Phys 132 2022

Lecture 28

Thurs: Seminar, 12:30 WS 115

Fri: HW by 5pm Ex 166, 167, 168, ~~16~~ 170, 171, 173, 175, 176

Induced EMF

Whenever the magnetic flux through a loop changes with time, there will be an induced current and an induced EMF in the loop. The laws that describe this are:

Lenz's Law

The direction of the induced current is such that the induced magnetic field (produced by the induced current) opposes the change in the magnetic flux.

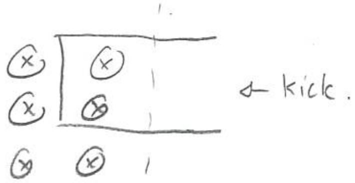
Faraday's Law:

Let Φ be the magnetic flux through a loop. Then the induced EMF has magnitude

$$\mathcal{E} = \left|\frac{d\Phi}{dt}\right|$$

Quiz 1 90%

Warm Up 1



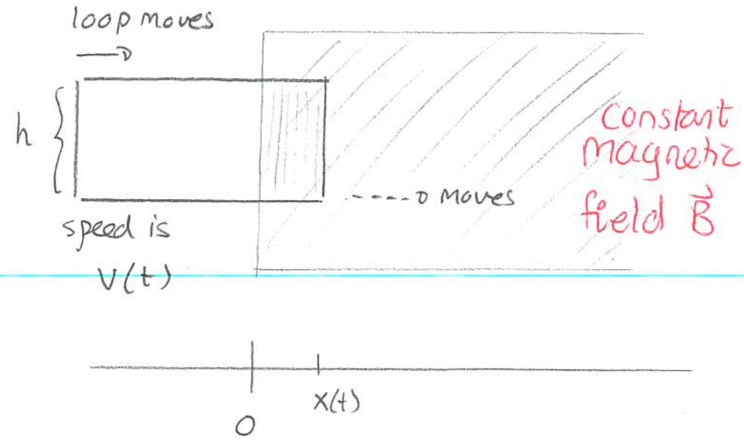
Demo: PSU-S Lenz's Law

We can assess the motional EMF as in the following example.

Consider a rectangular loop moving as illustrated

Then

$$\mathcal{E} = \left| \frac{d\Phi}{dt} \right|$$



and

$$\Phi = AB\cos\theta$$

Then we see that the area of the loop inside the field changes with time. So $A = A(t)$. Then:

$$\mathcal{E} = \left| \frac{d}{dt}\left[AB\cos\theta \right] \right| = \left| \frac{dA}{dt} \underbrace{B\cos\theta}_{\text{constant}} \right| = \left| \frac{dA}{dt} \right| B\cos\theta$$

We need to express area as a function of time. So with the illustrated co-ordinates:

$$A(t) = h\,x(t) \quad \Rightarrow \quad \frac{dA}{dt} = h\frac{dx}{dt} = h\,v(t)$$

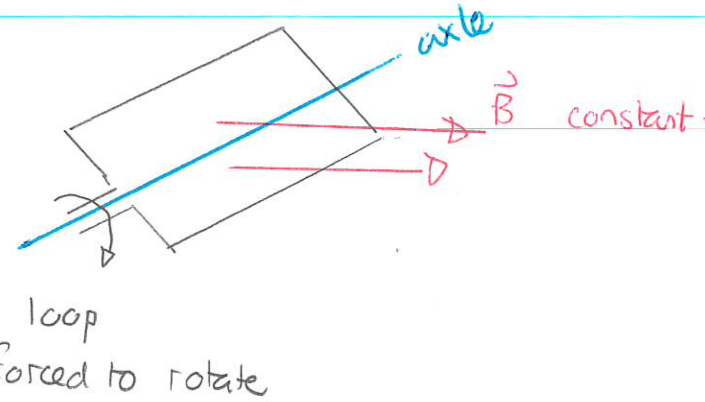
Thus, in this case,

$$\mathcal{E} = h\,|v(t)|\,B\cos\theta$$

Generators

We can see that motion of a loop relative to a field can generate a current. In order to do this constantly we need constant motion through a field. A rotating loop can accomplish this. We consider a

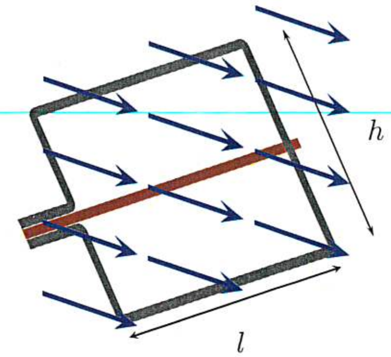
loop rotating through a constant uniform field.



Warm Up2

177 Generator

A generator consists of a loop which is forced to rotate about a fixed axle while it is in a uniform magnetic field as illustrated. Suppose that initially the loop is oriented vertically and then is forced (by a hand or something else external) to rotate with constant angular velocity, ω, about the illustrated axle. The aim of this exercise is to determine an expression for the EMF produced around the loop.



a) Sketch a side view of the loop, indicate the normal and the angle between the normal and the field, θ. Express θ in terms of ω and time.

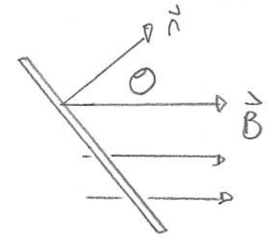
b) Determine an expression for the flux through the loop as a function of time.

c) Determine an expression for the EMF around the loop as a function of time.

d) Does the EMF remain constant?

e) Suppose that the loop is connected to a resistor with resistance R. Determine an expression for the power delivered to the resistor.

Answer a)



$\theta = \omega t$

b) $\Phi(t) = AB\cos\theta = hl\,B\cos(\omega t)$

c) $\mathcal{E} = \dfrac{d\Phi}{dt} = -hl\omega B\sin(\omega t)$

d) It varies with time.

e) $\mathcal{E} = IR$ and $P = \mathcal{E}I$ $\Rightarrow$ $P = \mathcal{E}\mathcal{E}/R = \mathcal{E}^2/R$

$P = \dfrac{h^2 l^2 \omega^2}{R}\sin^2(\omega t)$

In such a generator we see that the power

* increases as the angular velocity increases
* increases as the loop area increases

Demo: PhET generator

Quiz 2

Quiz 3

One way to effectively increase the loop area is to add many loops. Each loop will contribute the same EMF and they add together. So

$$\mathcal{E}_{N\ loops} = N\,\mathcal{E}_{single\ loop}$$

Then with $\mathcal{E}_{single\ loop} = -\omega AB\sin(\omega t)$ we get

$$\mathcal{E}_{N\ loops} = -N\omega AB\sin(\omega t)$$

The maximum value of the EMF is

$$\mathcal{E}_{max} = N\omega AB$$

Exercise Consider a square loop with sides 10cm long. Suppose the loop has 300 turns. It rotates through a uniform magnetic field with strength 5.0×10^{-3}T. Determine the angular velocity s.t. $\mathcal{E}_{max} = 12V$.

Answer: $\mathcal{E}_{max} = N\omega AB \Rightarrow \omega = \dfrac{\mathcal{E}_{max}}{NAB}$ and $A = L^2$

$$\Rightarrow \omega = \frac{\mathcal{E}_{max}}{NL^2B} = \frac{12V}{300\times(0.10m)^2\times5.0\times10^{-3}T} = 800\,rad/s$$

To convert $\omega = 800\,\frac{rad}{s}\times\frac{60s}{1\,min}\times\frac{1rev}{2\pi\,rad} = 7600\,rpm.$