UT DALLAS

PHYS2326
Lecture #21

Prof. Fabiano Rodrigues

Department of Physics
The University of Texas at Dallas

Reminder

- Exam #3: April 13 (Thursday)

Today's Lecture

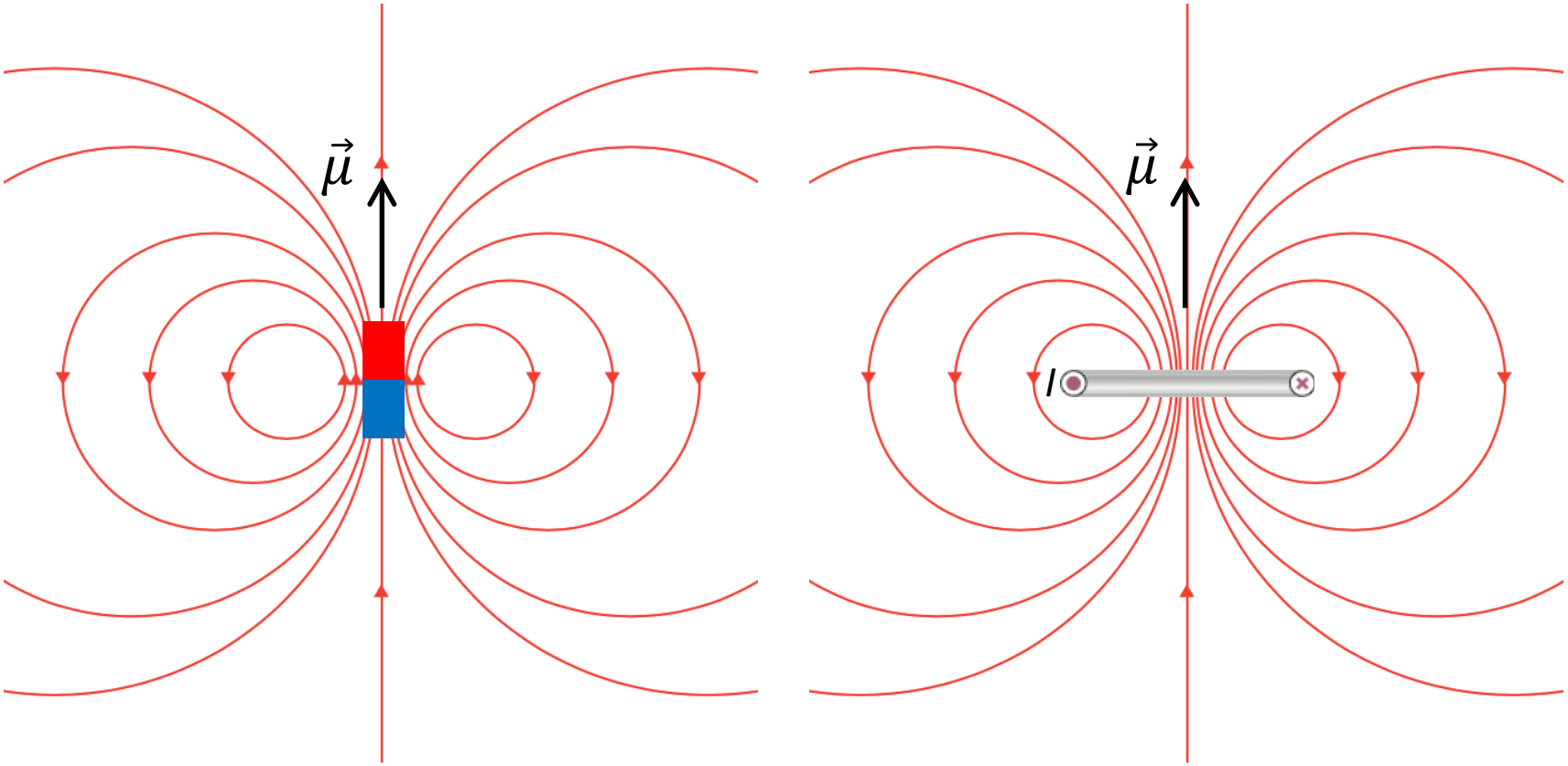
- Understand how magnets work
  - Permanent magnets
  - Attraction between magnets and some metals

- Understand the source of magnetic fields
  - Magnetic field of a moving charge
  - Magnetic field of a current element
  - Magnetic field of a straight current-carrying conductor
  - Magnetic field of a circular current loop

Chapters 27 and 28

- Understand how magnets work
  - Permanent magnets
  - Attraction between magnets and some metals

Magnetic Field and Electric Current



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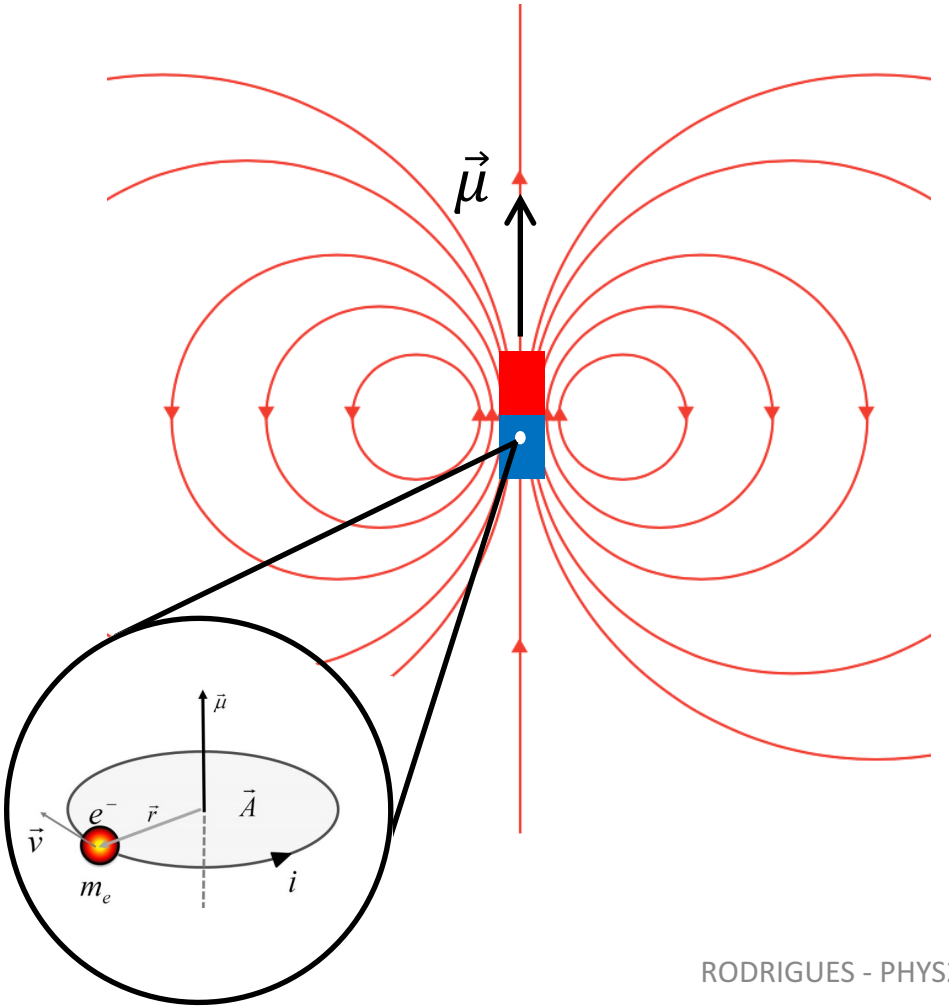

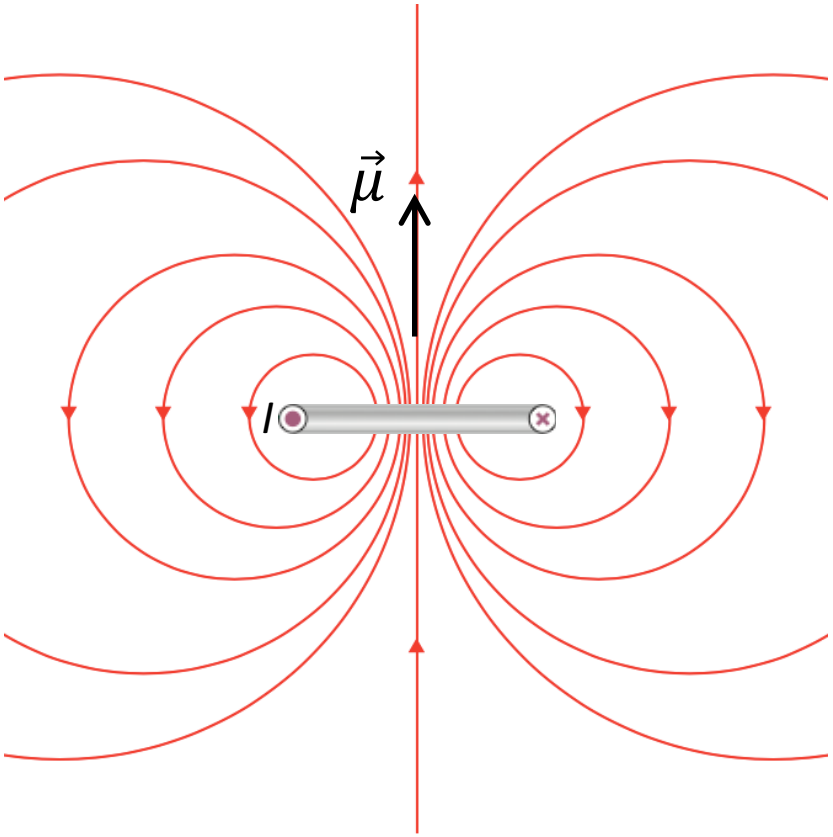

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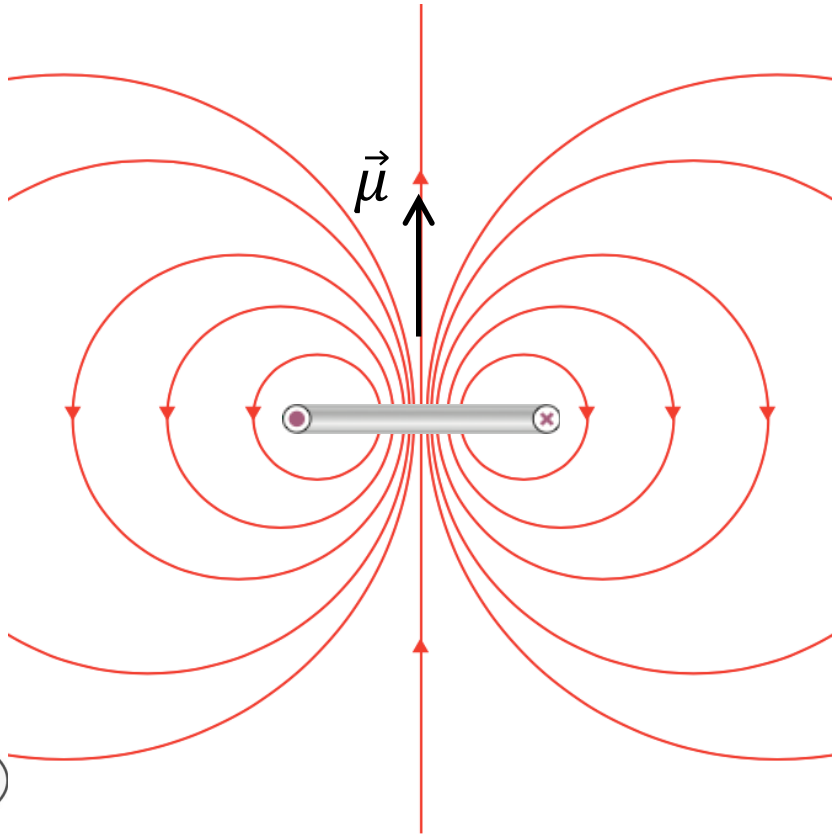

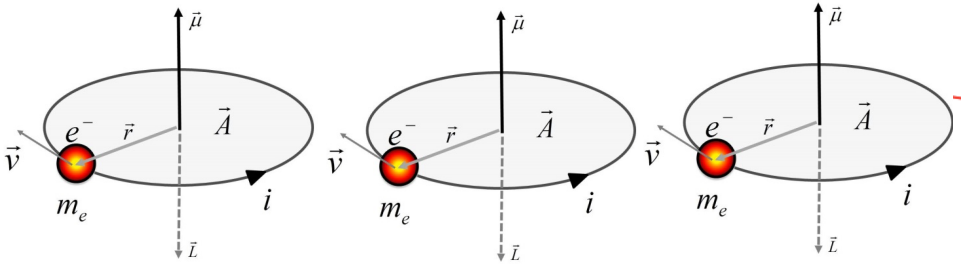

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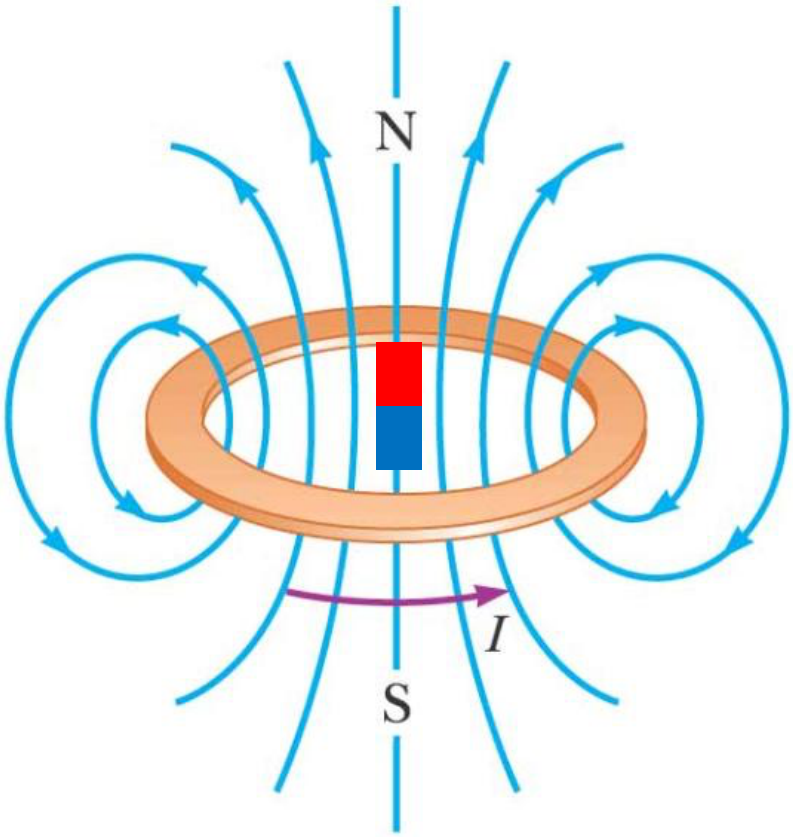
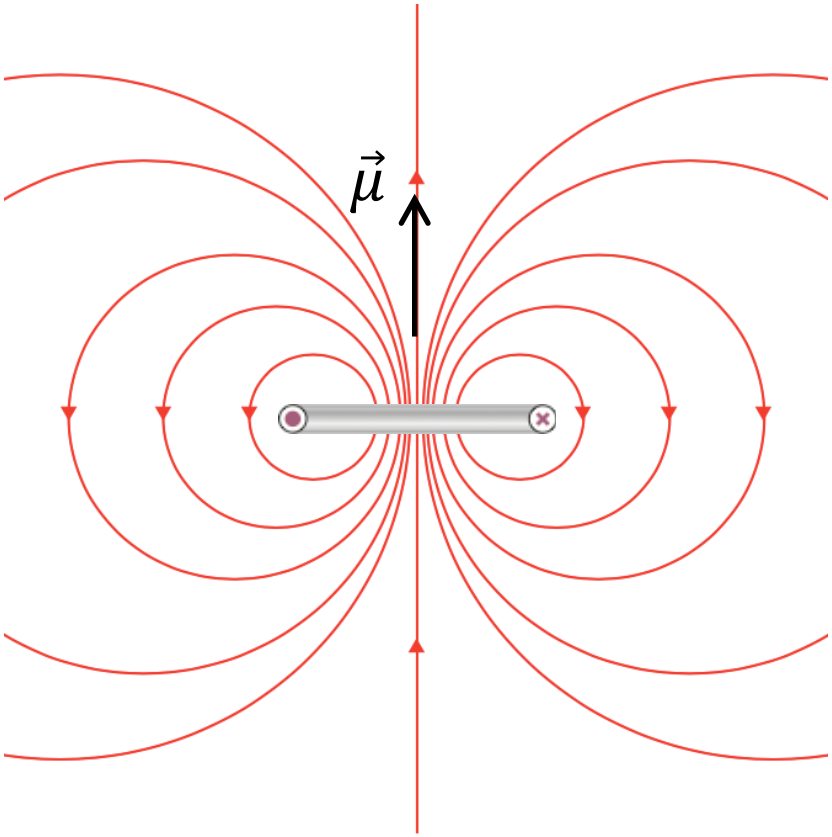
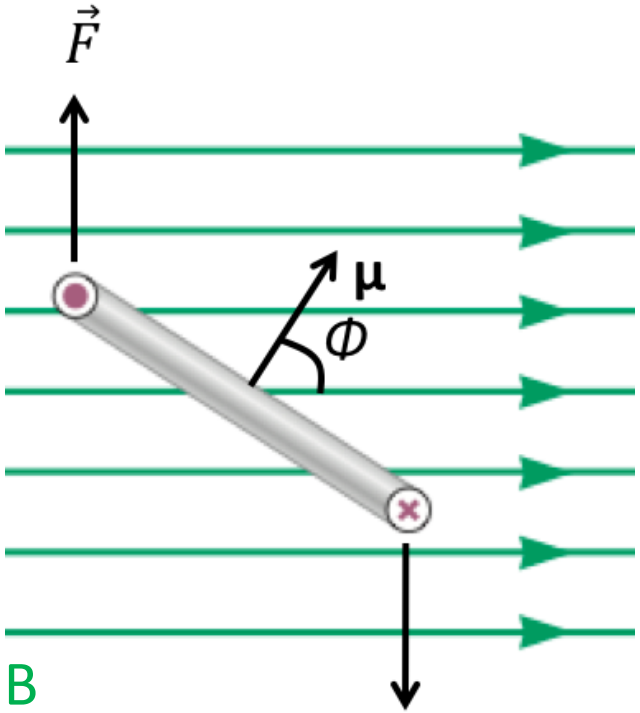




