Phys 132 2022

Lecture 25

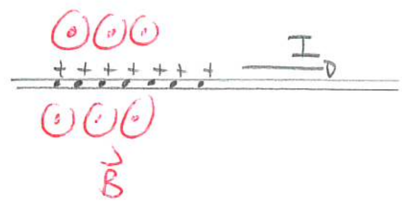
Thurs: Seminar WS 115 12:30

Fri: SPS meeting, WS 218 1pm - meet guest.

Mon: Ex 133, 138, 145, 146, 147, 150, 151, 152

Magnetic forces on a current

Since a current consists of moving charges

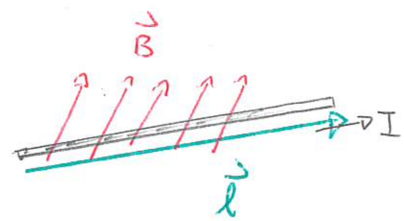


> A magnetic field exerts a force on a current

Quiz 1 10% → 40%

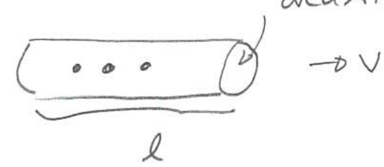
We seek a rule for the force.

> Consider a straight section of current in a uniform field, $\vec{B}$. The magnetic field exerts a force
>
> $$\vec{F} = I\vec{l} \times \vec{B}$$
>
> where $\vec{l}$ is a vector along the current in the direction of the current. This has magnitude equal to the length of the current section.



To derive this:

Consider particles moving with speed v. Let n be the number of particles per unit volume. Then the net force is



$$\vec{F} = q\, n\, \underbrace{A l}_{\text{volume}}\, \vec{v} \times \vec{B}$$

charge per particle

$$= n l A\, q \vec{v} \times \vec{B}$$

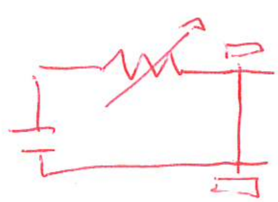
Now all of these particles leave the end in time $T = \frac{l}{v}$. Thus the current is

$$I = \frac{lAnq}{T} = \frac{nqA\cancel{l}}{\cancel{l}/v} = nqAv$$

So $\vec{F} = \vec{l} I \times \vec{B}$ ∎

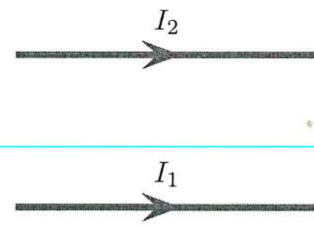
Quiz 2 50%

Demo: ~~Coast~~ Magnetic rail demo



153 Interacting parallel wires

Two parallel wires each carry currents in the illustrated directions. Each wire has length L and they are separated by distance d.



a) Determine an expression for the magnitude of the field produced by the upper wire at the location of the lower wire and use this to determine an expression for the magnitude of the force exerted by the upper wire on the lower wire.

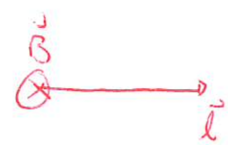
b) Use the field to determine the direction of the force exerted by the upper wire on the lower wire.

c) Suppose that the wires are each 1.5 m long and are separated by 3.0 mm. Each carries current 2.5 A. Determine the force exerted by the upper wire on the lower wire.

Answer: a) The field is into the page. Assume that the wire can be approximated as infinitely long

$$B_2 = \frac{\mu_0 I_2}{2\pi d}$$

b) $\vec{F} = I_1 \underbrace{\vec{l} \times \vec{B}_2}$



direction is $\uparrow$

$$F = I_1 L B_2 \sin 90^\circ \Rightarrow F = \frac{\mu_0}{2\pi} \frac{I_1 I_2 L}{d}$$

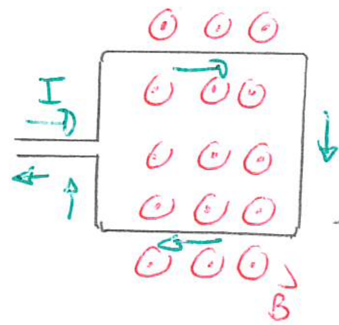
c) $$F = \frac{4\pi\times10^{-7}\,\text{Tm}/\cancel{\text{A}}}{2\pi} \times \frac{2.5\,\text{A}\times2.5\,\cancel{\text{A}}\times1.5\,\cancel{\text{m}}}{0.0030\,\cancel{\text{m}}} = 6.3\times10^{-4}\,\text{N}$$

The example illustrates the following

Parallel currents flowing in the same direction attract
" " " in the opposite " repel

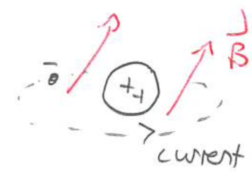
Warm up 1

Magnetic force on a current loop



There are situations where a current loop is placed in a magnetic field. We need to consider these because:

