c) A proton passes undeviated through the velocity selector.

An alpha particle enters the velocity selector at the same speed as the proton.

State how the expression in **(a)** predicts that the alpha particle also passes undeviated through the velocity selector.

....

.... [1]

(d) By reference to Fig. 6.1 and to the forces acting on a positive ion, determine the direction of the magnetic field. Explain your reasoning.

....

....

....

....

....

.... [3]

(e) The positive ions in **(b)** enter the velocity selector with greater kinetic energy.

On Fig. 6.1, sketch the path of these ions. [2]

[Total: 11]

A-LEVEL PHYSICS • EXERCISE SHEET

20.4 Magnetic fields due to currents

Name: ____________ Class: ________ Date: __________ **Total: 22 marks**

KEY WORDS solenoid 螺线管 • iron core 铁芯 • coil 线圈 • current 电流 • magnetic field 磁场

Objective

Build the skills to answer exam questions on **magnetic fields due to currents** and the force between currents.

You must be able to:

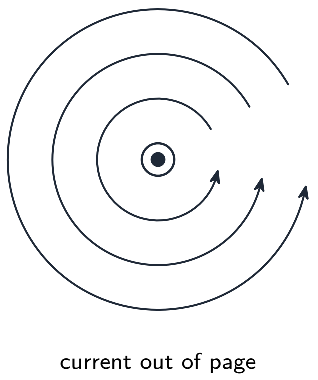
- sketch the field of a straight wire, a coil and a **solenoid**
- explain the **force between parallel currents**

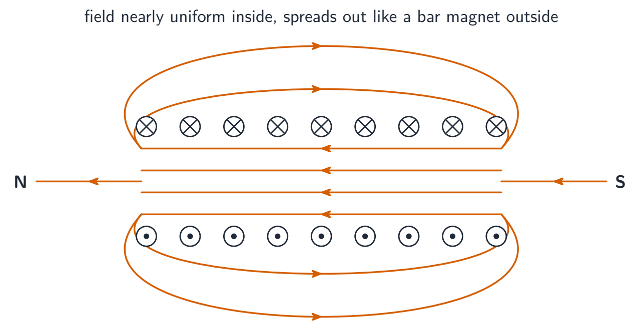
1 Worked examples

Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

Field around a wire

A current in a long straight wire makes **concentric circular** field lines (use the **right-hand grip rule**):





The magnetic field of a solenoid

A **solenoid** makes a field like a bar magnet (uniform inside); adding a **ferrous (iron) core** makes it much stronger.

Force between parallel currents

Each wire sits in the other's field. By Fleming's left-hand rule:

- currents in the **same** direction → **attract**;
- currents in **opposite** directions → **repel**.

2 Practice

Now apply the methods above.

2.1 A long straight wire carries a current **into** the page. In the space below, sketch the magnetic field pattern in the plane of the page, marking the **direction** of the field. State what happens to the pattern when the current is **reversed**. [3]

2.2 State **one** way to make a **solenoid's** field stronger. [1]

2.3 State whether two parallel currents in the **same** direction attract or repel. [1]

3 Exam-style questions

3.1 Two parallel wires carry currents in the **same** direction. They: [1]

- **A** attract
- **B** repel
- **C** feel no force
- **D** rotate

3.2 Sketch the magnetic field pattern around a long straight current-carrying wire. [2]

3.3 Explain why two **antiparallel** currents (opposite directions) **repel**. [2]

3.4 A long solenoid of length 0.35 m has 700 turns and carries a current of 2.4 A. A long straight wire runs parallel to its axis some distance away.

(a) **State** the shape of the magnetic field **inside** a long solenoid, away from its ends. [2]

(b) In the space below, **draw** the field pattern of a long straight wire carrying a current **out of** the page, showing at least three field lines and their direction. [3]

(c) **State** two ways of increasing the flux density inside the solenoid **without** changing its current. [2]

(d) A small coil of 50 turns and cross-sectional area 1.8×10^{-4} m^2 is placed at the centre of the solenoid, with its plane perpendicular to the axis. The flux density there is 6.0×10^{-3} T. **Determine** the magnetic flux linkage of the small coil. [3]