- Understand how magnets work
  - Permanent magnets
  - Attraction between magnets and some metals

Current Loop and non-uniform B

- Current loop and uniform B:



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

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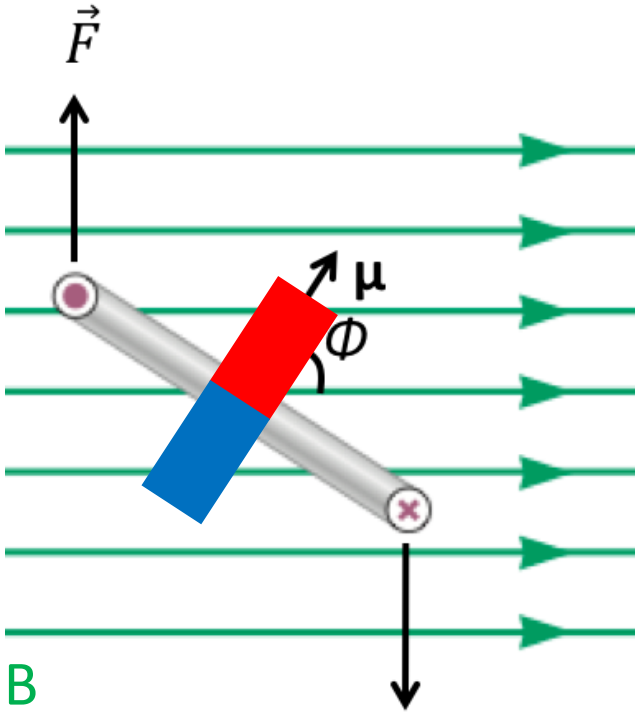

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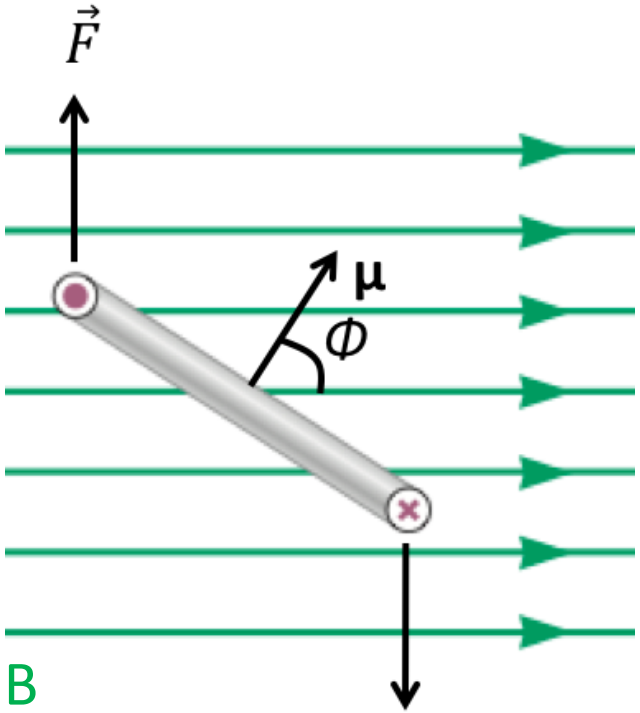

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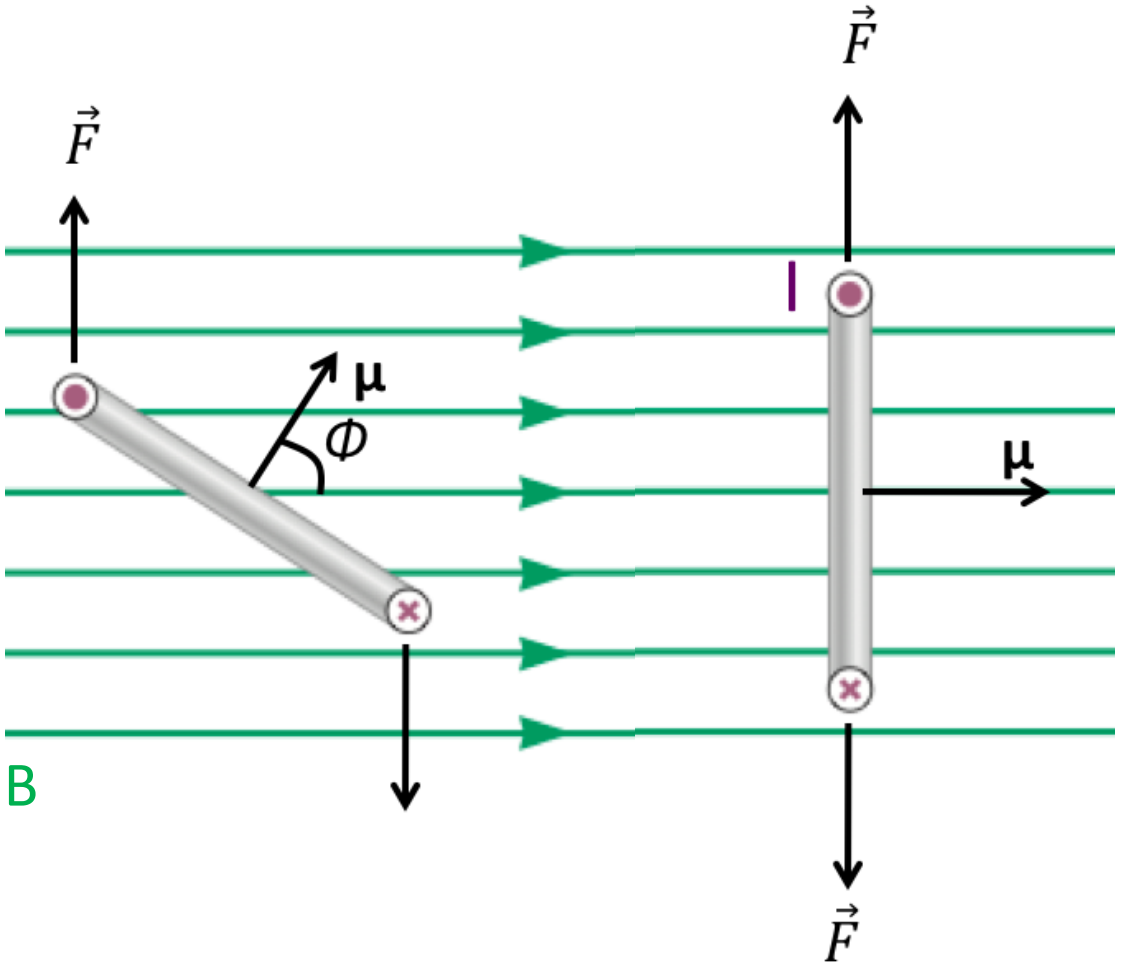

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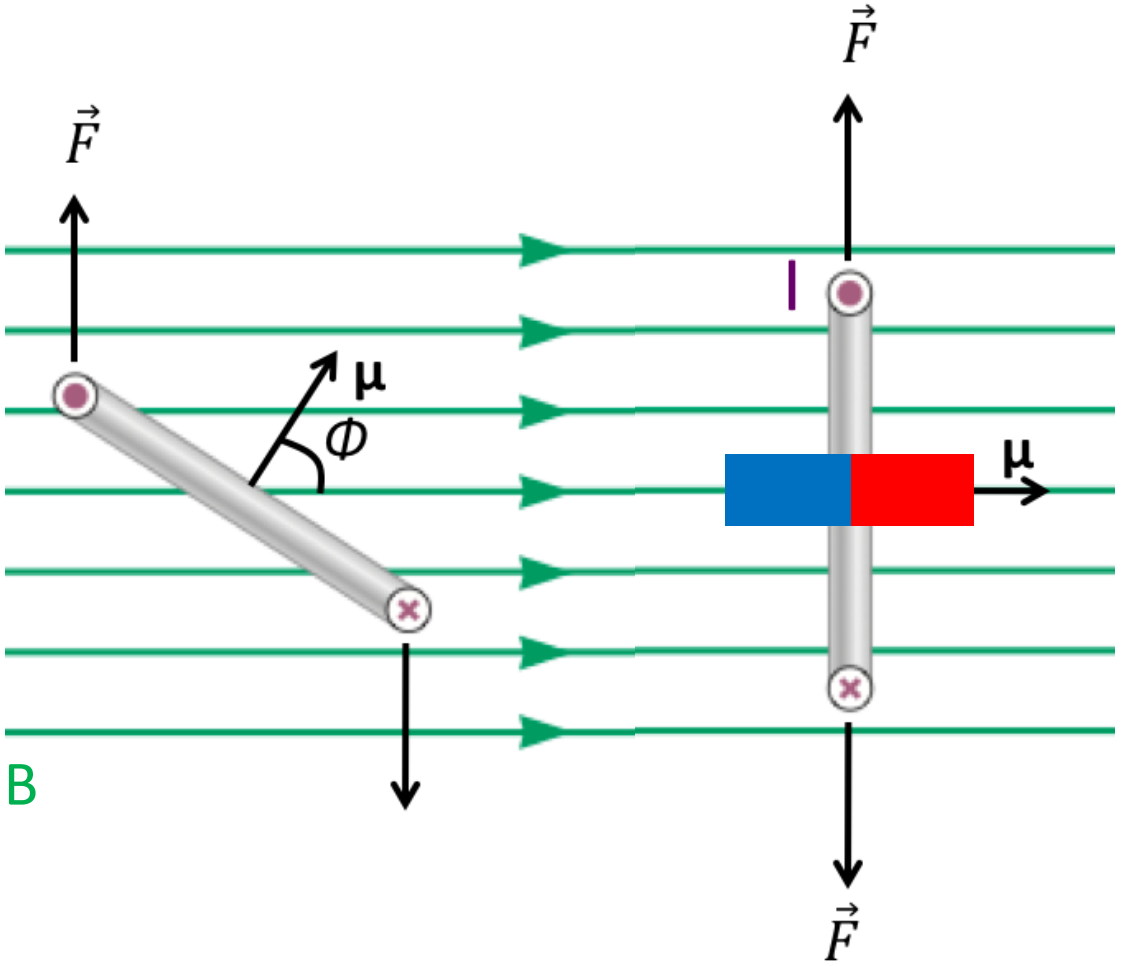
Current Loop and non-uniform B

- Current loop and uniform B: No net force, only torque



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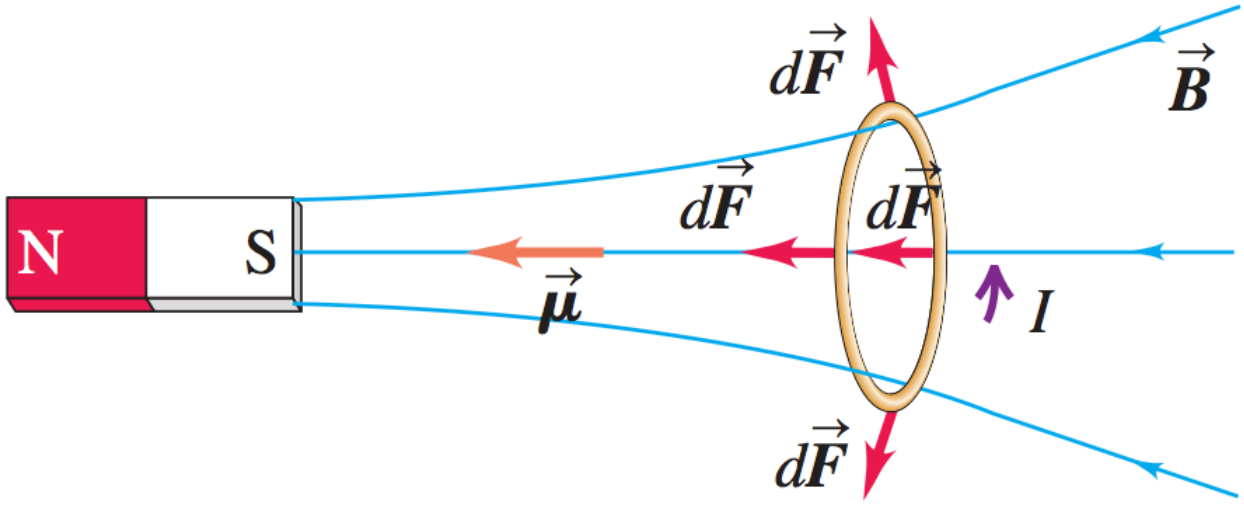

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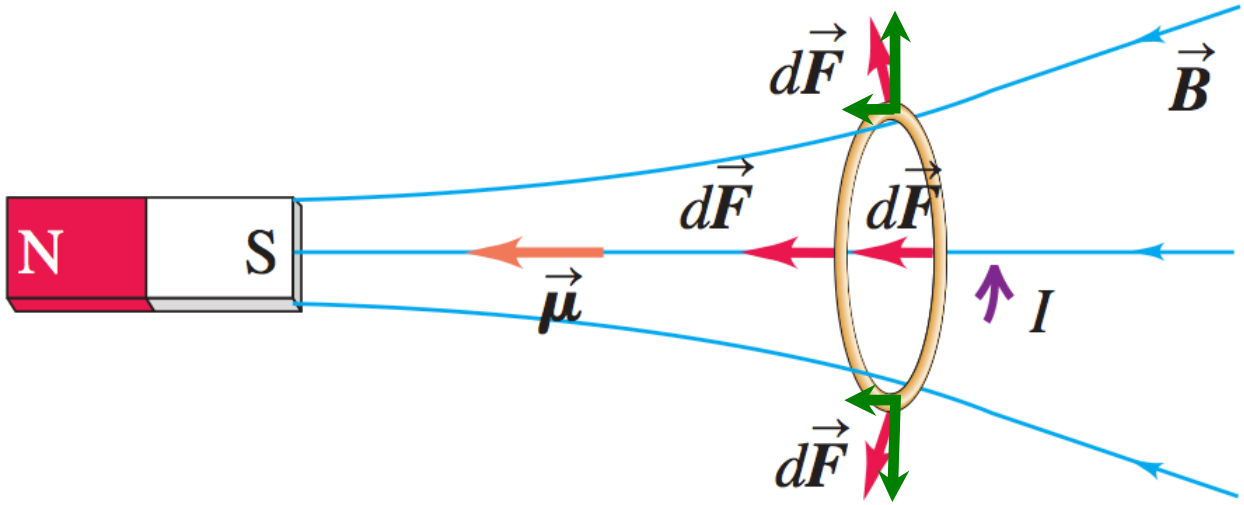

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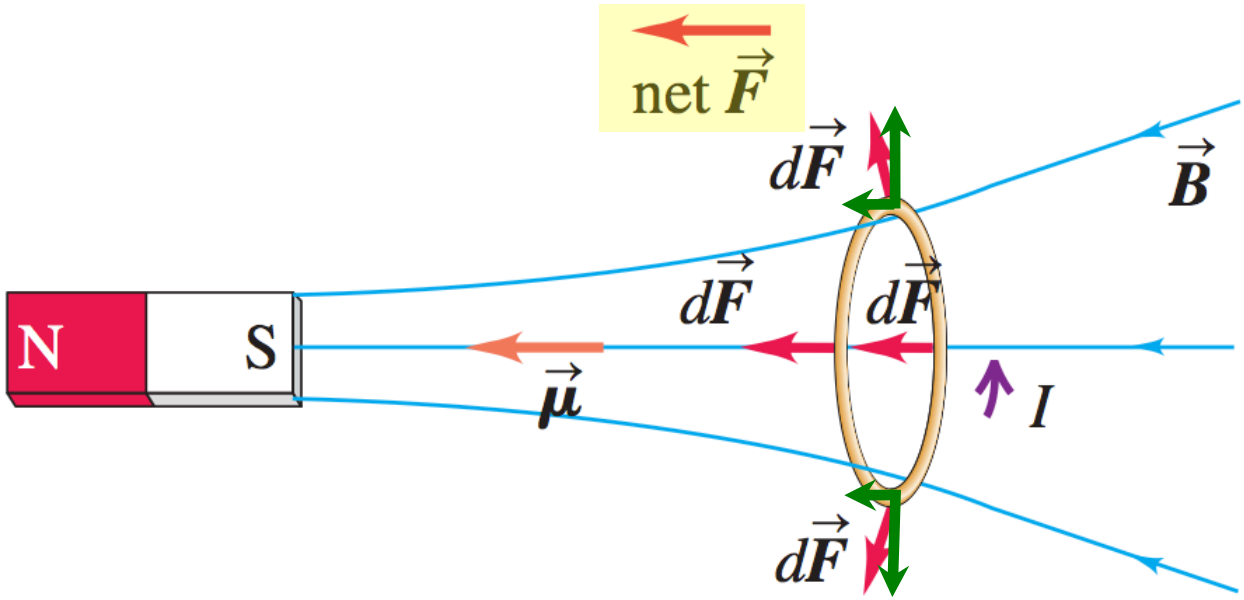
Current Loop and non-uniform B

- Current loop and non-uniform B: Net force is non-zero!