1) they form the basis for electric motors
2) looped currents appear in atomic + molecular situations

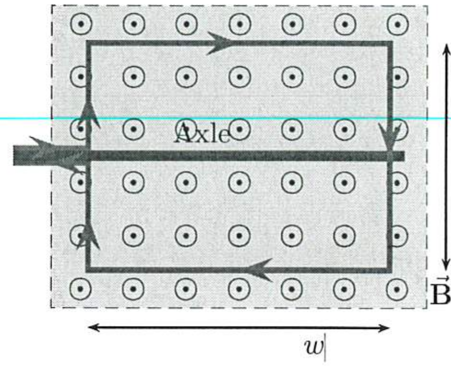


We can apply the rule for forces that fields exert on currents to each segment of the loop

Warm Up2

diagram like

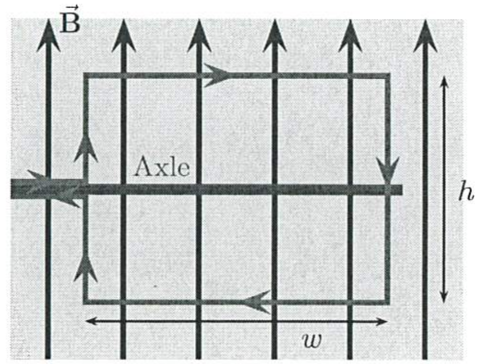
159 Current loop in a uniform magnetic field: force magnitude and directions



A loop is placed in a uniform magnetic field and a current flows as illustrated. The magnetic field strength is B and the magnitude of the current is I. Initially the loop lies perpendicular to the magnetic field as illustrated.

a) For the initial configuration, determine an expression for the force on each side of the loop. Determine an expression for the net force on the loop.

b) For the initial configuration, determine an expression for the torque (about the axle) on each side of the loop and the net torque on the loop.



Suppose that the loop lies in the plane of the magnetic field as illustrated.

c) In this configuration, determine an expression for the force on each side of the loop. Determine an expression for the net force on the loop.

d) In this configuration, determine an expression for the torque (about the axle) on each side of the loop and the net torque on the loop. Rewrite the expression in terms of the area of the loop.

e) Describe how the loop would begin to move if it were released from this position.

Answers: a) On each side $\vec{F} = I\vec{\ell} \times \vec{B}$ $\quad \vec{B} = B\hat{k}$

	$\vec{\ell}$	$\lvert\vec{\ell}\rvert$	F direction	F magnitude	
top	$w\hat{\imath}$	w	$-\hat{\jmath}$	IwB	$-IwB\hat{\jmath}$
right	$-h\hat{\jmath}$	h	$-\hat{\imath}$	IhB	$-IhB\hat{\imath}$
bottom	$-w\hat{\imath}$	w	$\hat{\jmath}$	IwB	$IwB\hat{\jmath}$
left	$h\hat{\jmath}$	h	$\hat{\imath}$	IhB	$+IhB\hat{\imath}$

b) In each case $\vec{\tau} = \vec{r} \times \vec{F}$ where $\vec{r}$ is a vector from the axle to the loop

	$\vec{r}$	$\vec{F}$	$\vec{\tau}$
top	$h/2\,\hat{j}$	$-IwB\hat{j}$	0
right	$w/2\,\hat{i}$	$-IhB\hat{i}$	0
bottom	$-h/2\,\hat{j}$	$IwB\hat{j}$	0
left	$-w/2\,\hat{i}$	$IhB\hat{i}$	0

$\vec{\tau}_{net} = 0$

c) d) Here $\vec{B} = B\hat{j}$ $\qquad \vec{F} = IB\vec{l} \times \hat{j}$

	$\vec{l}$	$\vec{F}$	$\vec{r}$	
top	$w\hat{i}$	$IBw\hat{k}$ (out)	$h/2\,\hat{j}$	$IBwh/2\,\hat{i}$
right	$-h\hat{j}$	0	$w/2\,\hat{i}$	0
bottom	$-w\hat{i}$	$-IBw\hat{k}$ (in)	$-h/2\,\hat{j}$	$IBwh/2\,\hat{i}$
left	$h\hat{j}$	0	$w/2\,\hat{i}$	0

$$\vec{\tau} = 2IBwh/2\,\hat{i} = IB\underbrace{wh}_{A}\hat{i} \Rightarrow \vec{\tau} = IAB\hat{i}$$

We can see that the dipole moment of the loop is $\vec{\mu} = -IA\hat{k}$. Thus

$$\vec{\tau} = \mu B\hat{i} = \vec{\mu} \times \vec{B}$$

e) Rotates c.c.w when viewed from right

This is an example of:

A loop with dipole moment $\vec{\mu}$ placed in a magnetic field $\vec{B}$ will experience a net torque

$$\vec{\tau} = \vec{\mu} \times \vec{B}$$