(e) The current in the solenoid is switched off, falling to zero in 0.020 s. **Determine** the average e.m.f. induced in the small coil. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- **concentric circles** centred on the wire, drawn further apart as the distance grows
- arrows **clockwise** when the current goes into the page (right-hand grip rule)
- reversing the current keeps the same circles but reverses every arrow, to anticlockwise

2.2

- any one: add a **ferrous/iron core**; increase the **current**; increase the **number of turns**

2.3

- they **attract**

3.1 A

- parallel currents in the same direction **attract**

3.2

- **concentric circles** centred on the wire
- closer together near the wire, with a direction (arrow) shown

3.3

- each wire lies in the other's magnetic field and feels a force ($F = BIL$)
- for opposite-direction currents Fleming's left-hand rule gives forces pushing the wires **apart** (repulsion)

3.4

(a) the field inside is **uniform**: straight lines parallel to the axis, evenly spaced

- running from the south end to the north end **inside** the solenoid

(b) at least three **concentric circles** centred on the wire

- spaced further apart as the distance grows
- arrows **anticlockwise** for a current out of the page

(c) any two: increase the **number of turns per unit length**; insert a **soft-iron core**; wind the turns closer together over a shorter length

(d) flux through one turn $= BA$

$$\Phi = (6.0 \times 10^{-3}\ \mathrm{T})(1.8 \times 10^{-4}\ \mathrm{m}^2) = 1.08 \times 10^{-6}\ \mathrm{Wb}$$

- flux **linkage** $= N\Phi$

$$N\Phi = 50 \times 1.08 \times 10^{-6}\ \mathrm{Wb} = \mathbf{5.4 \times 10^{-5}}\ \mathrm{Wb}$$

(e) $\varepsilon = \Delta(N\Phi)/\Delta t$

$$\varepsilon = \frac{5.4 \times 10^{-5}\ \mathrm{Wb}}{0.020\ \mathrm{s}} = \mathbf{2.7 \times 10^{-3}}\ \mathrm{V}$$

- the linkage falls to zero, so the whole of it is the change

6 **(a)** State what is meant by a magnetic field.

....

....

.... [2]

(b) A long, straight wire P carries a current into the page, as shown in Fig. 6.1.

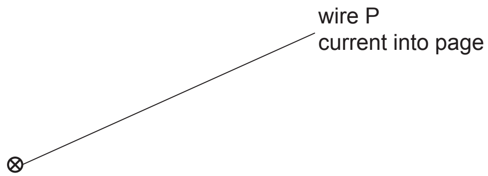


Fig. 6.1

On Fig. 6.1, draw four field lines to represent the magnetic field around wire P due to the current in the wire. [3]

(c) A second long, straight wire Q, carrying a current of 5.0 A out of the page, is placed parallel to wire P, as shown in Fig. 6.2.

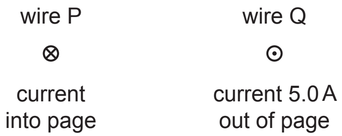


Fig. 6.2

The flux density of the magnetic field at wire Q due to the current in wire P is 2.6 mT.

(i) Calculate the magnetic force per unit length exerted on wire Q by wire P.

force per unit length = ... $N m^{-1}$ [2]

(ii) State the direction of the force exerted on wire Q by wire P.

.... [1]

(iii) The flux density of the magnetic field at wire P due to the current in wire Q is 1.5 mT.

Determine the magnitude of the current in wire P. Explain your reasoning.

current = ... A [2]

[Total: 10]

A-LEVEL PHYSICS • EXERCISE SHEET

20.5 Electromagnetic induction

Name: ____________ Class: ________ Date: __________ **Total: 31 marks**

KEY WORDS flux linkage 磁链 • lenz's law 楞次定律 • faraday's law 法拉第定律 • magnetic field 磁场 • magnetic flux 磁通量

Objective

Build the skills to answer exam questions on **electromagnetic induction**.

You must be able to:

- use **magnetic flux** $\Phi = BA$ and **flux linkage** $N\Phi$
- apply **Faraday's** and **Lenz's** laws

1 Worked examples

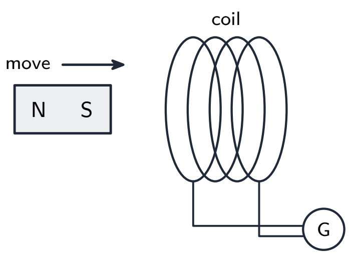
Study these first. Each one shows the method for a question type used later — follow the steps and you can do the Practice and Exam-style questions yourself.