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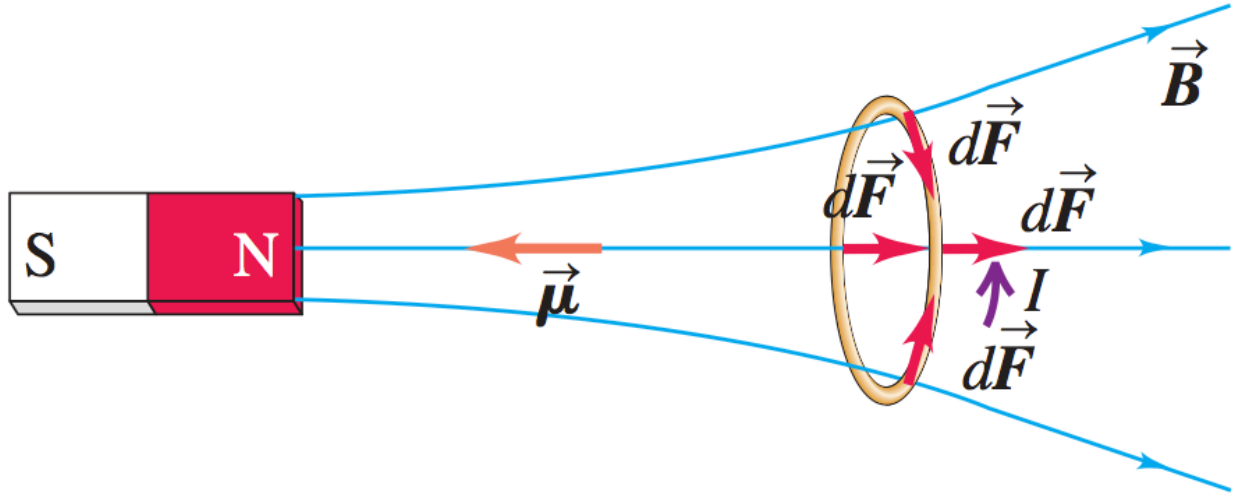

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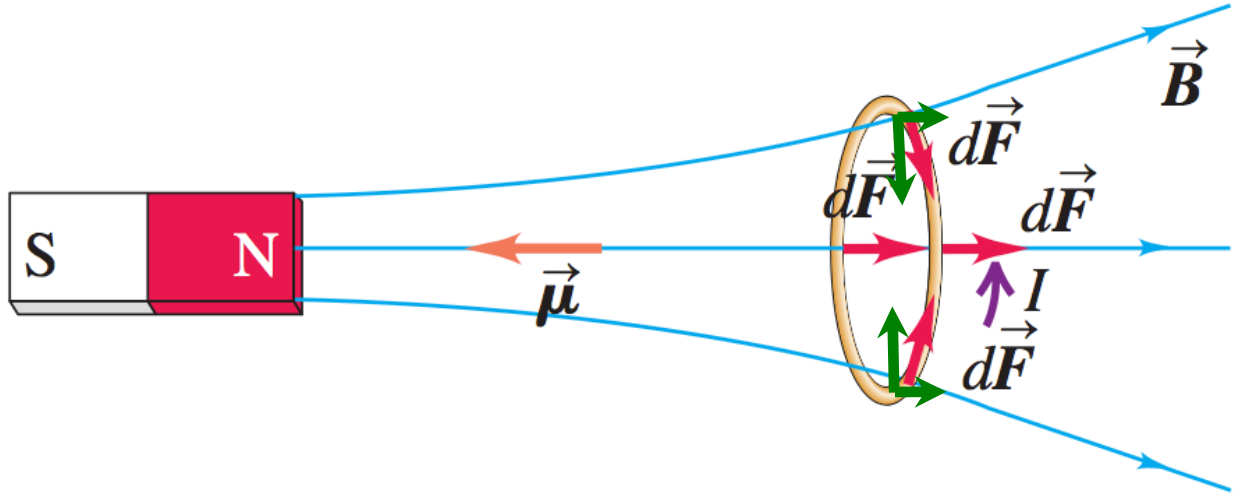

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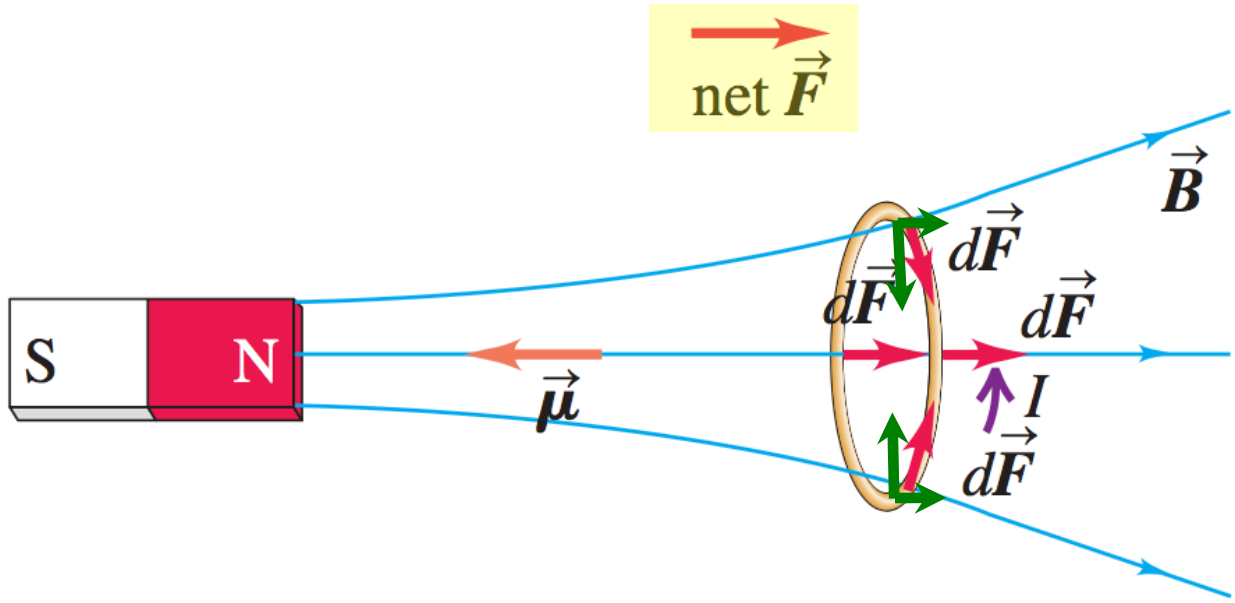

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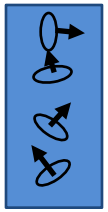
- Random directions, so net magnetic moment is zero.



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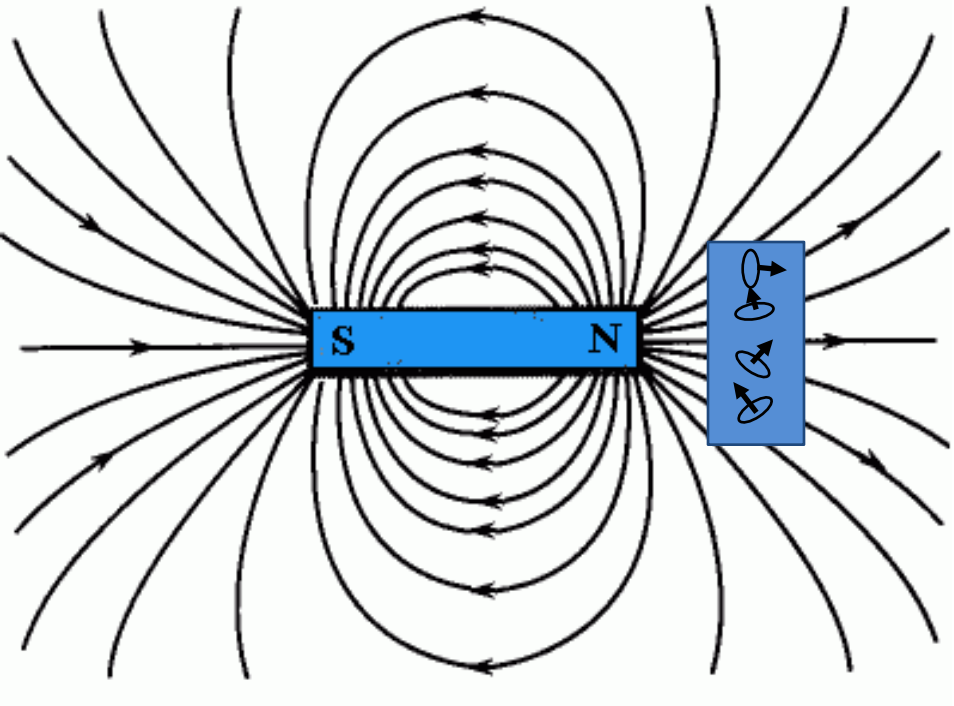

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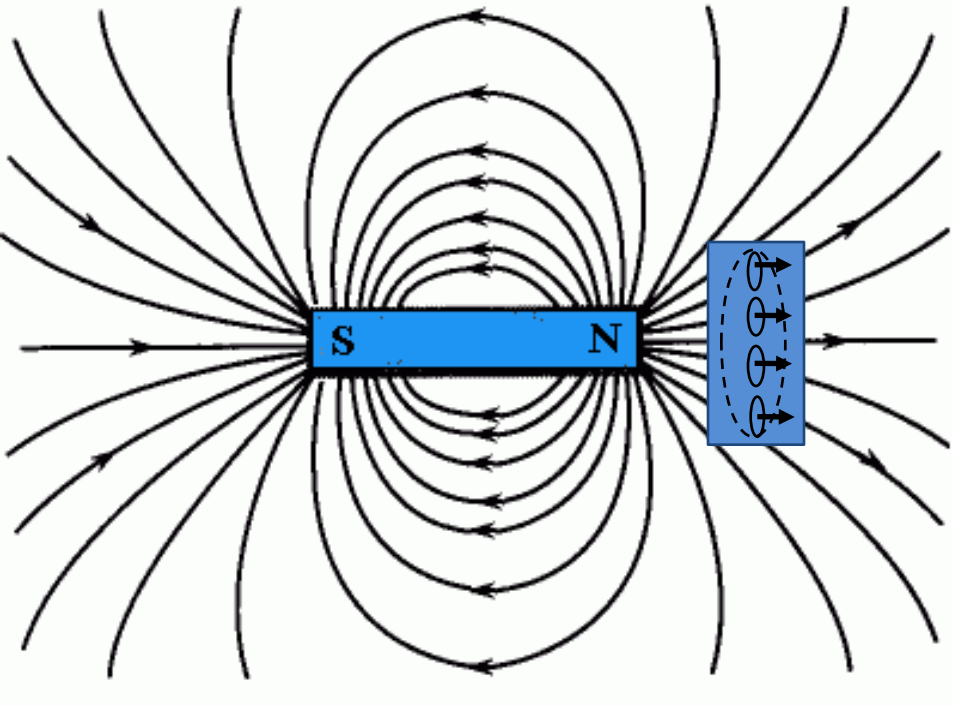
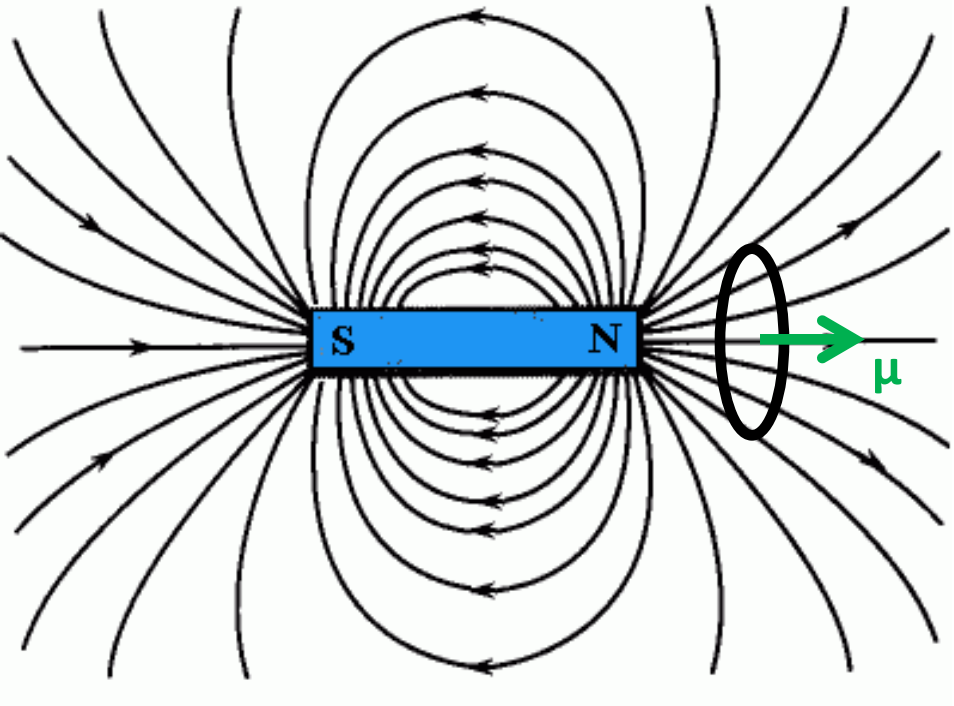


- Electrons spinning around the nucleus have magnetic moment.
- Random directions, so net magnetic moment is zero.
- Under an external magnetic field, moments align; net moment is no longer zero.

Current Loop and non-uniform B



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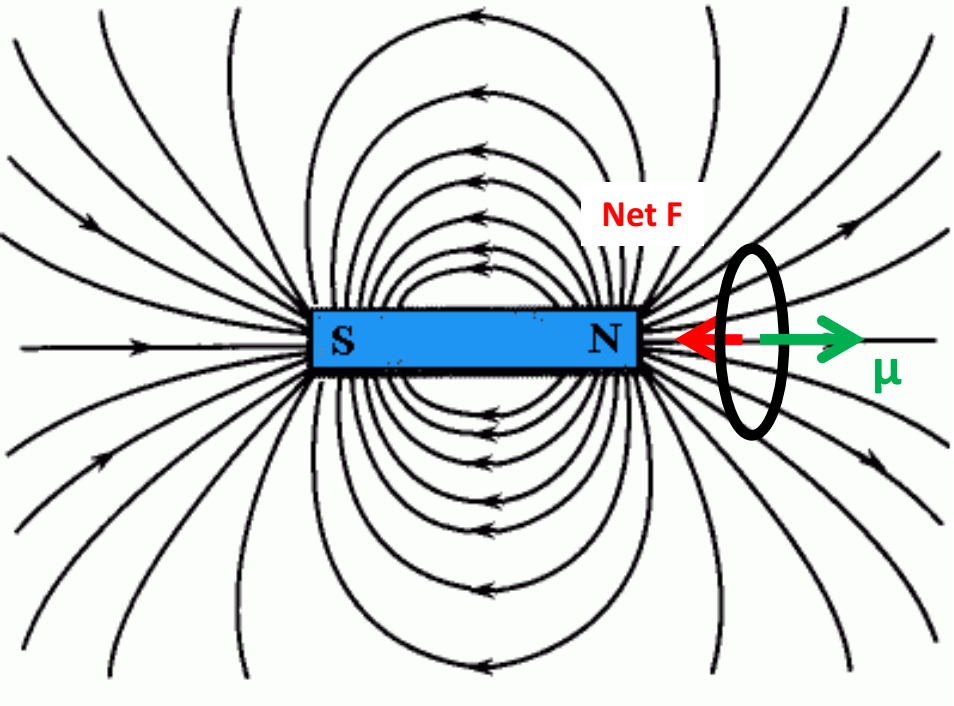
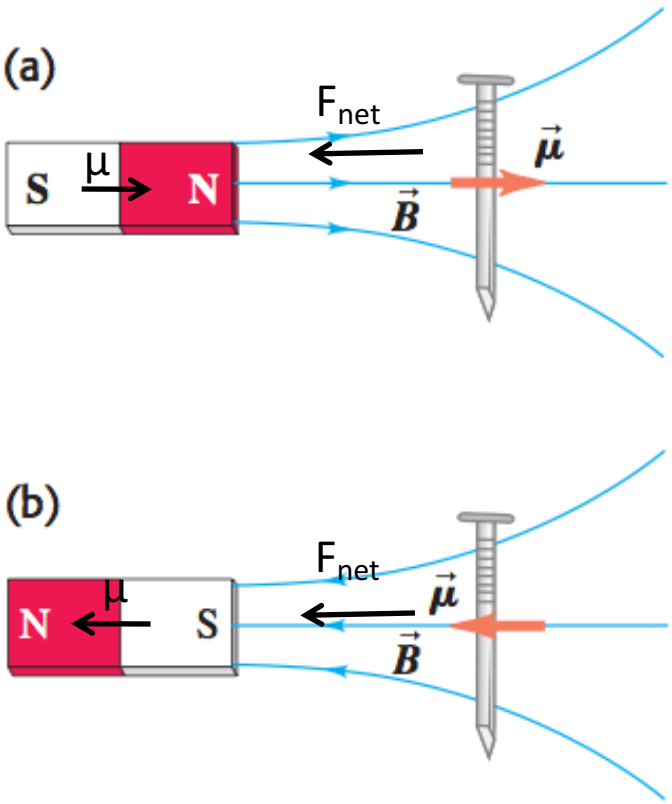


- Electrons spinning around the nucleus have magnetic moment.
- Random directions, so net magnetic moment is zero.
- Under an external magnetic field, moments align; net moment is no longer zero.
- If the external magnetic field is not uniform, there will be a net force.

