11.1 Electromagnetic Induction

Mark Schemes

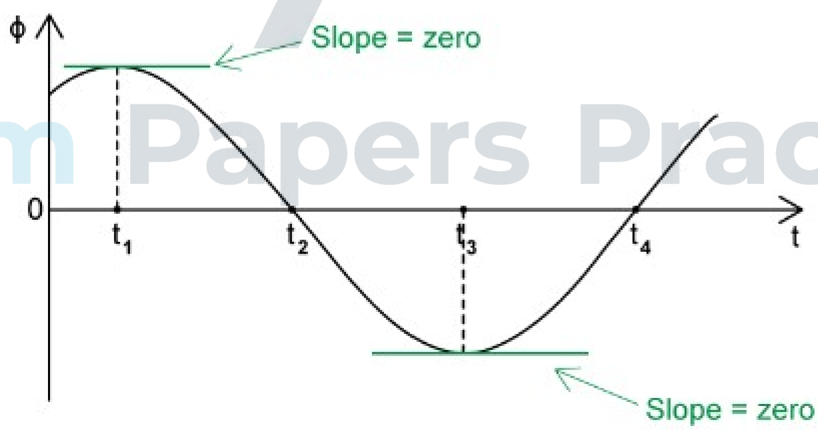
Course	DP IB Physics
Section	11. Electromagnetic Induction (HL only)
Topic	11.1 Electromagnetic Induction
Difficulty	Medium

To be used by all students preparing for DP IB Physics HL
Students of other boards may also find this useful

1

The correct answer is **C** because:

- From the data booklet:
  - $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$
    - ε = emf (V)
    - N = number of coils
    - φ = magnetic flux (Wb)
    - t = time (s)
  - So emf is **directly proportional** to the rate of change of magnetic flux
- The graph shows magnetic flux against time
  - Therefore in this case slope equals the rate of change of flux
  - This is $\frac{magnetic\ flux}{time}$
- The points where the slope is at a minimum indicate the least rate of change and therefore the minimum emf

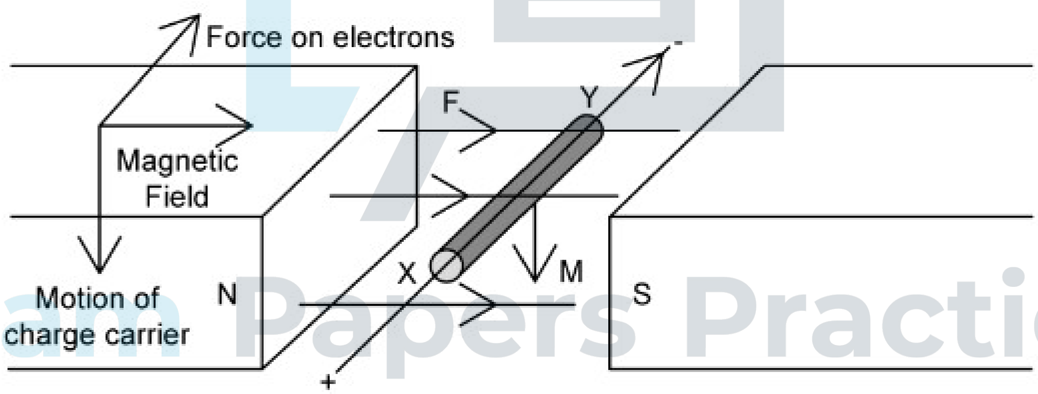


Remember that all graphs 'tell a story'. Always start by thinking about what the gradient represents. In this question that takes you straight to the correct answer. If gradient doesn't help, though, try looking at area under the line and then x- and y- intercepts.

