

Exercise walk-through

12.2

Magnetism and Moving Charges

AP Physics C: Electricity and Magnetism

Force on a moving charge

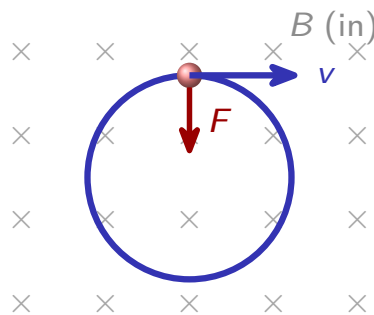
A cross product

$$\vec{F} = q \vec{v} \times \vec{B}$$

Size $qvB\sin\theta$; $\perp$ to $\vec{v}$, so it does **no work**. A wire feels $\vec{F} = I\vec{L} \times \vec{B}$.

Perpendicular entry $\Rightarrow$ a circle:

$$qvB = \frac{mv^2}{r}, \text{ so } r = \frac{mv}{qB}.$$



How a material answers a magnetic field

ferromagnetic

iron, nickel, cobalt: domains align *with* the field and stay aligned – a strong response that can be made permanent

paramagnetic

a weak alignment *with* the field, lost as soon as the field is removed

diamagnetic

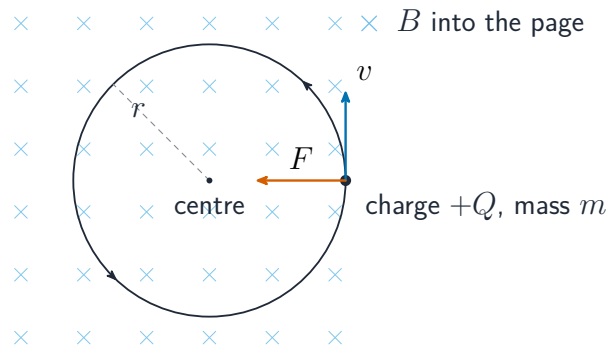
present in **all** materials: the electronic structure produces a usually weak alignment *opposite* to the field

permeability

the measure of that response. Free space has the constant $\mu_0 = 4\pi \times 10^{-7} \text{ T m/A}$

Diamagnetism is universal but weak, so it only shows when nothing stronger is present. The other two are extra effects layered on top of it.

A moving charge both makes and feels a field



$$BQv = \frac{mv^2}{r} \Rightarrow r = \frac{mv}{BQ}$$

A moving charge does **two** things: it *creates* a field, perpendicular to its velocity and circling it, and it *feels* a force in an external one. The force is perpendicular to both $\vec{v}$ and $\vec{B}$ – fingers along $\vec{v}$, curl toward $\vec{B}$, thumb gives the force on a **positive** charge – so it does no work and the path is a circle.

The velocity selector

the setup

an electric and a magnetic field, crossed, in the same region

they act independently

the two forces add as **vectors**: $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$

balance them

$qE = qvB$, so only particles with $v = E/B$ pass straight through

note

the selected speed depends on **neither** q nor m – so it filters by speed alone

Put a **velocity selector**

in front of a mass spectrometer and the second stage's radius $r = mv/qB$ then measures m/q cleanly, because v is already known.

Worked example – a proton circling in a field

A proton ($q = 1.6 \times 10^{-19} \text{ C}$, $m = 1.67 \times 10^{-27} \text{ kg}$) enters a 0.50 T field at $2.0 \times 10^5 \text{ m/s}$, perpendicular to it. Find r and T .

- the magnetic force is the **centripetal force** : $qvB = \frac{mv^2}{r}$

- $r = \frac{mv}{qB} = \frac{(1.67 \times 10^{-27})(2.0 \times 10^5)}{(1.6 \times 10^{-19})(0.50)} = 4.2 \times 10^{-3} \text{ m}$

- $T = \frac{2\pi m}{qB} = 1.3 \times 10^{-7} \text{ s}$

T contains **no** v . Faster particles ride larger circles in exactly the same time – which is the principle the cyclotron is built on.

Exercises 2.1-2.3

2.1 A charge of 3.0×10^{-6} C moves at 2.0×10^4 m s⁻¹ perpendicular to a 0.40 T field. Find the force. [2]

2.2 Explain why the magnetic force does no work on a moving charge. [2]

2.3 Write the formula for the radius of a charge's circular path in a magnetic field. [1]

Exercises 2.1-2.3

2.1 A charge of 3.0×10^{-6} C moves at 2.0×10^4 m s⁻¹ perpendicular to a 0.40 T field. Find the force. [2]

2.1

- $F = qvB = (3.0 \times 10^{-6})(2.0 \times 10^4)(0.40) = 2.4 \times 10^{-2}$ N

2.2 Explain why the magnetic force does no work on a moving charge. [2]

2.2

- the force is perpendicular to the velocity, so $\vec{F} \cdot \vec{v} = 0$ and no work is done – only the direction changes

2.3 Write the formula for the radius of a charge's circular path in a magnetic field. [1]

2.3

- $r = \frac{mv}{qB}$

Exercises 3.1-3.2

3.1 The magnetic force on a moving charge is

[1]

☐

A $q\vec{E}$

B $q\vec{v} \times \vec{B}$

C $I\vec{L}$

D $m\vec{a}$

3.2 The magnetic force on a moving charge does

[1]

☐

A positive work

B negative work

C no work

D maximum work

Exercises 3.1-3.2

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[1]

- ☐ **A** $q\vec{E}$
B $q\vec{v} \times \vec{B}$
C $I\vec{L}$
D $m\vec{a}$

3.1 B

- $q\vec{v} \times \vec{B}$.

3.2 The magnetic force on a moving charge does

[1]

- ☐ **A** positive work
B negative work
C no work
D maximum work

3.2 C

- no work.

Exercise 3.3 (a)

3.3 A proton ($q = 1.6 \times 10^{-19}$ C, $m = 1.67 \times 10^{-27}$ kg) moves at 4.0×10^6 m s⁻¹ perpendicular to a 0.50 T field.

(a) Find the magnetic force on it.

[2]

Exercise 3.3 (a)

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(a) Find the magnetic force on it.

[2]

(a)

- $F = qvB = (1.6 \times 10^{-19})(4.0 \times 10^6)(0.50) = 3.2 \times 10^{-13}$ N

Exercise 3.3 (b)

3.3 A proton ($q = 1.6 \times 10^{-19}$ C, $m = 1.67 \times 10^{-27}$ kg) moves at 4.0×10^6 m s⁻¹ perpendicular to a 0.50 T field.

(b) Find the radius of its circular path.

[2]

Exercise 3.3 (b)

3.3 A proton ($q = 1.6 \times 10^{-19}$ C, $m = 1.67 \times 10^{-27}$ kg) moves at 4.0×10^6 m s⁻¹ perpendicular to a 0.50 T field.

(b) Find the radius of its circular path.

[2]

(b)

- $$r = \frac{mv}{qB} = \frac{(1.67 \times 10^{-27})(4.0 \times 10^6)}{(1.6 \times 10^{-19})(0.50)} = 0.084 \text{ m}$$