Current Loop and non-uniform B



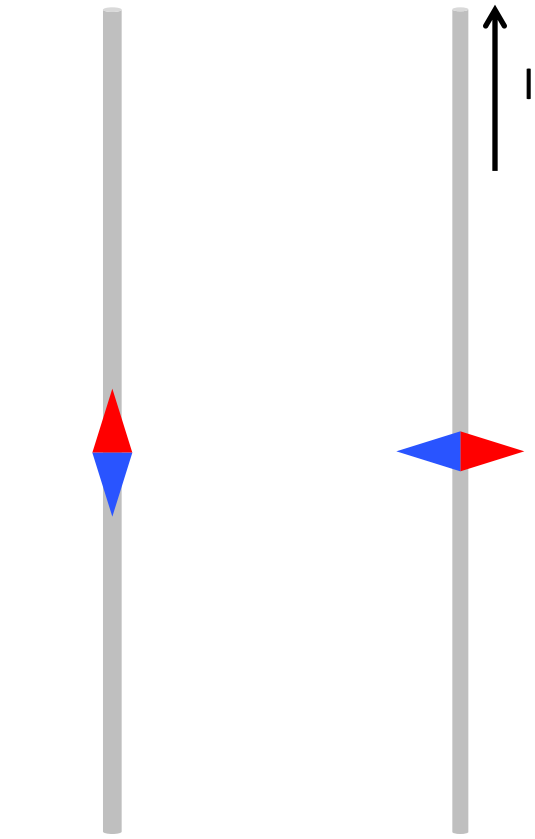
- Iron nail being attracted by a magnet
- Attraction is the same whether the iron nail is closer to the South or to the North magnetic pole.

Sources of Magnetic Field

Magnetic Field and Electric Current

No current

Magnetic Field and Electric Current



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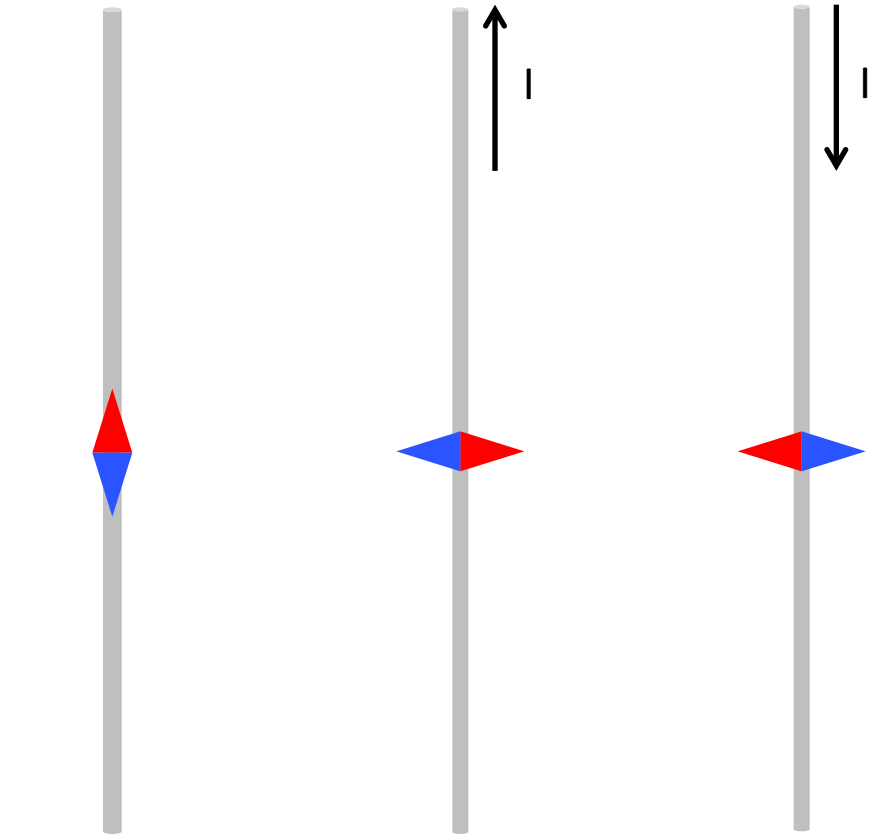

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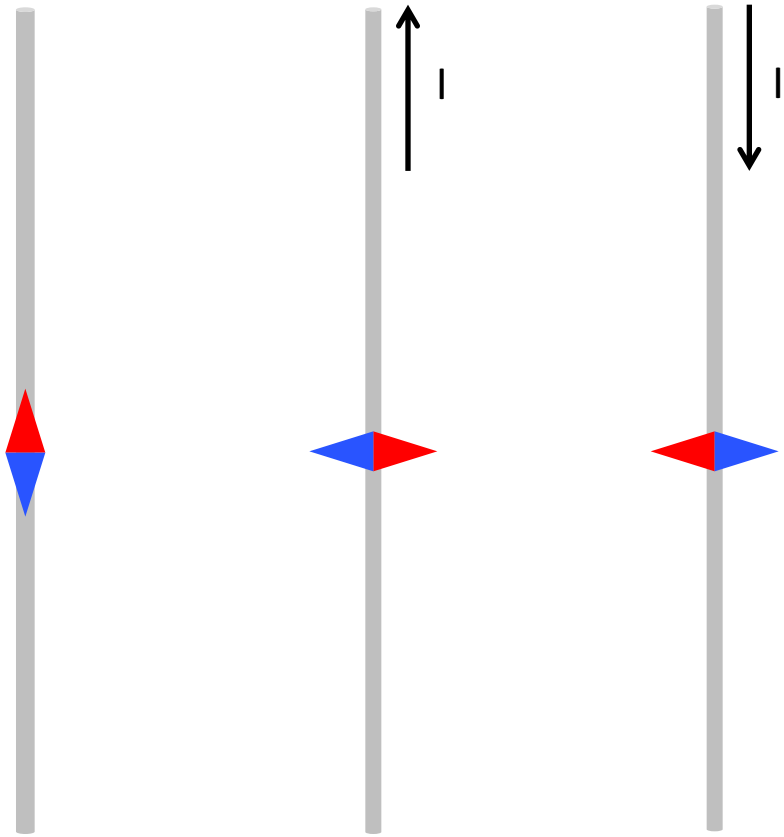


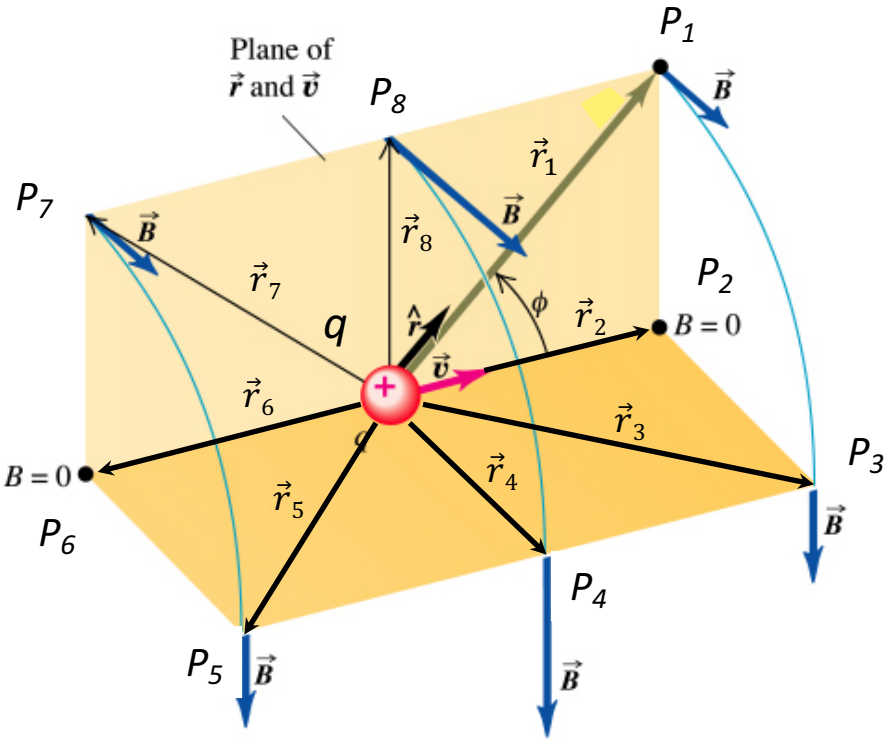
No current

It suggests that a magnetic field can be produced by electric current (moving charges)

Sources of Magnetic Field

- Magnetic field of a moving charge
- Magnetic field of a current element
- Magnetic field of a straight current-carrying conductor
- Magnetic field of a circular current loop

B-field of a moving charge



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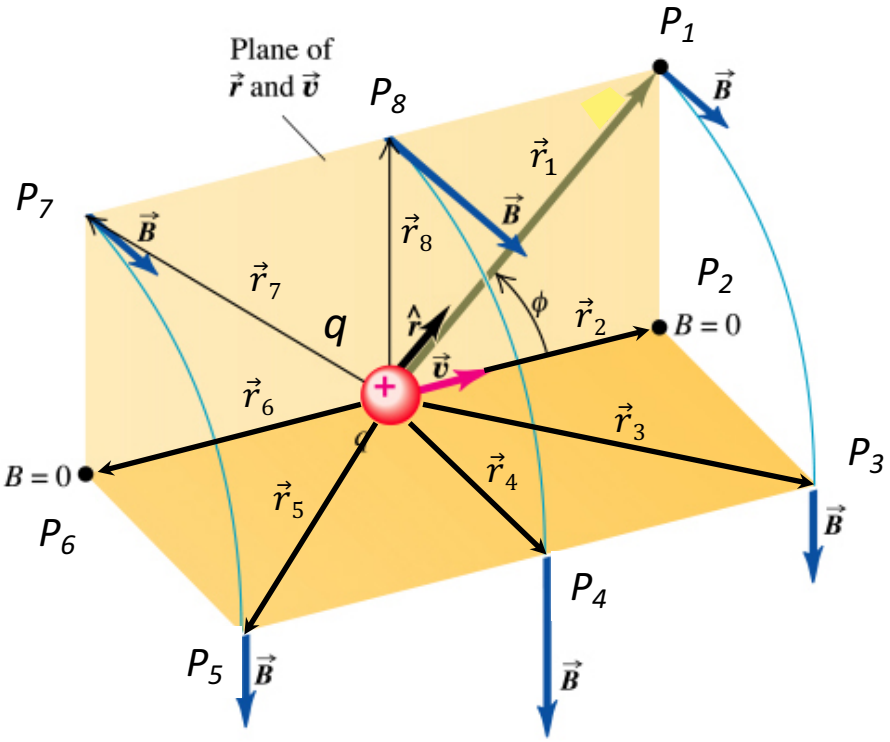

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$$

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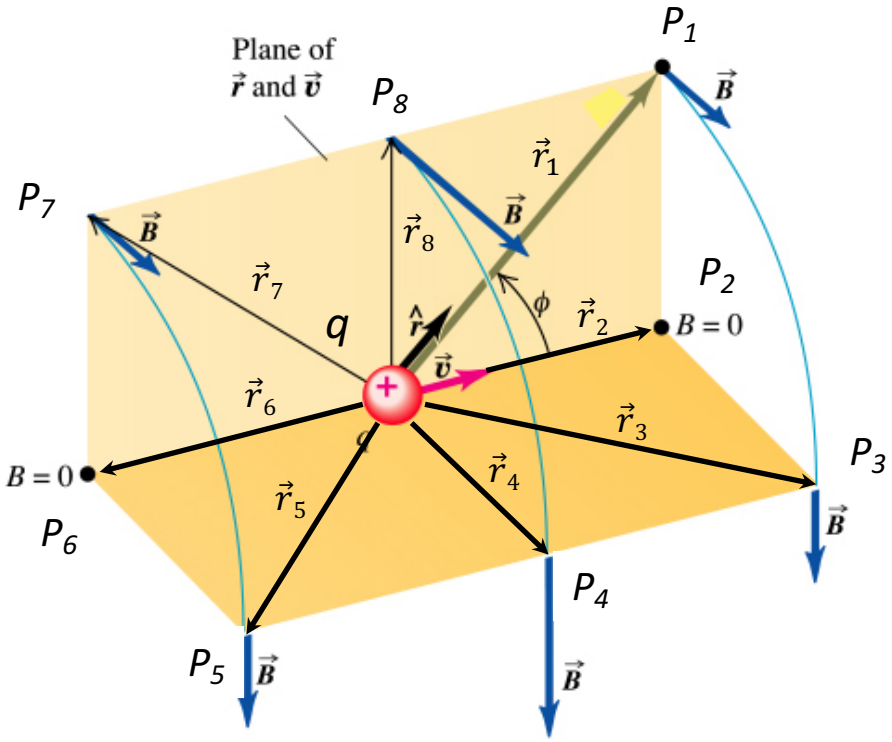

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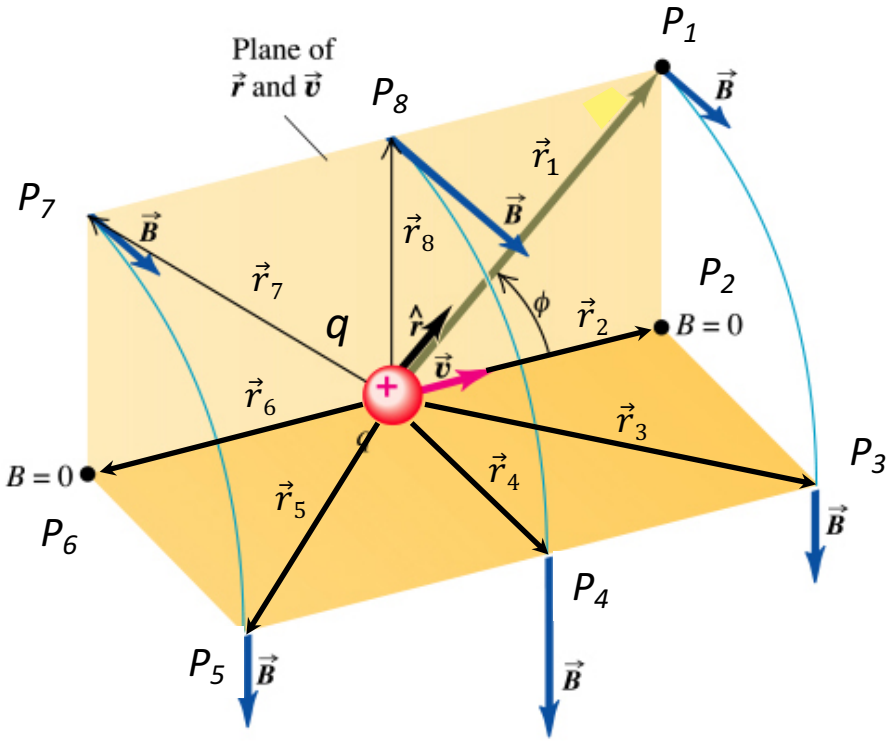