2

The answer is **B** because:

- Electrons are involved with the movement of charge and the force experienced by a current-carrying wire in a magnetic field
- To find the force on electrons, use the Left-Hand Rule, where the direction of the palm of the hand (or second finger) indicates the force on **electrons**
- Force on electrons is in the same direction as current
  - This shows that more electrons are found at end **Y**
- Another way to think of this is that conventional current flows from positive to negative
  - Since electrons carry **negative** charge, the least number of electrons will be found at the **positive** end of the wire



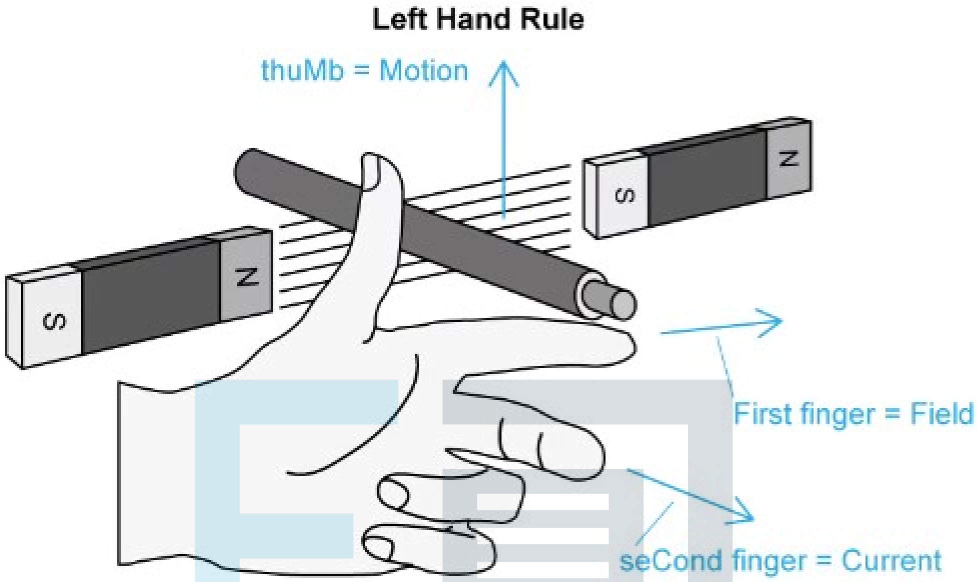
A is incorrect because	the highest number of electrons will be at the negative end of the wire
C and **D** are incorrect because	protons remain in the nucleus, they are not involved in electric current

There are various ways to remember the Left Hand Rule, and two left-hand rules! One trick which covers both rules is that the;

- **F**irst finger shows magnetic **F**ield
- se**C**ond finger shows **C**onventional **C**urrent (in motors)

OR

- s**E**cond **F**inger shows **F**orce on **E**lectrons
- the thu**M**b gives direction of **M**otion

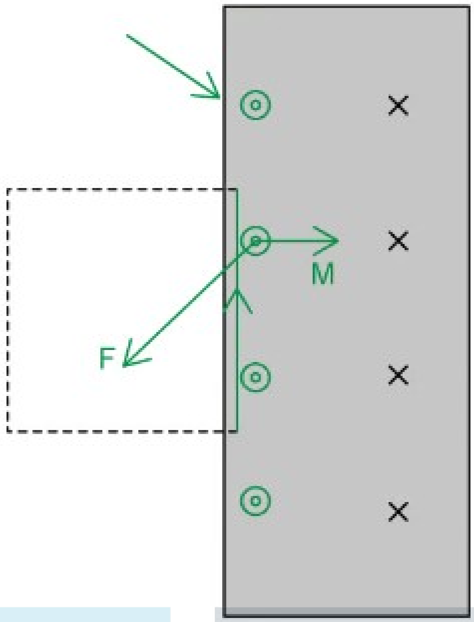


3

The correct answer is **C** because:

- Lenz's law states that induced emf will opposes the change which is making it
  - As the coil enters the magnetic field the induced emf will oppose it entering
  - As it leaves the induced emf will oppose it leaving
- This means the induced **current** must change direction, so only **C** or **D** could be correct

- As the coil enters the magnetic field **flux linkage is increasing** meaning that any induced current will try to **reduce flux linkage**
  - Hence at the start the current will be such as to set up a magnetic field coming out of the page
  - According to the Left Hand Rule the magnetic force on electrons will create an upwards current in the straight edge of the coil
  - This will create an anti clockwise current in the whole loop



