Past-paper walk-through

Electromagnetic induction ▪ 20.5

eXercise

Questions in this set

- 9702/41 N25 Q7 ▪ 11 marks
- 9702/44 J25 Q7 ▪ 8 marks
- 9702/42 M25 Q7 ▪ 9 marks

Reading the mark scheme

- **B1** a mark that stands on its own – the point is either made or not.
- **M1** a *method* mark: the right approach, even if the number is wrong.
- **A1** an *answer* mark, and it usually needs its M mark first.
- **C1** a working mark on the way to the answer.
- // separates answers the examiner accepts equally.
- **ecf** = error carried forward: a later part is marked on your own earlier answer.
- **owtte** = "or words to that effect" – the wording need not match.

Question 7

9702/41 N25 ▪ Q7 ▪ 11 marks

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

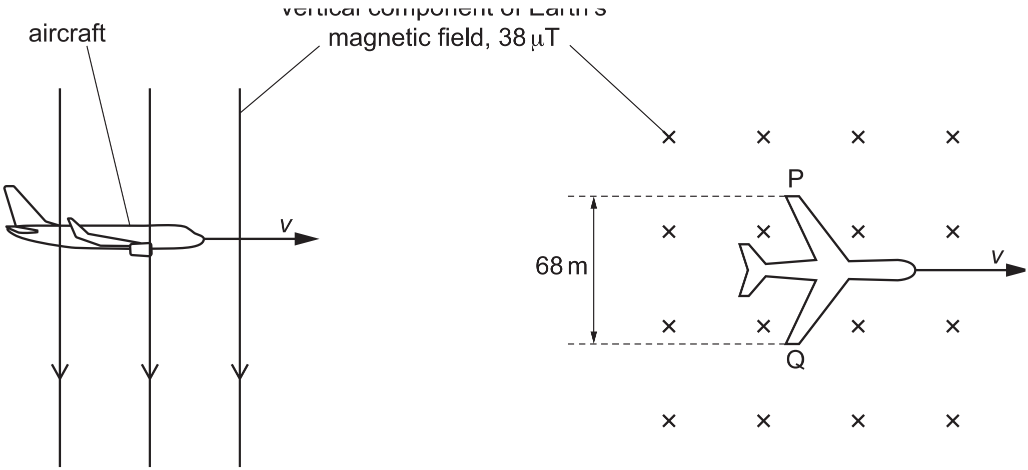
(b)(i) Calculate the magnetic flux cut by the wings of the aircraft in a time of 15 s. Give a unit with your answer. **[2]**

(b)(ii) Determine the area of flux cut by the wings in a time of 15 s. **[2]**

(b)(iii) Use your answer in **(b)(ii)** to determine the speed v of the aircraft. **[2]**

(b)(iv) Use Lenz's law of electromagnetic induction to explain which of the wingtips P and Q is at the higher induced potential. **[3]**

Question 7



aircraft
vertical component of Earth's magnetic field, 38 μT
v
P
68 m
Q
v

Solution 7

(a)

Mark scheme

- (induced) e.m.f. is (directly) proportional to rate **M1**
- of change of (magnetic) flux (linkage) **A1**

Solution 7

(b)(i) Worked steps

Faraday's law says the induced e.m.f. equals the **rate** of change of flux linkage, so for a steady e.m.f. the flux cut is simply the e.m.f. multiplied by the time.

- e.m.f. $= \dfrac{\Delta\Phi}{\Delta t}$, so $\Delta\Phi =$ e.m.f. $\times \Delta t$
- $\Delta\Phi = 0.54 \times 15$
- $\Delta\Phi = 8.1$ Wb

Solution 7

The question asks for a **unit**, and it carries a mark. The weber is the unit of magnetic flux: one weber is one volt second, which is exactly what this multiplication produced.

Mark scheme

- flux = e.m.f. $\times$ time **C1**
- flux = 0.54×15
- = 8.1 Wb **A1**

Solution 7

(b)(ii) Worked steps

Flux is the field strength times the area perpendicular to it, so rearrange for the area.

- $\Phi = BA$, so $A = \dfrac{\Phi}{B}$
- $A = \dfrac{8.1}{38 \times 10^{-6}}$
- $A = 2.1 \times 10^{5}$ m^2

Solution 7

Two things to watch. The field is given in **micro**tesla, so it is 38×10^{-6} T, not 38 — dropping the prefix makes the area a million times too small. And use your own flux from (b)(i): the method mark is available even if that answer was wrong.
An area of 2.1×10^5 m^2 is about 21 hectares, which is reasonable for a wide aircraft flying for fifteen seconds.

Mark scheme

- Φ = BA **C1**
- area = 8.1 / (38 × 10–6)
- = 2.1 × 105 m2 **A1**

Solution 7

(b)(iii) Worked steps

The area swept is a rectangle: the wingspan is its width and the distance flown is its length.

- area $=$ speed $\times$ time $\times$ width
- $v = \dfrac{A}{\Delta t \times \text{width}} = \dfrac{2.1 \times 10^5}{15 \times 68}$
- $v = 210\ \text{m}\,\text{s}^{-1}$

Solution 7

Sense-check it: 210 m s [1] is about 760 km/h, a normal cruising speed for an airliner. An answer in the thousands usually means the wingspan was left out of the denominator.