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Magnetic constant or
Permeability of free-space:

$$\mu_0 = 4\pi\times10^7\ Tm/A$$

B-field of a moving charge

$$\vec{E} = \frac{1}{4\pi\epsilon_0}\frac{q}{r^2}\hat{r}$$

$q = +9nC$

$a)\ Magnitude\ of\ \vec{E}\text{: } \left|\vec{E}\right| = ?$

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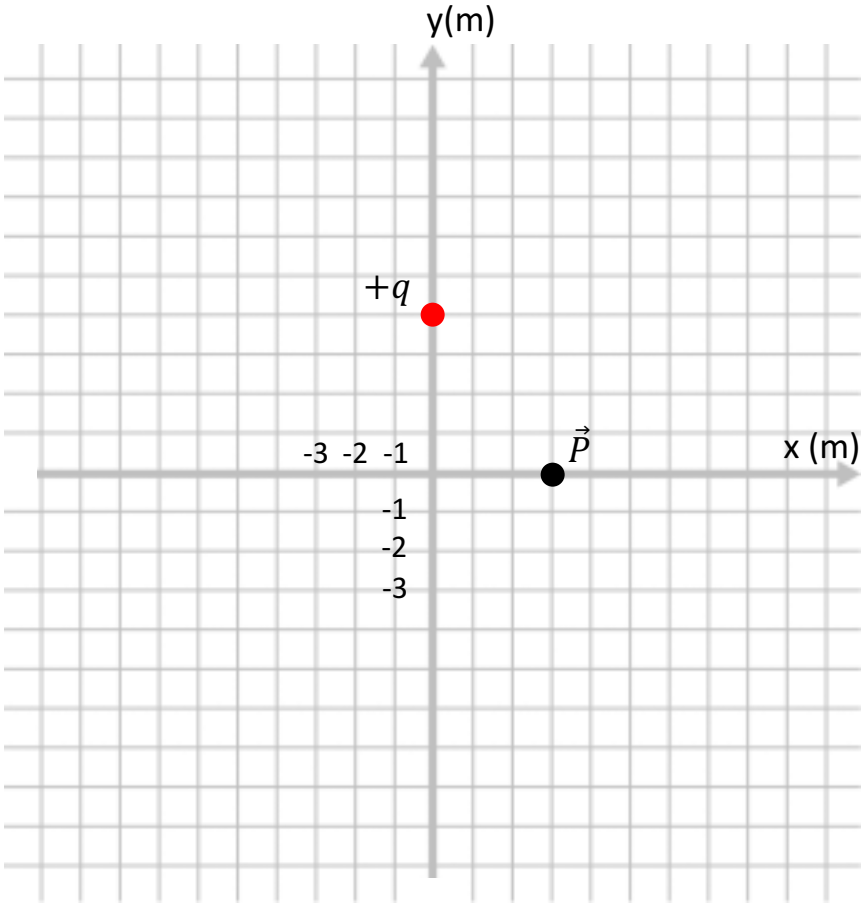

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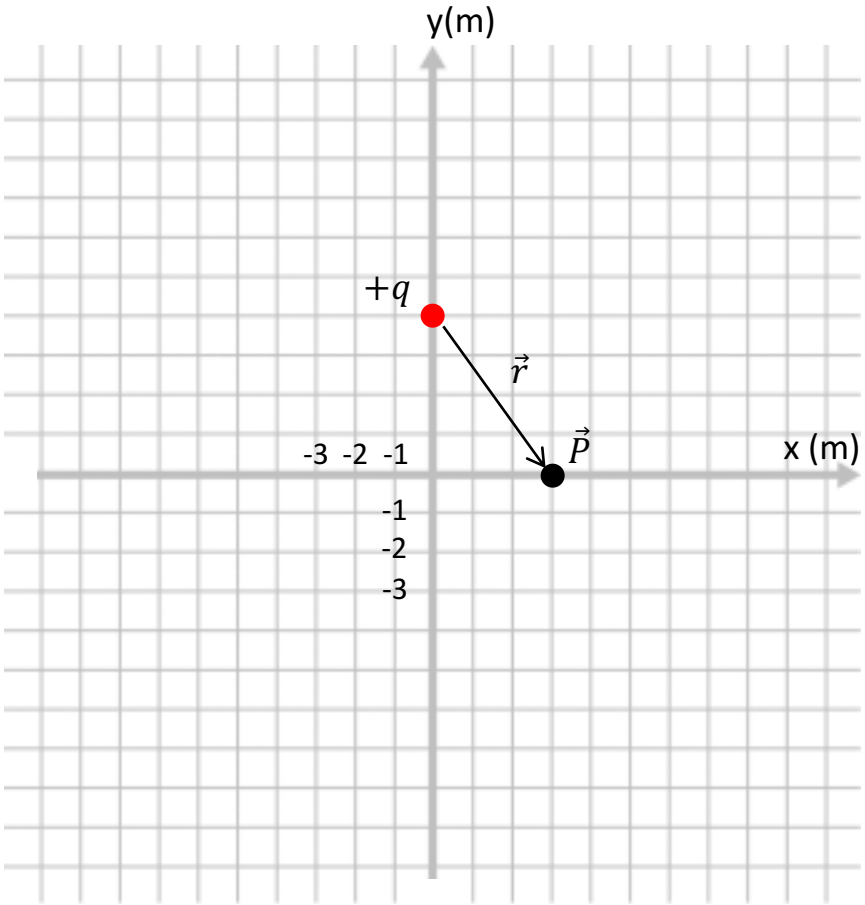

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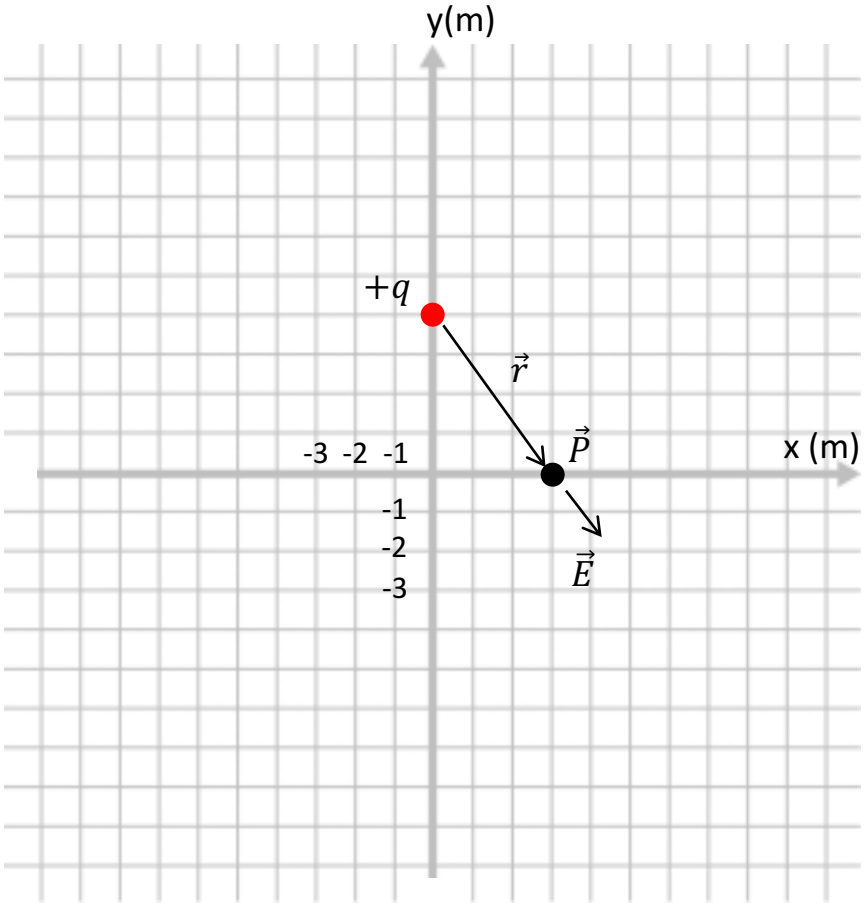

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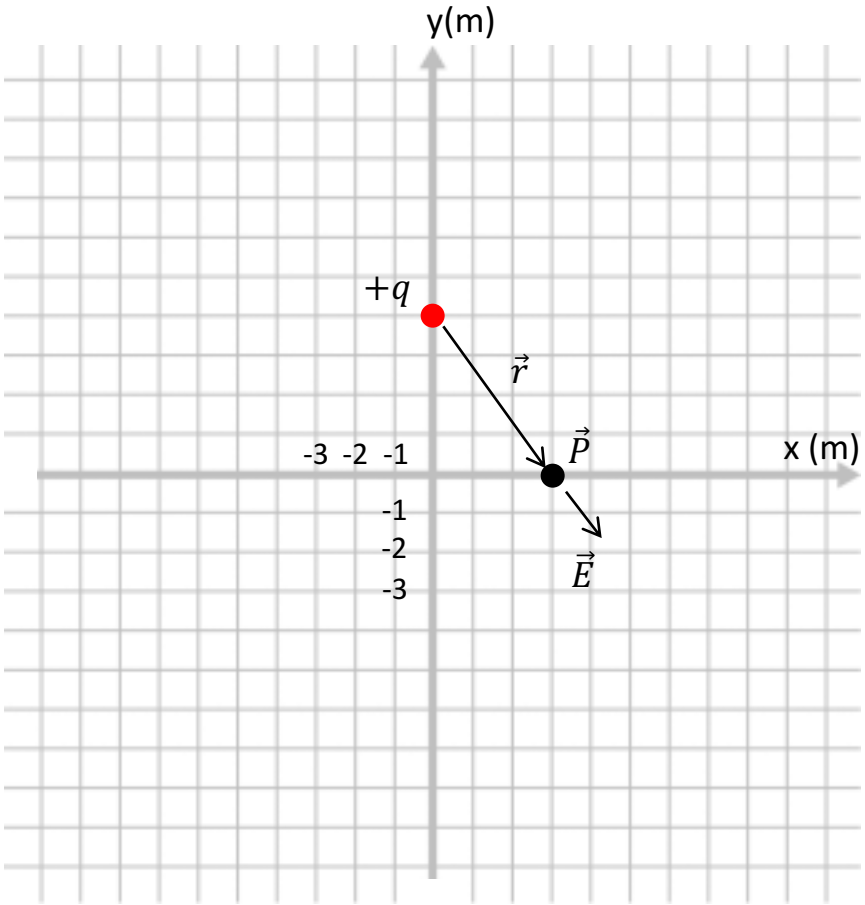

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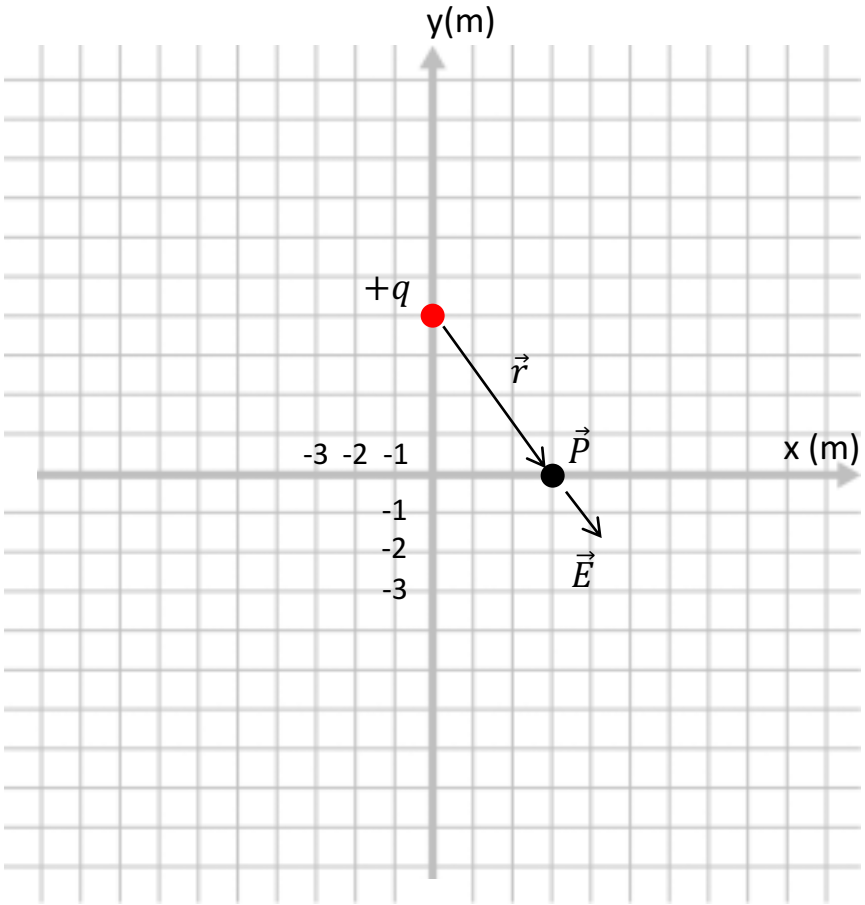

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$$r = \sqrt{3^2 + 4^2} = 5\ m$$

B-field of a moving charge

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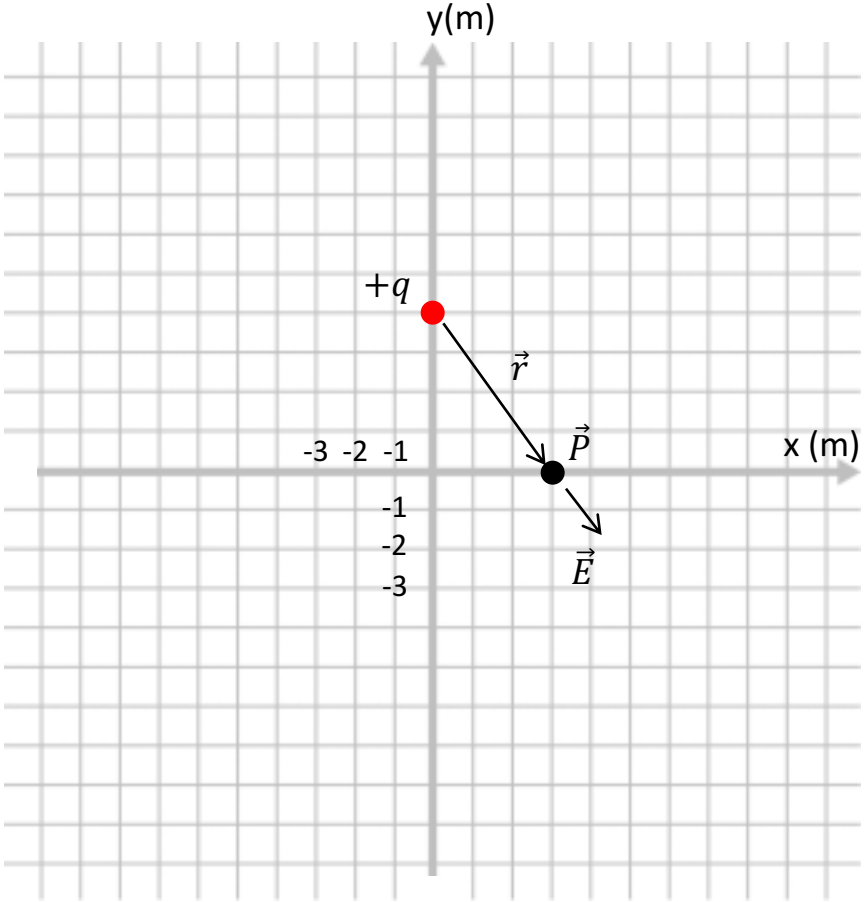

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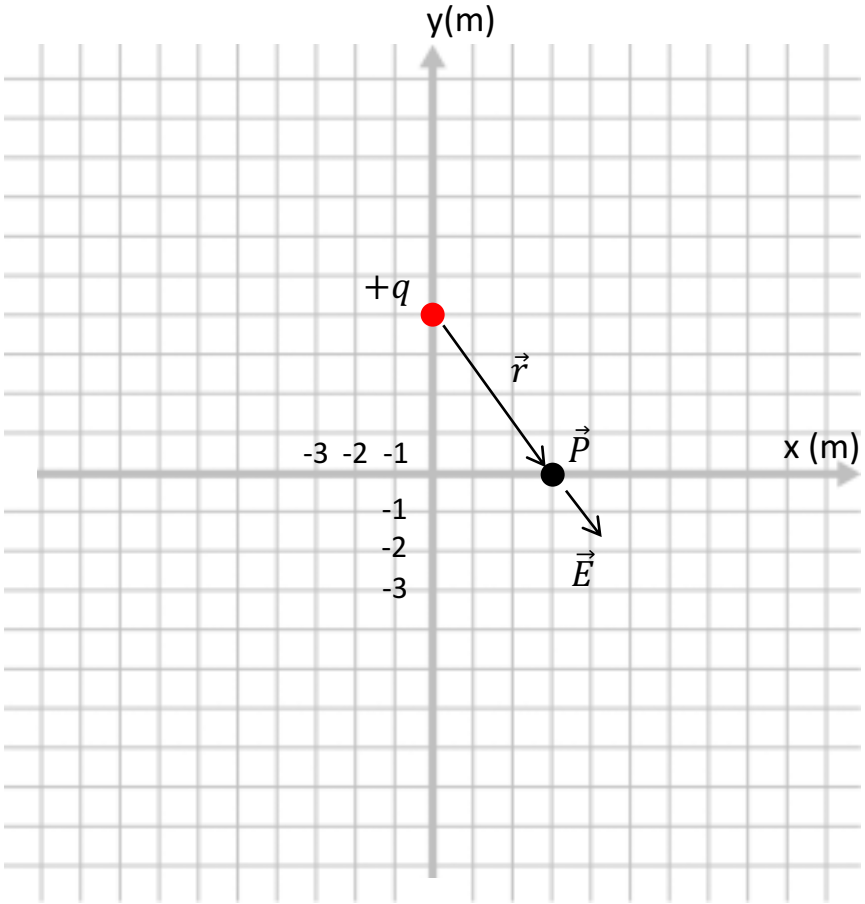