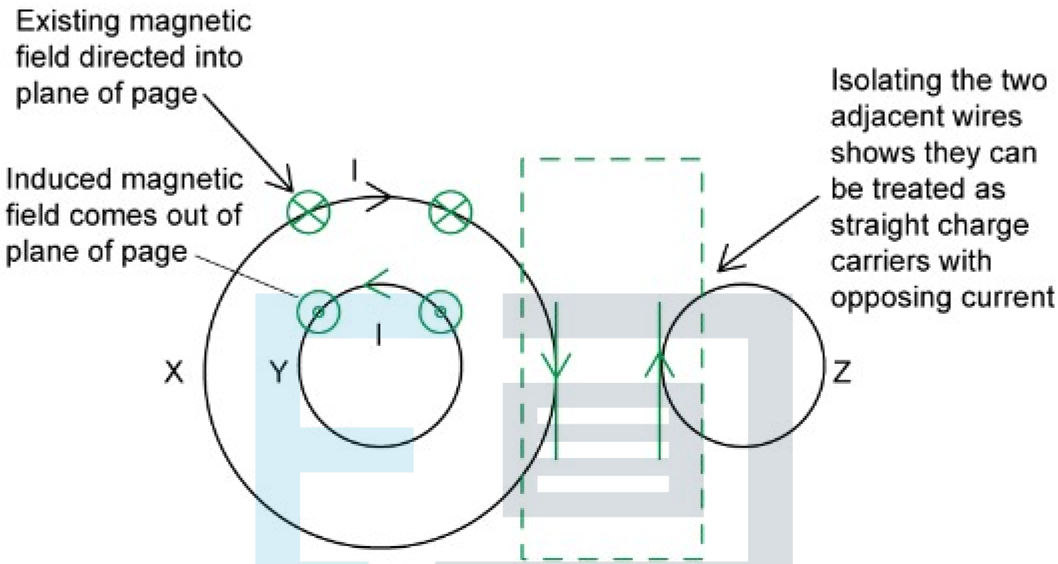
A and **B** are incorrect because	the coil enters and then leaves the magnetic field. This creates two situations with opposite effects, since the induced current will first oppose an increasing rate of change of flux, and then a decreasing one. The answer must have two parts in opposite directions, so neither of these can be right
D is incorrect because	the direction of this induced current would increase the rate of change of flux, which contraveners Lenz's law and conservation of energy

4

The correct answer is **D** because:

- The current in loop **X** will cause a magnetic field directed into the page, according to the right-hand grip rule
  - According to Lenz's law the induced emf is set up in a direction to produce effects that oppose the change causing it
  - This means that the induced current in **Y** must create a magnetic field in opposition to this
  - Therefore current in **Y** is anti-clockwise
  - Only answers **C** or **D** can be correct

- Where loops **X** and **Z** are close to each other they can be treated as two separate straight wires
  - The direction of the induced current in **Z** must oppose the change which is creating it, according to Lenz's law
  - Therefore the current in **Z** will be clockwise



5

The correct answer is **A** because:

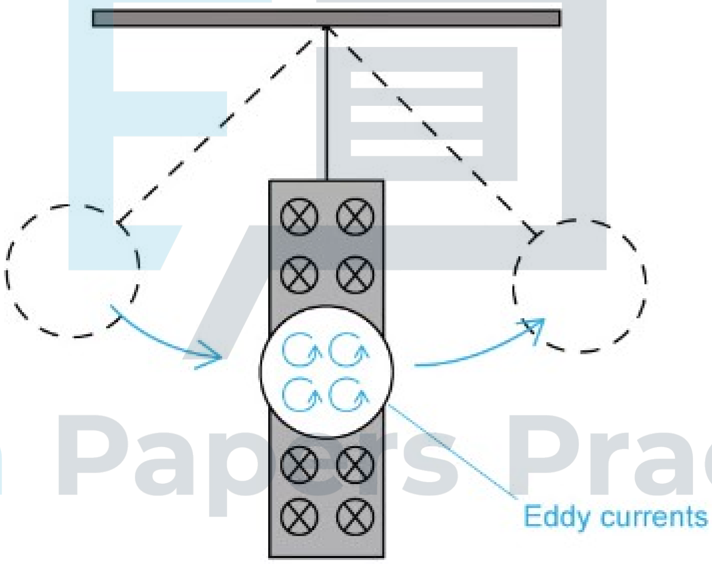
- Faraday's law states that the magnitude of the emf induced in a circuit is proportional to the rate of change of the magnetic flux which cuts across it **and** that the induced emf will oppose the change in the magnetic flux
  - As the pendulum enters the magnetic field the rate of change of flux increases and so emf increases
  - As the pendulum leaves the magnetic field the rate of change of flux decreases and so emf decreases
  - The change in direction means that only **A** or **B** can be correct
- Lenz's law states that induced current will flow in the direction which opposes the change that induced it
  - The movement of the copper sheet through the magnetic field induces eddy currents in the metal
  - These oppose the motion which caused them

- The effect of the opposition is to slow down the pendulum
  - The pendulum experiences a damping effect, reducing the amplitude of the oscillations
- Only answer **A** can be correct

Remember that in a laminar conductor like this copper sheet, eddy currents are induced. These will move such that they oppose the change being made, and so damping occurs.