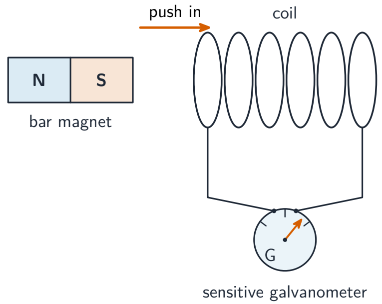
Flux and flux linkage

$$\Phi = BA \quad \text{(weber, Wb)}, \qquad \text{flux linkage} = N\Phi = NBA.$$

Induction

A **changing** flux linkage induces an e.m.f.:





Inducing an EMF by changing flux

- **Faraday's law:** the induced e.m.f. $\propto$ the **rate of change of flux linkage**: $E = \dfrac{\Delta(N\Phi)}{\Delta t}$.
- **Lenz's law:** the induced e.m.f. **opposes the change** producing it (from conservation of energy).

Worked example. $N = 200$ turns, $A = 0.010\ \text{m}^2$, B changes from 0.10 to 0.30 T in 0.50 s: $E = N\dfrac{A\Delta B}{\Delta t} = 200 \times \dfrac{0.010 \times 0.20}{0.50} = 0.80$ V.

A moving conductor (motional e.m.f.)

A straight conductor of length L moving at speed v **perpendicular** to a field B **cuts** field lines, sweeping out area at the rate Lv. So flux is cut at the rate $B\,Lv$, inducing:

$$E = BLv.$$

The flux **cut** in a time Δt is then $\Phi = E\,\Delta t$ (since $E = \Delta\Phi/\Delta t$).

Worked example. A rod of length 0.30 m moves at 5.0 m s^{-1} across a 0.40 T field: $E = BLv = 0.40 \times 0.30 \times 5.0 = 0.60$ V.

2 Practice

Now apply the methods above.

2.1 Define **magnetic flux**. [1]

2.2 Write $\Phi = BA$ and the **flux linkage** for a coil of N turns. [2]

2.3 State **Faraday's law**. [1]

2.4 State **Lenz's law**. [1]

3 Exam-style questions

3.1 The induced e.m.f. in a coil is proportional to the: [1]

- **A** magnetic flux
- **B** rate of change of flux linkage
- **C** area of the coil
- **D** current in the coil

3.2 A coil of 200 turns and area 0.010 m^2 is in a field that changes from 0.10 T to 0.30 T in 0.50 s. Calculate the induced **e.m.f.** [3]

3.3 State **Lenz's law** and explain how it follows from **conservation of energy**. [3]

3.4 Describe an experiment to show that a **changing magnetic flux** induces an e.m.f. [2]

3.5 An aircraft of wingspan 30 m flies horizontally at 250 m s^{-1} through the vertical component of the Earth's magnetic field, $B = 4.5 \times 10^{-5}$ T.

(a) Calculate the e.m.f. induced between the wingtips. [2]

(b) Calculate the magnetic flux **cut** by the wings in 15 s. [2]

3.6 An aircraft with a wingspan of 34 m flies horizontally through the Earth's magnetic field. The **vertical** component of the field is 4.4×10^{-5} T. An e.m.f. of 0.55 V is induced between the wingtips P and Q.

(a) **State** Faraday's law of electromagnetic induction. [2]

(b) **Calculate** the magnetic flux cut by the wings in 15 s. Give a **unit** with your answer. [2]

(c) **Determine** the area swept by the wings in that time. [2]

(d) Hence **determine** the speed of the aircraft. [2]

(e) Use **Lenz's law** to explain how you would decide which wingtip is at the higher potential. [3]

(f) **State and explain** what happens to the induced e.m.f. if the aircraft flies at the same speed directly over the magnetic **equator**, where the field is horizontal. [2]

Solutions

Each answer shows the steps, then the **result**.

