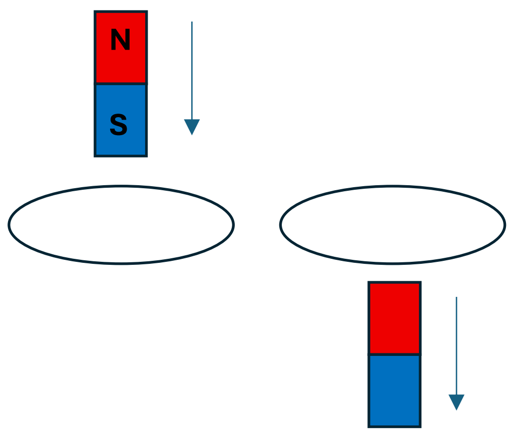
Electromagnetic induction

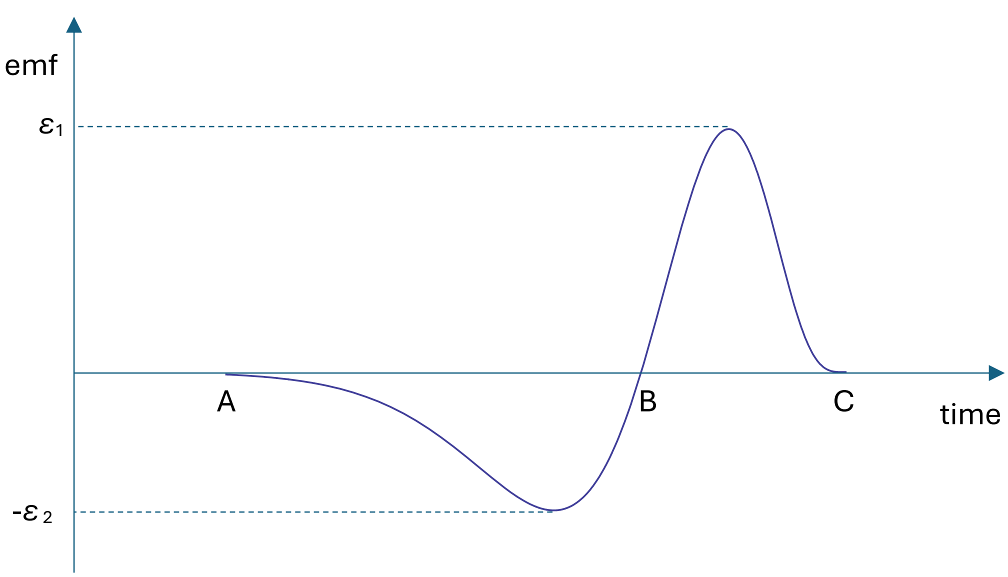
(a) A bar magnet falls vertically through a loop of conducting wire.



(i) Looked at from above, what is the direction of the induced current when the magnet is above the loop.

(ii) Does your answer to (i) depend on your choice of normal vector at the loop surface? Explain.

The graph shows the variation with time of the emf induced in the loop.

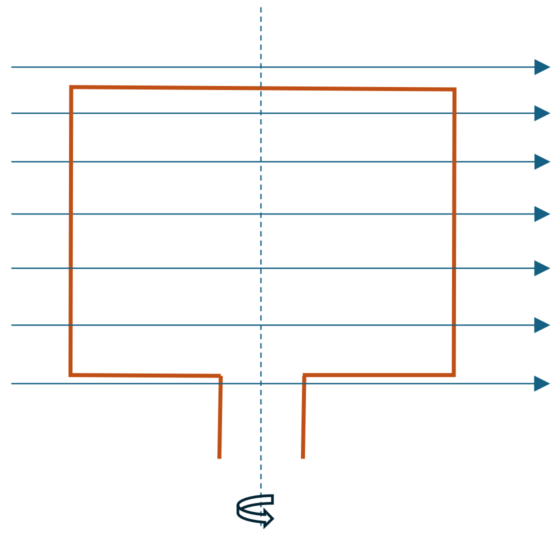


(b)