You may have seen a demonstration of Lenz's law where a magnet dropped into a copper pipe falls more slowly than it would normally.

This question is testing you on the same effect but using a flattened laminar sheet instead of one rolled into a cylindrical shape like a pipe.



6

The correct answer is **B** because:

- From the data booklet
  - Magnetic flux, $\varphi = NBA$ (equation 1)
  - The area of a circle, $A = \pi r^2 = \frac{\pi d^2}{4}$ (equation 2)
- Substituting equation 1 into equation shows that
  - For the first coil, magnetic flux, $\varphi = \frac{NB\,\pi d^2}{4}$

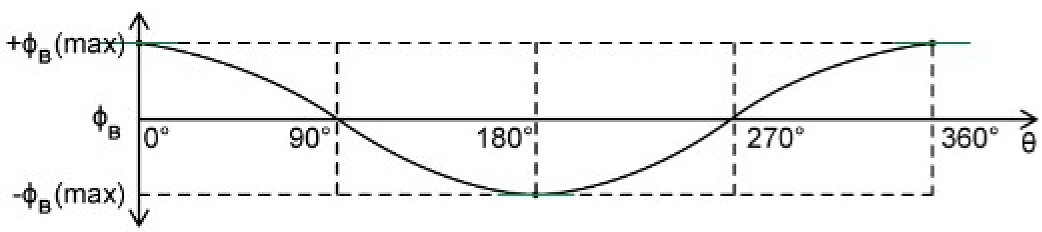
- For the second coil, magnetic flux,
  $$\varphi_2 = \frac{(3N)B\pi(2d)^2}{4} = 3NB\pi d^2$$
- Find the ratio of the two values of flux
  - $\frac{\varphi}{\varphi_2} = \frac{NB\pi d^2}{4 \times (3NB\pi d^2)} = \frac{1}{12}$

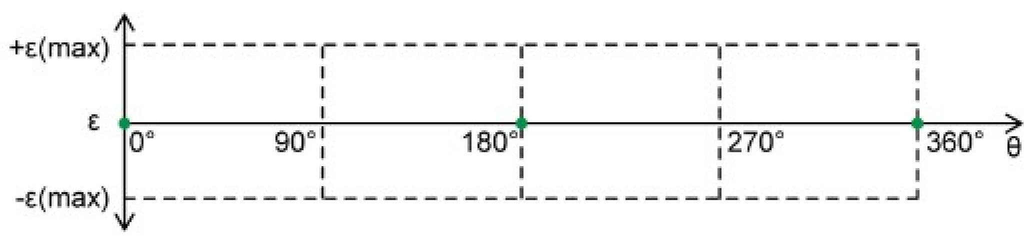
A and **C** are incorrect as	the 2 in the fraction indicates that the new diameter, 2d was not squared. The 2 should have become 4
D is incorrect as	when dividing the fractions in the final step to get the ratio, the '4' in '1/4' has been left in the numerator (above the line) rather than going in the denominator (underneath the line)