2.1

- the product of the **magnetic flux density** and the **area perpendicular** to it ($\Phi = BA$)

2.2

- $\Phi = BA$
- flux linkage $= N\Phi = NBA$

2.3

- the induced e.m.f. is **proportional to the rate of change of flux linkage**

2.4

- the induced e.m.f. (or current) is in a direction that **opposes the change** that produces it

3.1 B

- Faraday: e.m.f. $\propto$ **rate of change of flux linkage**

3.2

- $E = N\Delta\Phi/\Delta t = NA\Delta B/\Delta t$

$$E = 200 \times \frac{(0.010 \text{ m}^2)(0.30 \text{ T} - 0.10 \text{ T})}{0.50 \text{ s}} = \mathbf{0.80} \text{ V}$$

3.3

- the induced e.m.f./current **opposes the change** producing it
- if it aided the change, the current would grow without an energy source — impossible
- so opposing it conserves energy (work must be done against the force)

3.4

- move a **magnet into a coil** connected to a galvanometer
- the galvanometer **deflects** while the flux changes (and reads zero when the magnet is still)

3.5

(a) $E = BLv$

$$E = (4.5 \times 10^{-5} \text{ T})(30 \text{ m})(250 \text{ m s}^{-1}) = \mathbf{0.34} \text{ V}$$

(b) $\Phi = E\Delta t$

$$\Phi = (0.34 \text{ V})(15 \text{ s}) = \mathbf{5.1} \text{ Wb}$$

3.6

(a) the magnitude of the induced e.m.f. is **proportional to the rate of change of magnetic flux linkage**

- the flux linkage is the flux through the circuit multiplied by the number of turns

(b) $\Phi = \varepsilon t$

$$\Phi = (0.55\ \text{V})(15\ \text{s}) = \mathbf{8.25}\ \text{Wb}$$

— the weber, equal to a volt second

(c) $\Phi = BA$, so $A = \Phi/B$

$$A = \frac{8.25\ \text{Wb}}{4.4 \times 10^{-5}\ \text{T}} = \mathbf{1.9 \times 10^5}\ \text{m}^2$$

(d) the wings sweep an area $A = (\text{span}) \times (\text{distance})$

$$\text{distance} = \frac{1.875 \times 10^5\ \text{m}^2}{34\ \text{m}} = 5.5 \times 10^3\ \text{m}$$

$$v = \frac{5515\ \text{m}}{15\ \text{s}} = \mathbf{3.7 \times 10^2}\ \text{m s}^{-1}$$

(e) the induced e.m.f. drives a current in the direction that **opposes the change producing it**

- imagine completing the circuit: the induced current must create a magnetic field opposing the change in flux through it
- the wingtip that the conventional current flows **towards** inside the wing is the one at the higher potential

(f) the e.m.f. becomes **zero**

- only the component of the field **perpendicular** to the swept area cuts through it, and a horizontal field is parallel to the area a horizontally-flying wing sweeps out, so no flux is cut

7 **(a)** State Faraday's law of electromagnetic induction.

....

....

.... [2]

(b) An aircraft is flying horizontally at constant speed v through the Earth's magnetic field, as shown in Fig. 7.1.

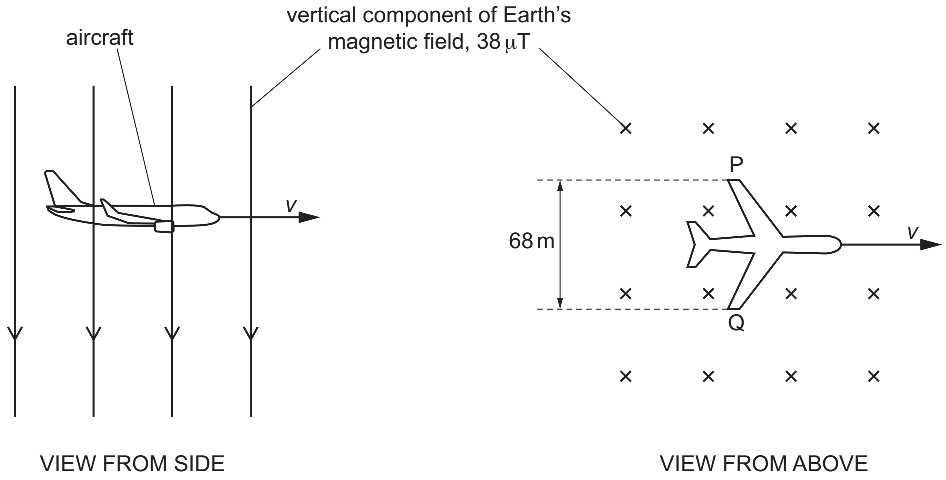


Fig. 7.1

At the location of the aircraft, the vertical component of the Earth's magnetic field is 38 µT towards the ground.