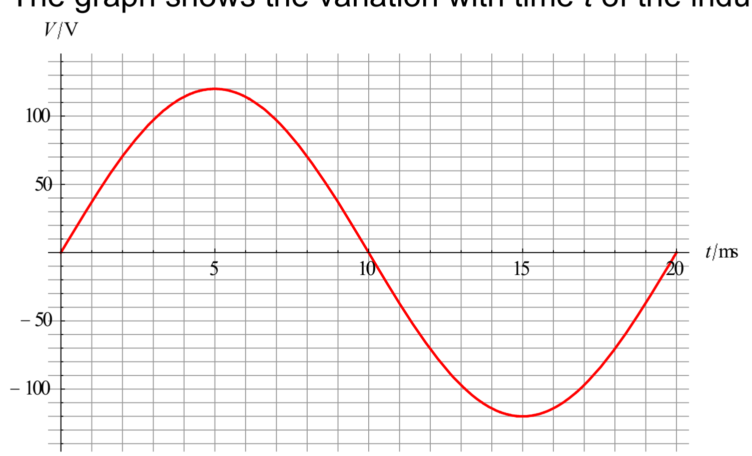
(i) Explain why $\varepsilon_1 > \varepsilon_2$ and BC < AB.

(ii) Suggest how the areas between the time axis and the graph from A to B and from B to C compare.

(c) A square loop of size 0.30 m × 0.30 m rotates in a region of uniform magnetic field 0.50 T. At a particular instant in time τ the plane of the loop is parallel to the magnetic field as shown.



The graph shows the variation with time t of the induced voltage V in the loop.



(i) State the frequency of revolution of the loop.

(ii) State a possible value of τ .

(iii) The resistance of the loop is 30 Ω. Calculate the maximum current in the loop.

(iv) Determine the maximum torque on the loop.

(v) The frequency of rotation is halved. Draw, on the axes above, the new variation with time of the induced voltage in the loop.

Answers

(a)

(i) It is clockwise. Taking the normal to the loop to be upward we see that the flux is increasing as the magnet approaches the loop. Hence, we must oppose this increase by creating a magnetic field pointing downwards. This means the current is clockwise.

(ii) No, the answer would be the same. If the normal is taken downwards then the flux is getting more and more negative. To oppose this change the induced magnetic field must be downward so as to produce positive flux. Hence the current is clockwise.

(b)

(i) From B to C the magnet is moving faster so the rate of change of flux is greater.

(ii) The areas are equal and opposite in sign because both correspond to the same change in flux.

A to B: $area = \int_A^B V dt = -\int_A^B \frac{d\Phi}{dt} dt = -\int_A^B d\Phi = -\Phi(B) + \Phi(A) = -\Phi(B) - 0 = -\Phi(B)$

B to C: $area = \int_B^C V dt = -\int_B^C \frac{d\Phi}{dt} dt = -\int_B^C d\Phi = -\Phi(C) + \Phi(B) = 0 + \Phi(B) = \Phi(B)$

(c)

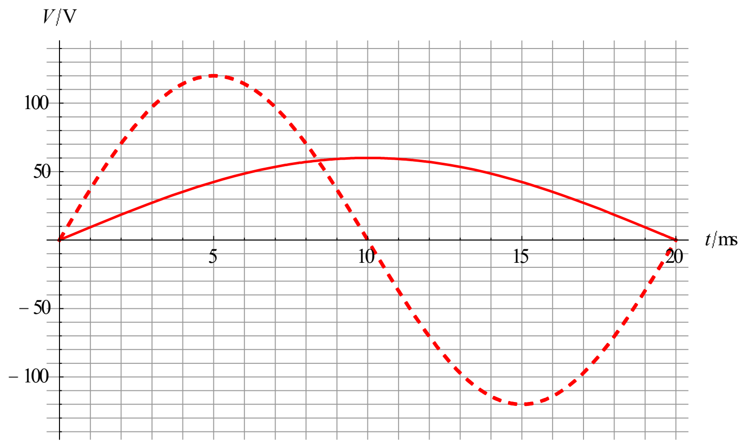
(i) The period is 20 ms so the frequency is $\frac{1}{20 \times 10^{-3}} = 50\text{ Hz}$.

(ii) 5 or 15 ms.

(iii) $\frac{120}{30} = 4.0\text{ A}$.

(iv) The force is $BIL = 0.50 \times 4 \times 0.30 = 0.60\text{ N}$. This produces a torque of $0.60 \times 0.15 = 0.090\text{ N m}$. There is a torque in the same direction from the opposite leg so the maximum torque is 0.18 N m.

(v)


V/V
100
50
− 50
− 100
5
10
15
20
t/ms