Mark scheme

- area = speed × time × width **C1**
- v = (2.1 × 105) / (15 × 68)
- = 210 m s–1 **A1**

Solution 7

(b)(iv)

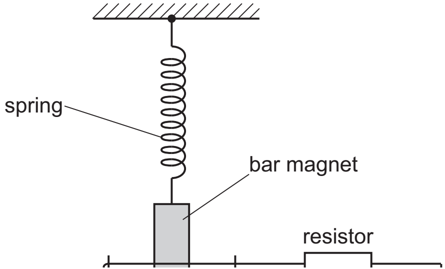
Mark scheme

- opposing force (due to current in wings) must be backwards **B1**
- from Fleming's left-hand rule, current (in wings) must be from Q to P **B1**
- current is from – to + inside an e.m.f. source so P is at higher potential **B1**

Question 7

9702/44 J25 ▪ Q7 ▪ 8 marks

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.



Question 7

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.

Question 7

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

Question 7

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

Question 7

(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.

Question 7

[Total: 8]

Solution 7

(a)(i)

Mark scheme

- loss of energy (of oscillations)
- due to resistive forces

Solution 7

(a)(ii)

Mark scheme

- amplitude (of oscillations) decreases gradually
- or
- oscillations continue (for several periods)

Solution 7

(a)(iii) Mark scheme

- cutting of (magnetic) flux causes induced e.m.f. (in coil)
- or
- induced e.m.f. causes current (in resistor / circuit)
- current causes dissipation of thermal energy in resistor
- or
- current in resistor causes dissipation of thermal energy
- thermal energy comes from energy of oscillations

Solution 7

(b) Worked steps

Follow the chain from resistance to amplitude — every link is one step, and the marks are for naming two of them.

- The induced e.m.f. is unchanged (it depends on the rate of change of flux linkage, not on the circuit), so a **higher resistance means a lower induced current**.
- By Lenz's law that current opposes the motion, so a smaller current means a **smaller resistive force** on the magnet — and, equivalently, less energy dissipated as I^2R per second.
- Less energy removed each cycle means the **oscillations are less damped**: a smaller decrease in amplitude per period, and the motion continues for longer.

Solution 7

Start from the **current**, not from the e.m.f. Saying “the e.m.f. is smaller” is wrong — the e.m.f. is set by the magnet’s motion, and it is the current the resistance controls.

Mark scheme

- (for any given e.m.f.) current is lower so thermal energy dissipated at a lower rate
- or
- (for any given e.m.f.) current is lower so the resistive force is lower
- oscillations are less damped
- or
- smaller decrease in amplitude of oscillations (in each period)

Solution 7

- or
- oscillations continue for longer
- 9702/44
- May/June 2025

Question 7

9702/42 M25 ▪ Q7 ▪ 9 marks

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

Question 7

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

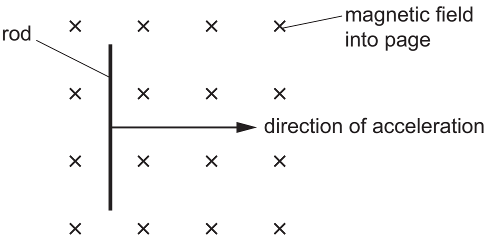


Fig. 7.1

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.

Question 7

time E is shown in Fig. 7.2.

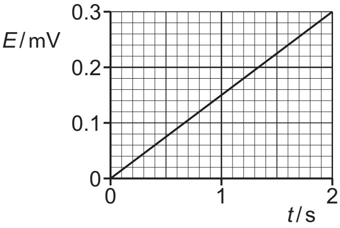


Fig. 7.2

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

Question 7

(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.

Question 7

[3]

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

Determine the value of B.

Question 7

[Total: 9]

Solution 7

(a)

Mark scheme

- (induced) e.m.f. is (directly) proportional to rate
- of change of (magnetic) flux (linkage)

Solution 7

(b)(i) Worked steps

Two proportionalities, chained. Say both — one mark each.

- The motion has **uniform acceleration** from rest, so $v = at$: the velocity is directly proportional to the time.
- The induced e.m.f. of a conductor moving through a field is $E = BLv$, and B and L are fixed, so $E \propto v$.

The graph shows the e.m.f. rising **linearly with time**, and the two statements together are why: $E \propto v$ and $v \propto t$, so $E \propto t$.

Solution 7

The order matters in the answer. Starting from "the graph is a straight line" describes the evidence; the marks are for the physics that produces it.

Mark scheme

- (uniform acceleration so) velocity is (directly) proportional to time
- (Fig. 7.2 shows) e.m.f. is (directly) proportional to time so E is proportional to v.
- 9702/42
- February/March 2025

Solution 7

(b)(ii)

Mark scheme

- ($v = at$ so) distance moved in time $\Delta t = at\Delta t$
- $\Phi = BA$
- $E = (\Delta\Phi \,/\, \Delta t) = B \times L \times (at\Delta t) \,/\, \Delta t = BLat$

Solution 7

(b)(iii) Worked steps

Combine the same two relations and solve for the flux density.

- $E = BLv$ with $v = at$, so $E = BLat$ and $B = \dfrac{E}{Lat}$.
- $B = \dfrac{0.30 \times 10^{-3}}{0.45 \times 7.8 \times 2.0}$
- $B = 4.3 \times 10^{-5}$ T

Solution 7

Every quantity must be in SI units: the e.m.f. in volts (0.30 mV is 0.30×10^{-3} V), the length in metres, the acceleration in $\mathrm{m\,s^{-2}}$ and the time in seconds.

4.3×10^{-5} T is about the strength of the Earth's magnetic field, which is a useful sanity check for this kind of question — an answer near 1 T would mean a laboratory electromagnet, not the surroundings.

Mark scheme

- B = (0.30 × 10–3) / (0.45 × 7.8 × 2.0)
- = 4.3 × 10–5 T