The distance between the wingtips P and Q of the aircraft is 68 m.

As the aircraft moves through the magnetic field, an electromotive force (e.m.f.) of 0.54 V is induced between the wingtips P and Q.

(i) Calculate the magnetic flux cut by the wings of the aircraft in a time of 15 s. Give a unit with your answer.

magnetic flux .... unit .... [2]

(ii) Determine the area of flux cut by the wings in a time of 15 s.

area = ... m^2 [2]

(iii) Use your answer in **(b)(ii)** to determine the speed v of the aircraft.

v = ... $m\,s^{-1}$ [2]

(iv) Use Lenz's law of electromagnetic induction to explain which of the wingtips P and Q is at the higher induced potential.

....

....

....

....

.... [3]

[Total: 11]

7 A bar magnet is suspended from a spring. One pole of the magnet oscillates freely in a coil of wire, as shown in Fig. 7.1.

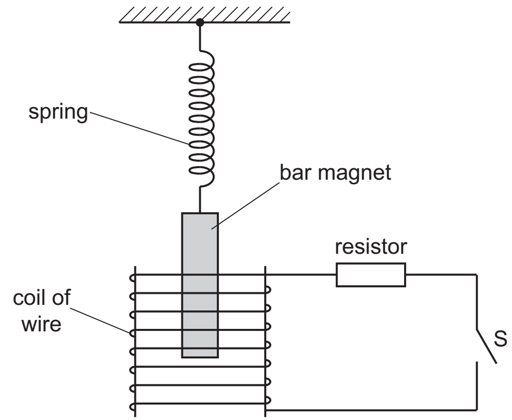


Fig. 7.1

The switch S is initially open.

(a) The switch S is now closed. As a result, the oscillations of the magnet are lightly damped.

(i) State what is meant by damping.

....

....

.... [2]

(ii) Describe what is observed to indicate that the damping is light.

....

.... [1]

(iii) By reference to electromagnetic induction and to conservation of energy, explain why the oscillations are damped.

....

....

....

.... [3]

(b) The procedure in **(a)** is repeated after replacing the resistor with one of greater resistance.

Suggest, with a reason, the effect of this change on the oscillations.

....

....

.... [2]

[Total: 8]

7 **(a)** State Faraday's law of electromagnetic induction.

....

....

.... [2]

(b) A metal rod is accelerated uniformly from rest in a uniform magnetic field as shown in Fig. 7.1.

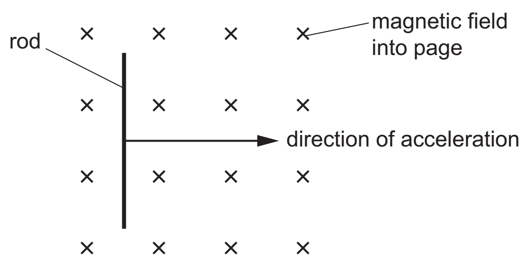


Fig. 7.1

The rod has length l and the flux density of the magnetic field is B.

An electromotive force (e.m.f.) is induced in the rod. The variation with time t of the induced e.m.f. E is shown in Fig. 7.2.

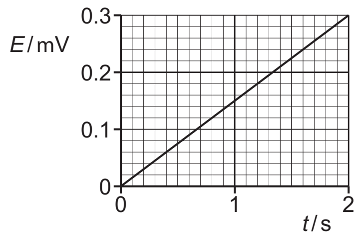


Fig. 7.2

(i) Explain how Fig. 7.2 shows that E is proportional to the velocity v of the rod.

....

....

.... [2]

(ii) Use Faraday's law to show that the variation of E with time t is given by

$$E = Blat$$

where a is the acceleration of the rod.

[3]

(iii) The length of the rod is 0.45 m. The acceleration a of the rod is 7.8 m s^{-2}.

Determine the value of B.

B = ... T [2]

[Total: 9]