7

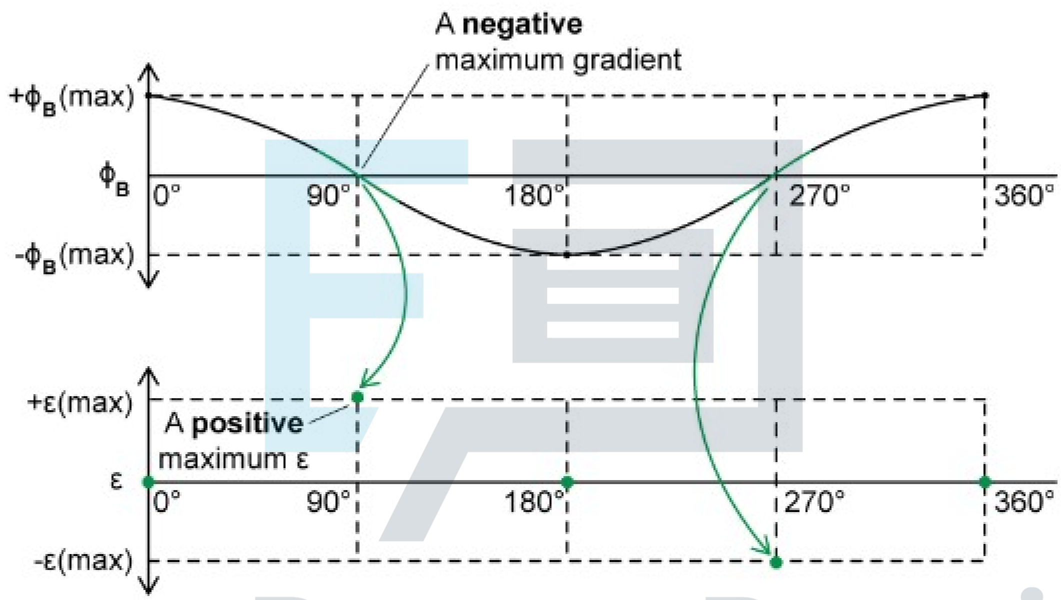
The correct answer is **D** because:

- From the data booklet Faraday's law states that:
  - $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$





- Applying this equation to the first graph shows that:
  - emf, ε is proportional to the rate of change of magnetic flux $\frac{\Delta\phi}{\Delta t}$
    - This is the gradient of the first graph
  - When the gradient of the first graph = zero then the induced emf = 0
  - So, the second graph must start at zero
  - So, only **A** or **D** can be correct



- Since emf is proportional to the **negative** value of rate of change of magnetic flux
  - A maximum gradient with **negative** slope will produce a maximum emf with **positive** value
  - A maximum gradient with **positive** slope will produce a maximum emf with **negative** value
  - Marking these points on the graph shows that only **D** can be correct

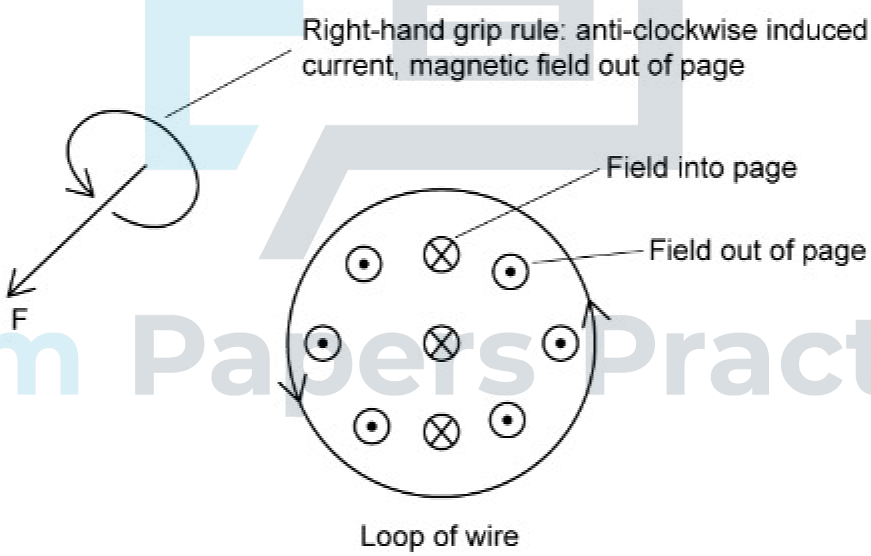
With graphical analysis like this it is important to take the working step by step. Mark out the first set of points you can ascertain, as shown. Then move on to the next set.

Never try to solve the answer in one go, always break it down.