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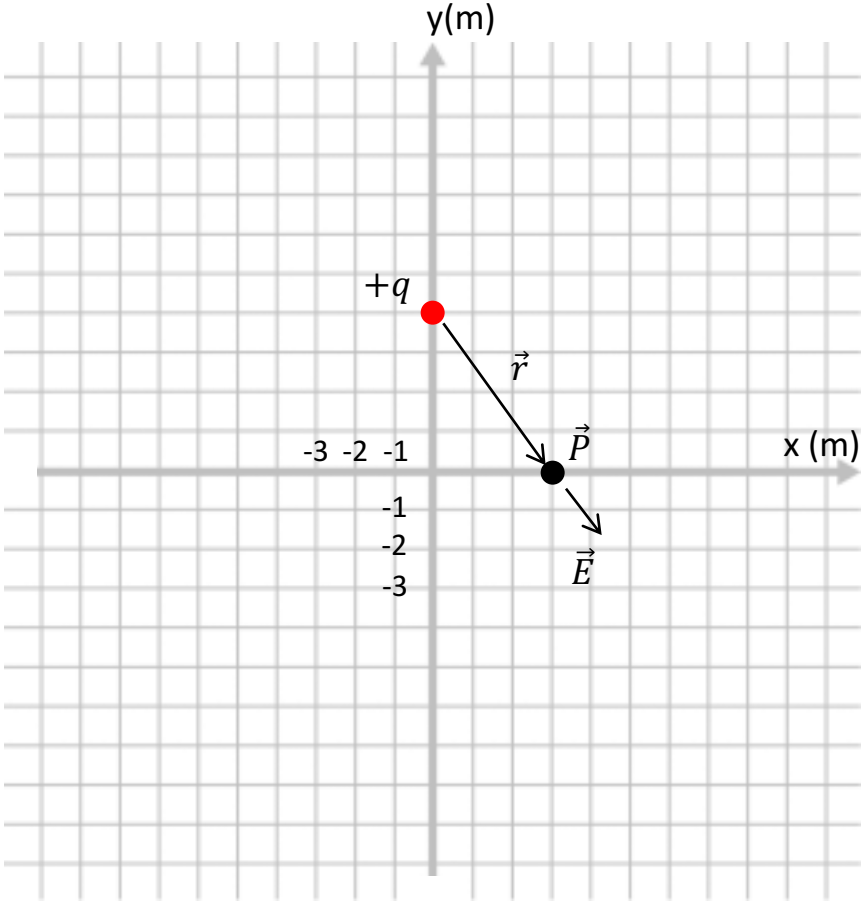

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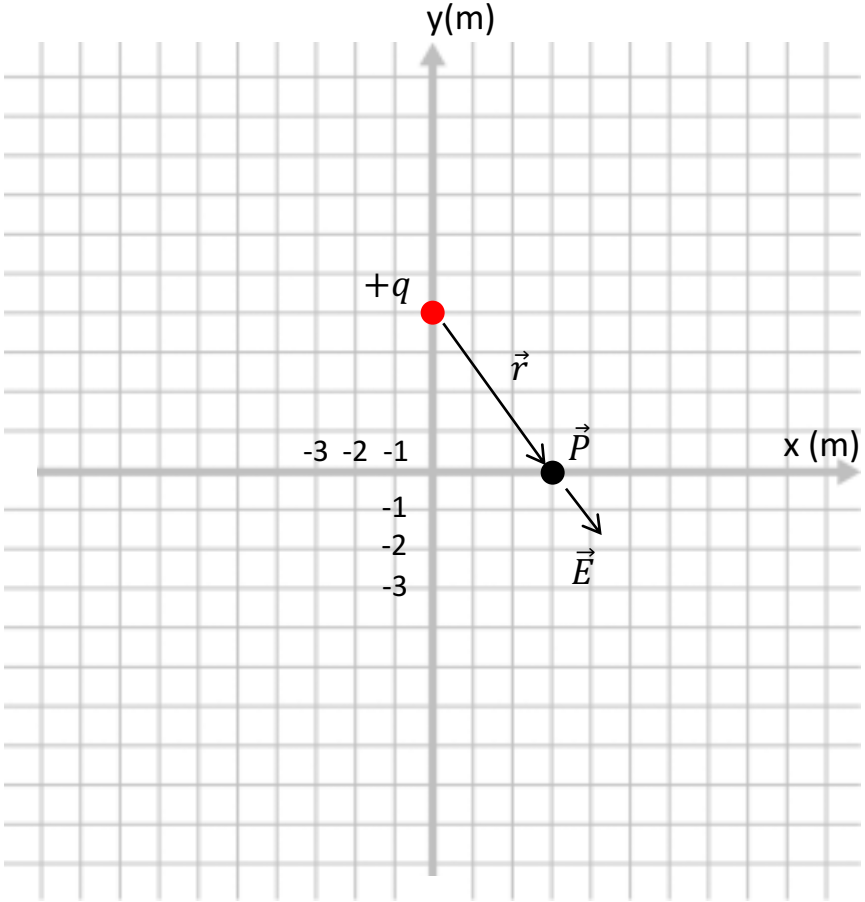

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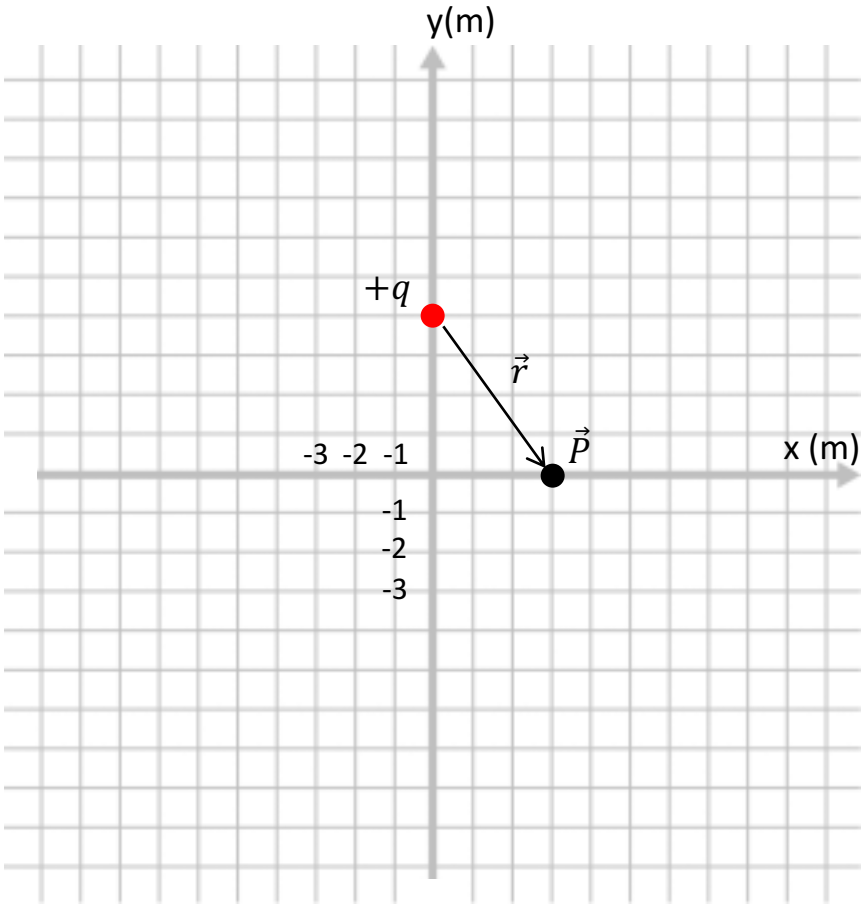
$$\hat{E} = \frac{\vec{r}}{|\vec{r}|} = \frac{3\hat{x} - 4\hat{y}}{5}$$

B-field of a moving charge

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{q\vec{v}\times\hat{r}}{r^2}$$

$$q = +9nC$$



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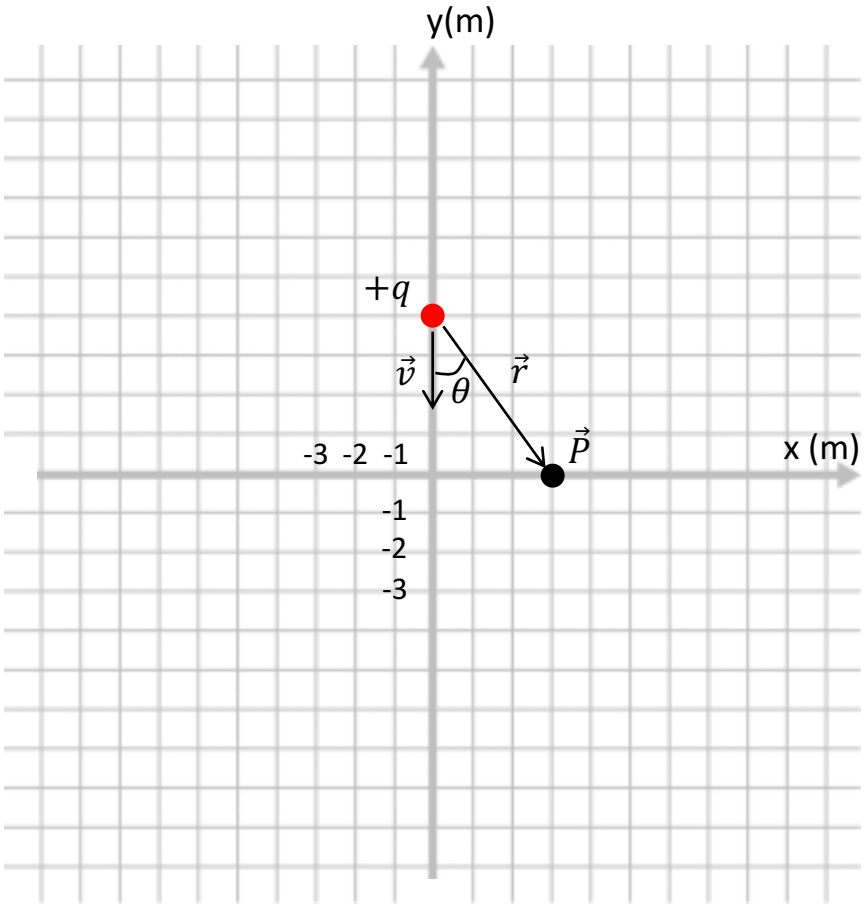

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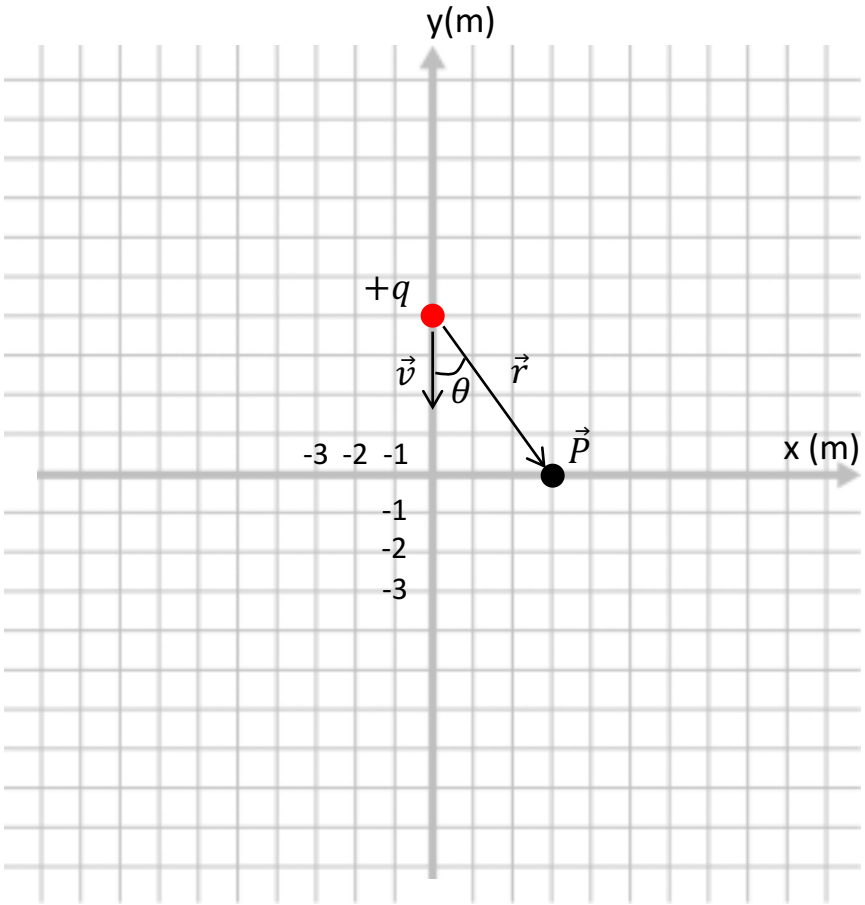

$q = +9nC$
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$b)\ Direction\ of\ \vec{B}$: $\hat{B} = ?$

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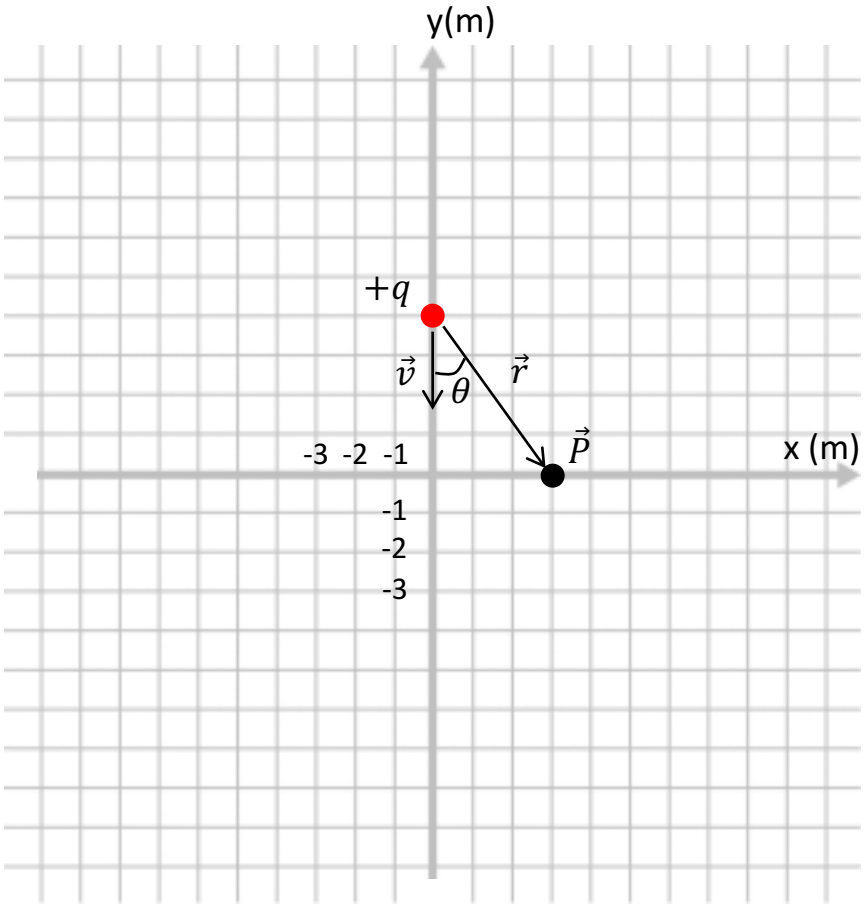

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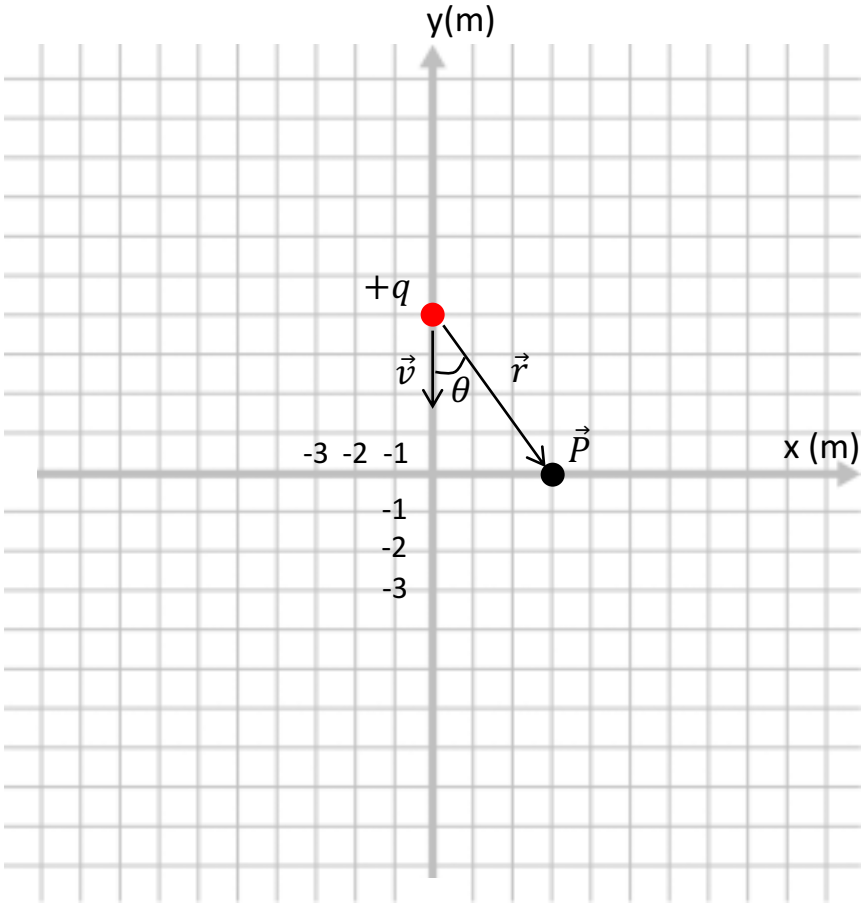

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$$r = \sqrt{3^2 + 4^2} = 5\ m$$

$$\theta = \sin^{-1}\left(\frac{3}{5}\right) = 36.9°$$

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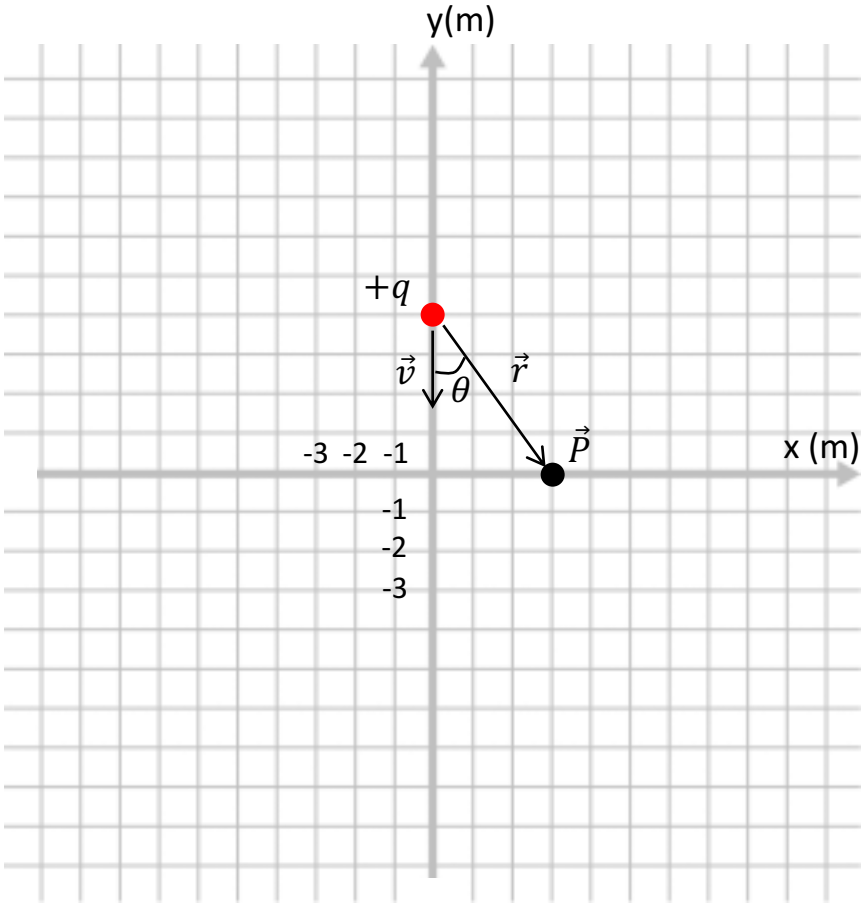

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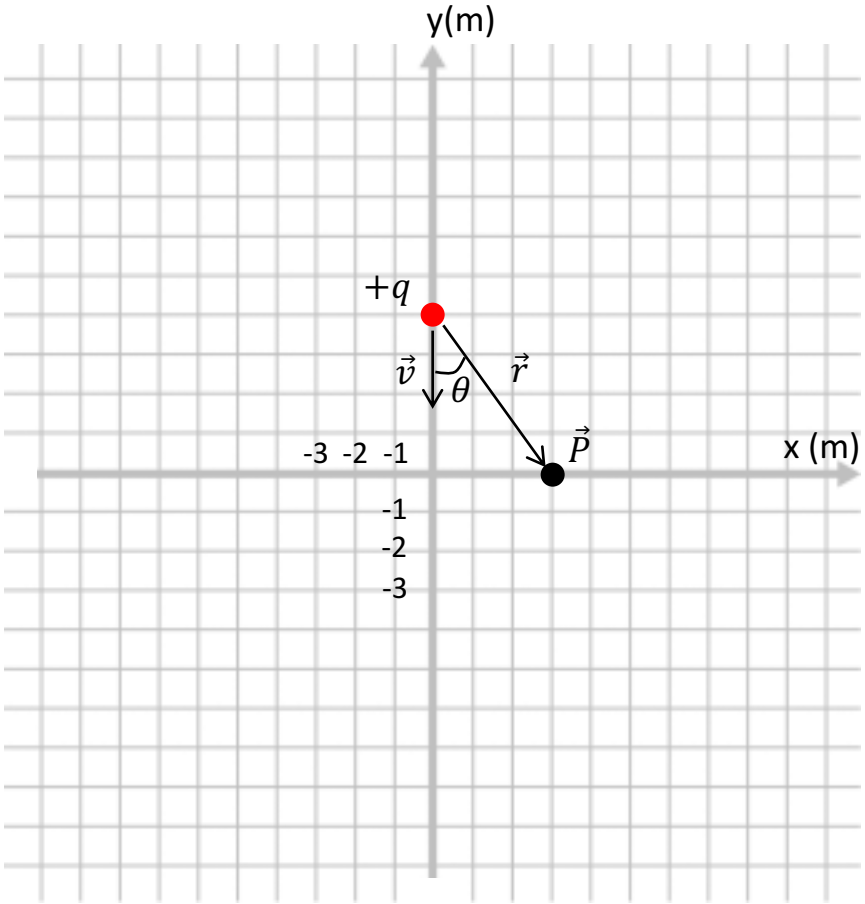

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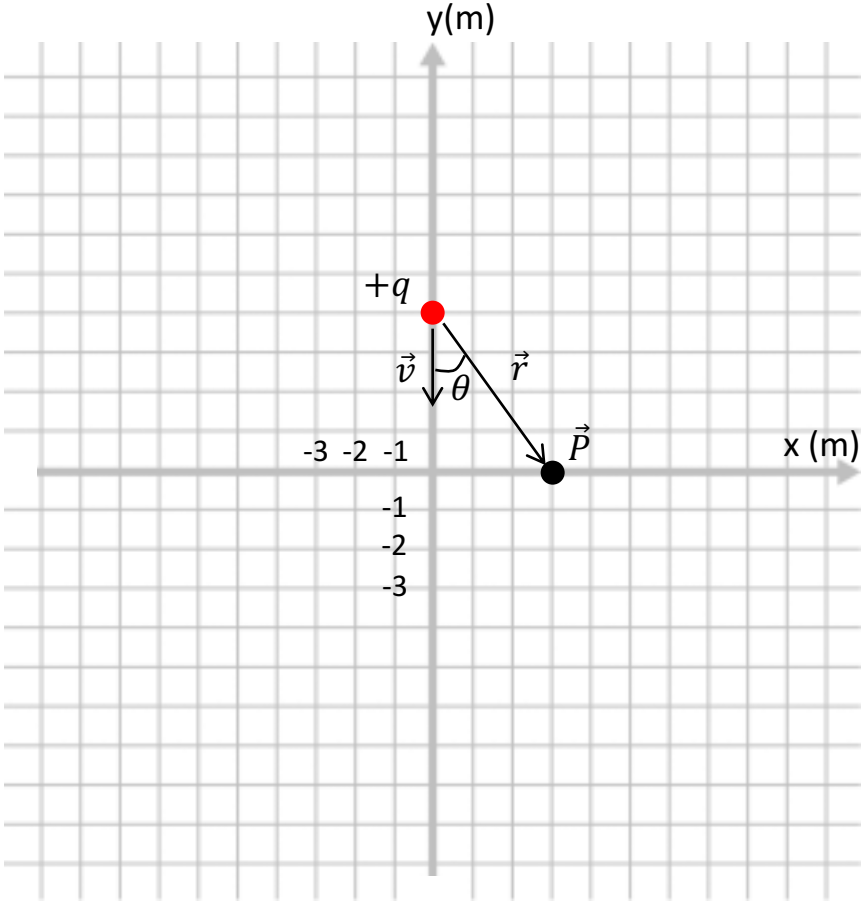

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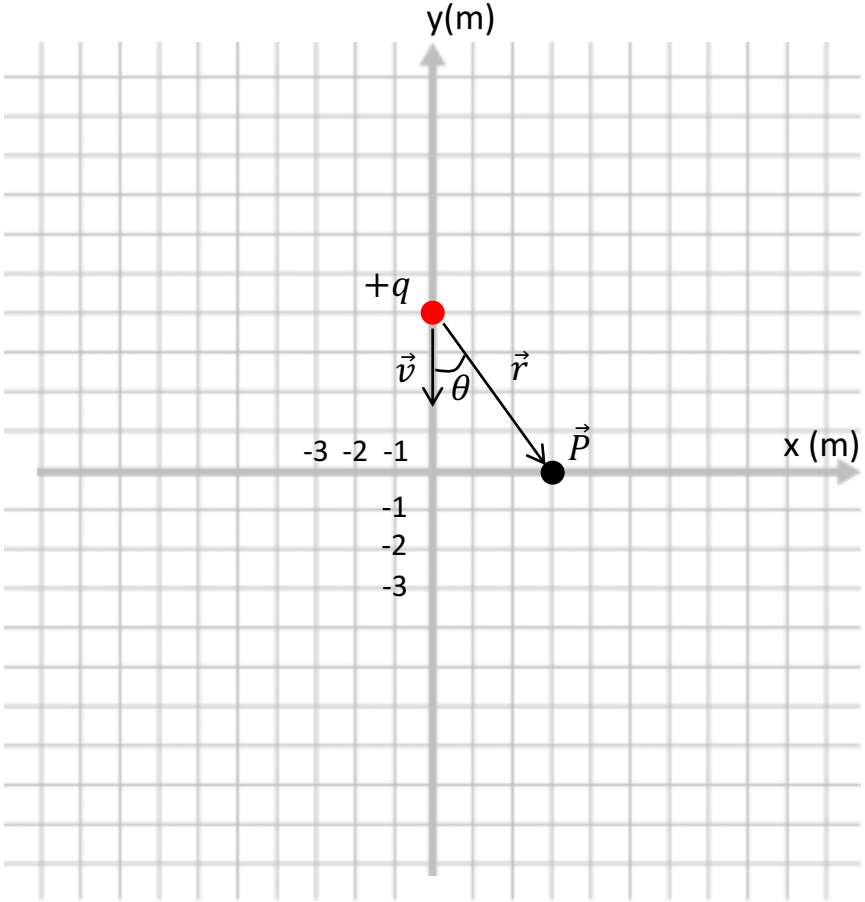

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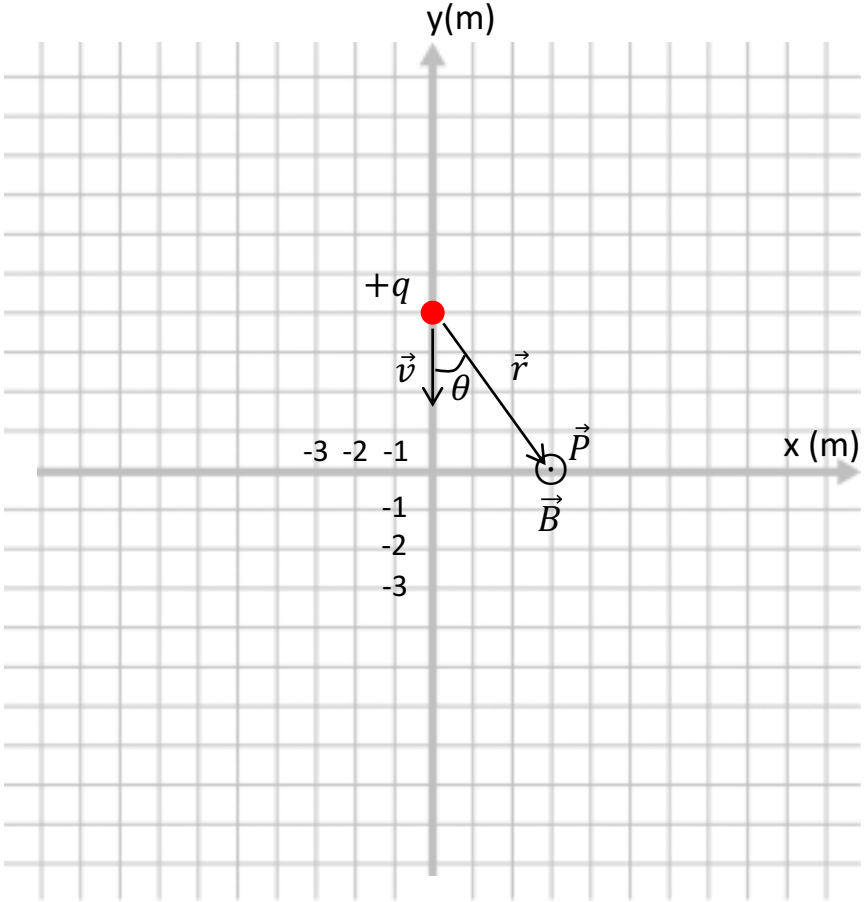

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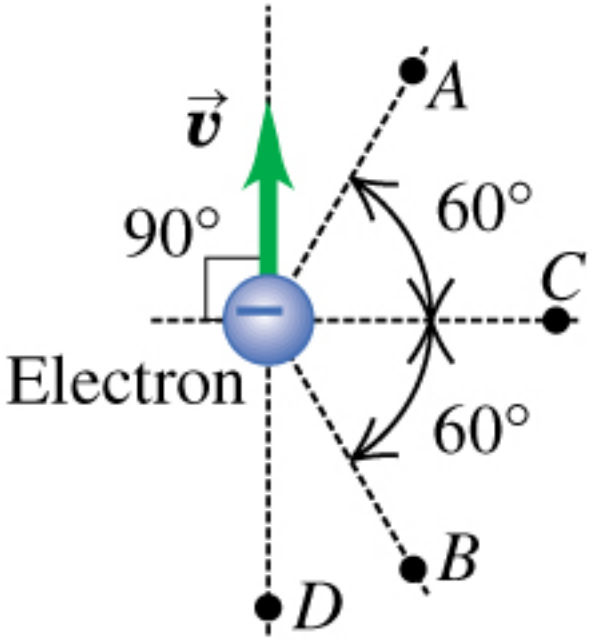
Example: An electron moves at 0.3×10^8 m/s as shown in the figure. What is the direction and magnitude of the magnetic field this electron produces at point A, which is 1.70×10^{-6} m from the electron.