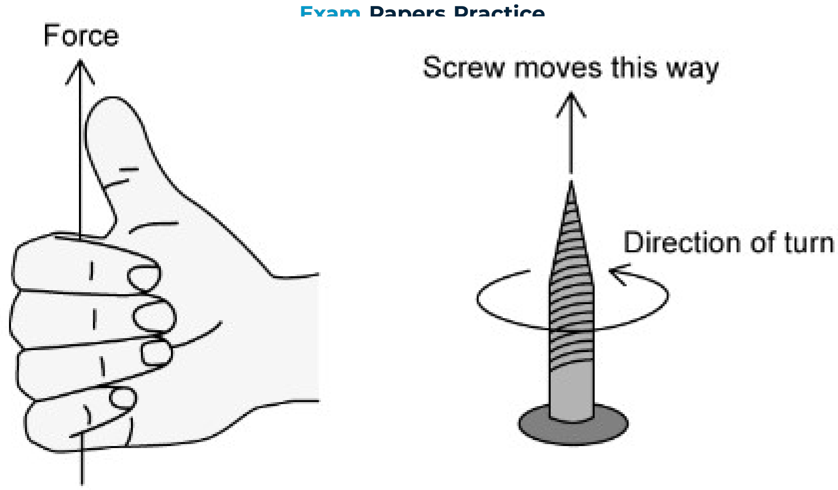
8

The correct answer is **C** because:

- As the coil is brought near to the magnet it experiences a magnetic field with a direction **into** the coil
- According to Lenz's law the induced current in the coil must oppose this change by producing a magnetic field in the opposite direction, coming out of the coil
  - Looking from the direction of the magnet, and using the right-hand grip rule, this requires an anti-clockwise current to flow in the coil
- Follow the direction of the wires to see that an anti-clockwise current at the magnet end will move from **X** to **Y**



Diagrams have to be in two dimensions since they are drawn on paper. You will need to practice thinking your way 'into' a diagram to see it in three dimensions. With this question, the trick is to rotate the coil in your mind so that you can 'virtually' look down into it from one end. This allows you to apply the right-hand grip rule and makes the solution much easier to find.



A is incorrect as	the coil and magnet move towards each other but not away, and there is no suggestion that the magnet passes through the coil and out again. Nothing is happening to cause the induced current to change direction
B is incorrect as	the coil and magnet are moving relative to each other so some emf and current must be induced
D is incorrect as	the direction would increase the kinetic energy of the coil, contravening Lenz's law and conservation of energy

9

The correct answer is **B** because

- The graph shows the magnetic flux plotted against time
  - Therefore the slope of the line represents rate of change of magnetic flux
- In the second situation magnetic field strength, *B* and area of the loop, *A* both increase
  - From the data booklet, $\varphi = BA\cos\theta$
  - This shows that as *B* and *A* increase, φ will increase
- Therefore the new slope must be steeper than the first one
  - Both **I** and **II** are steeper, so **B** is the correct answer

A is incorrect because	both of the lines I and II are steeper. The question does not state how much magnetic field strength and area have increased, so either could be correct
C is incorrect because	although the slope is steeper, the magnetic flux does not start at t=0, so some other condition has changed

D is incorrect because	the slope is less steep so the rate of change of magnetic flux has fallen rather than increased

10

The correct answer is **B** because:

- From the question, convert all values into standard form to make multiplication simpler
  - Number of loops, $N = 200 = 2.0 \times 10^2$
  - Rate of change in magnetic field, $\frac{\Delta B}{t} = 0.5\ \text{T s}^{-1} = 5.0 \times 10^{-1}\ \text{T s}^{-1}$
  - Area of loops, $A = 30\ \text{cm}^2 = 30 \times 10^{-4}\ \text{m}^2$
- Changing magnetic flux, $\varphi = BA\cos\theta$ but the coils are parallel
  - Therefore use equation for **maximum** changing magnetic flux, $\varphi = BA$ (equation 1)
- And emf, $\varepsilon = \frac{\Delta \varphi}{t}$ (equation 2)
  - Combine the equations to show that for each loop $\varepsilon = \frac{\Delta BA}{t}$
- There are 200 loops, therefore
  - $\varepsilon = \frac{\Delta BA}{t} \times N$
  - $\varepsilon = (5.0 \times 10^{-1}) \times (30 \times 10^{-4}) \times (2.0 \times 10^{2})$
- gather terms together to find that
  - $\varepsilon = (300) \times (10^{-3}) = 300\ \text{mV}$

A, **C** and **D** are incorrect because	the indices have been multiplied incorrectly