Direction:

(a) To the left
(b) To the right
(c) Out of the page
(d) Into the page

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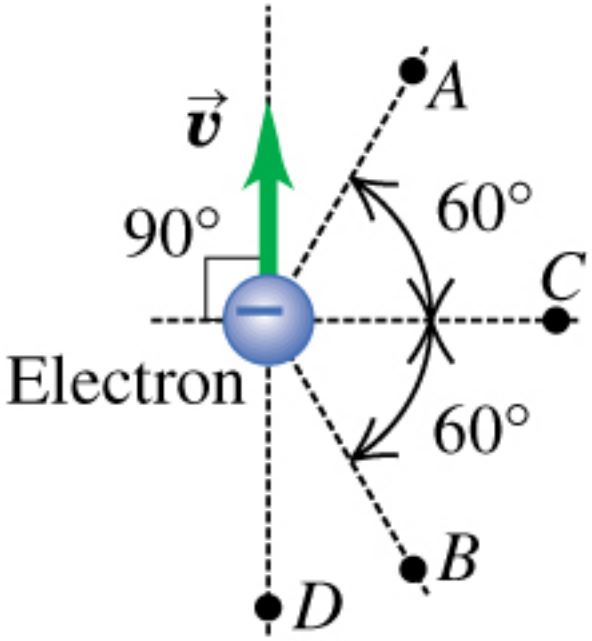

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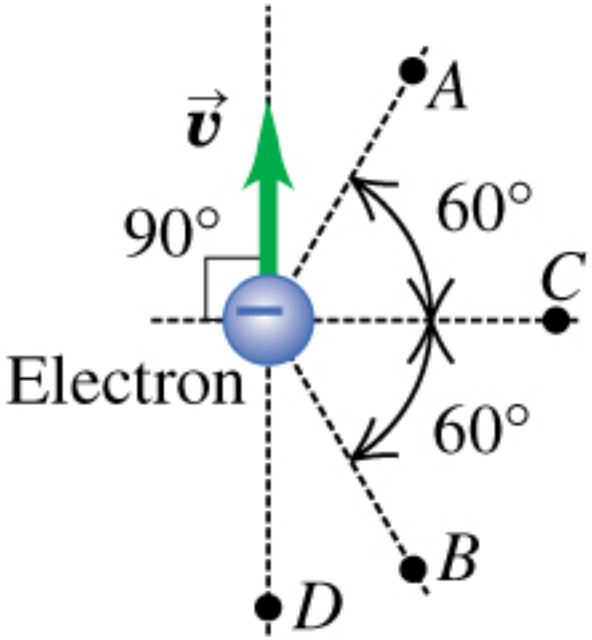

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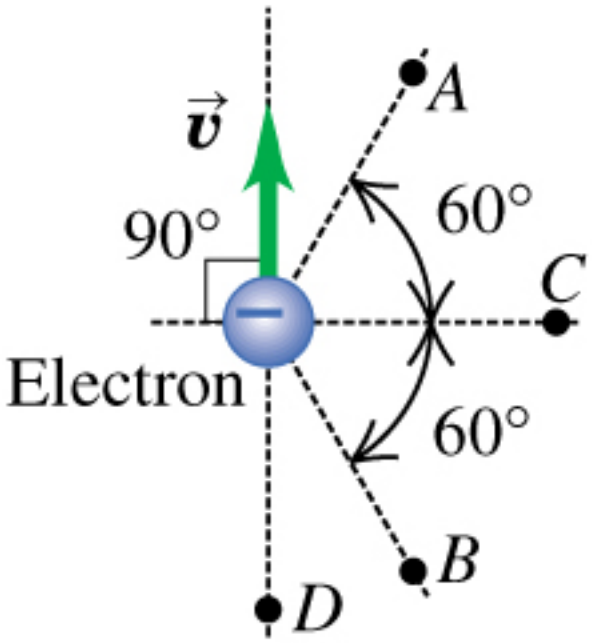

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$\mu_0 = 4\pi\times10^{-7}\ Tm/A$
$v = 0.3\times10^{8}\ m/s$
$q = 1.6\times10^{-19}\ C$
$r = 1.70\times10^{-6} m$
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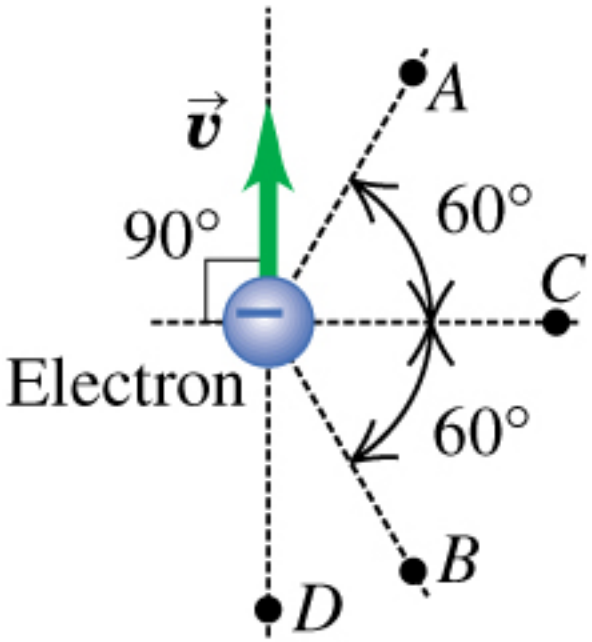

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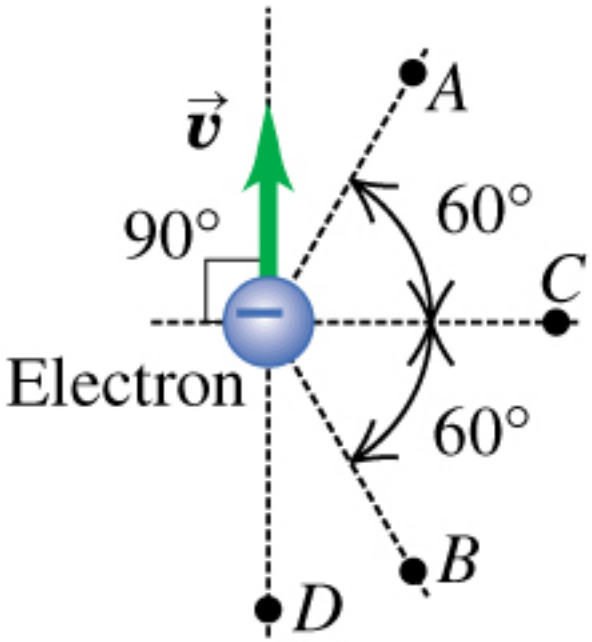

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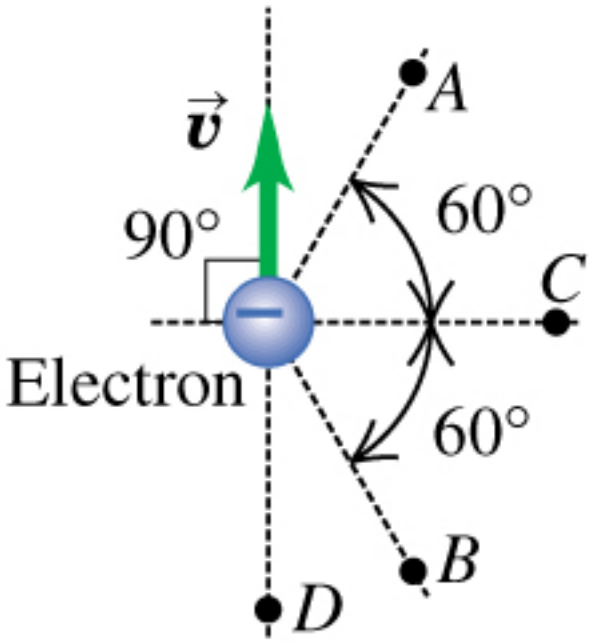

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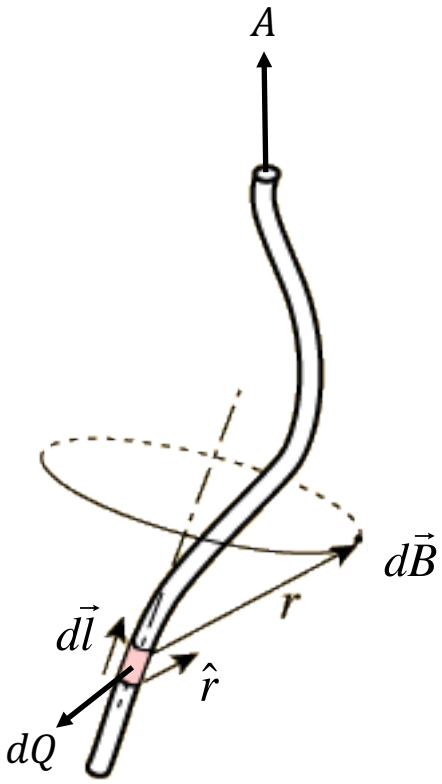
$$dB = 8.3\times10^{-8}\ T$$

B-Field of a Current Element



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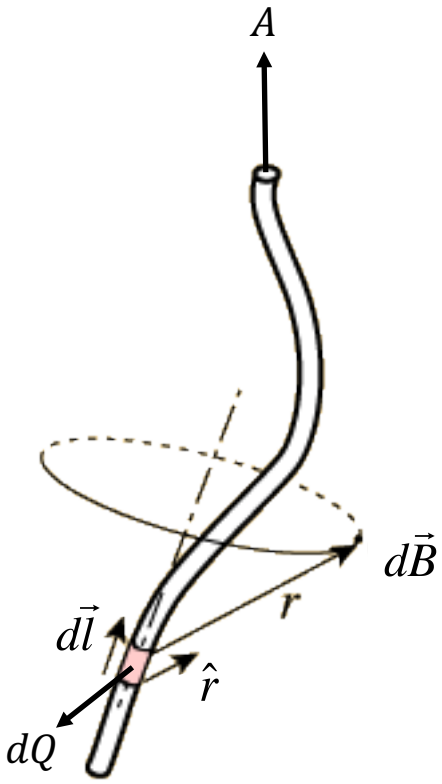

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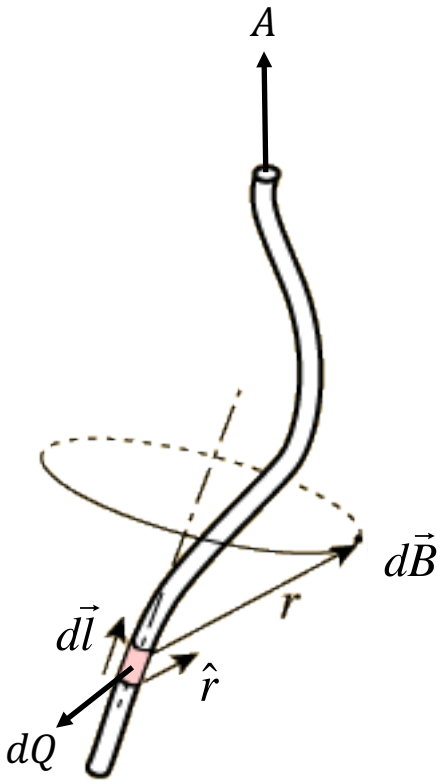

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$dQ = nqAdl$
$\vec{v} = \vec{v}_d$ (drift velocity)

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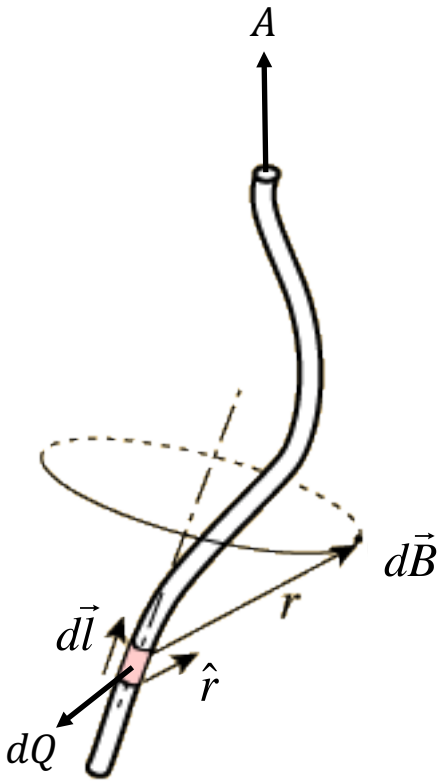

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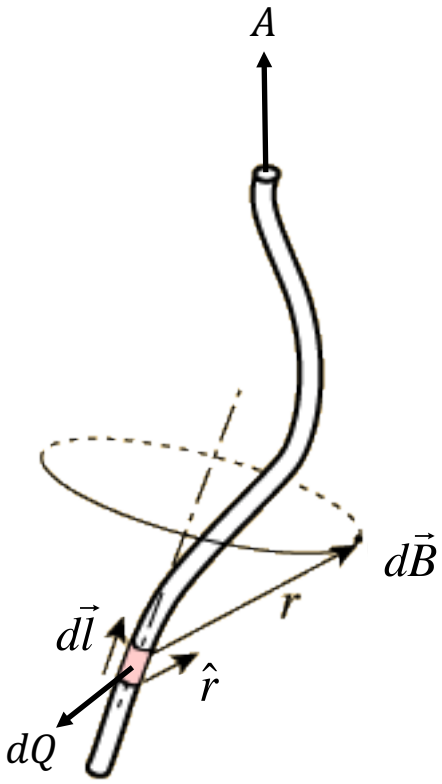

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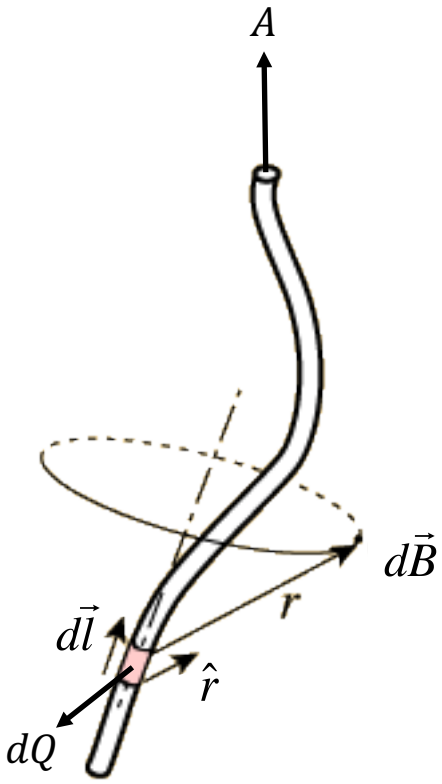

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$But\ I = nqv_dA$

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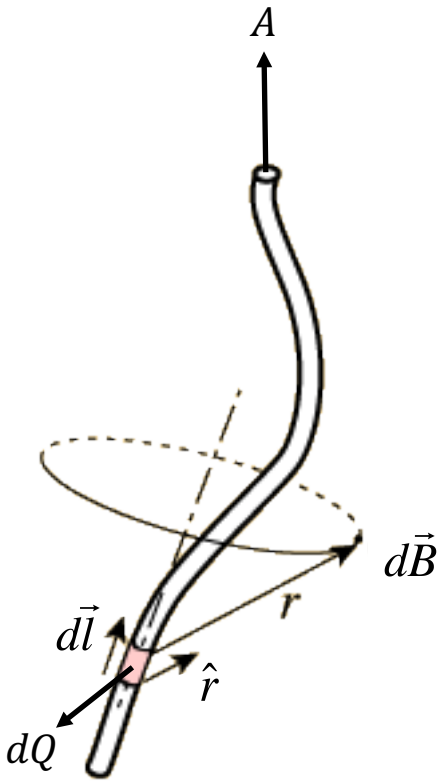

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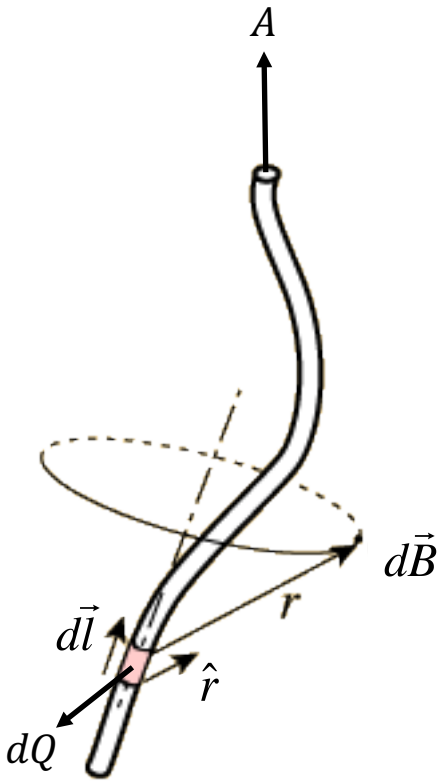

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$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{(nqAdl)\vec{v}_d\times\hat{r}}{r^2}$$

$But\ I = nqv_dA$

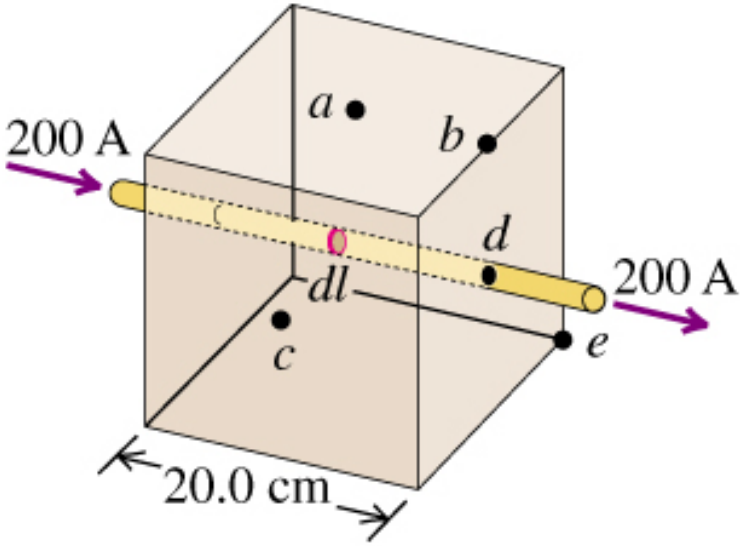
$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2}$$

$$\vec{B} = \frac{\mu_0}{4\pi}\int\frac{Id\vec{l}\times\hat{r}}{r^2}$$

Law of Biot and Savart

$n = volumetric\ density\ of\ charges\ [m^{-3}]$
$q = single\ charge\ value\ [C]$
$dl = segment\ of\ current - carrying\ conductor\ [m]$
$A = cross - section\ area\ of\ conductor\ [m^2]$

Example: Consider an element dl (0.100cm long) of the wire at the center of the box. Compute the magnitude dB of the magnetic field produced by this element at point b.



$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2}$$

$$|d\vec{B}| = \frac{\mu_0}{4\pi}\frac{Idlsin(\theta)}{r^2}$$

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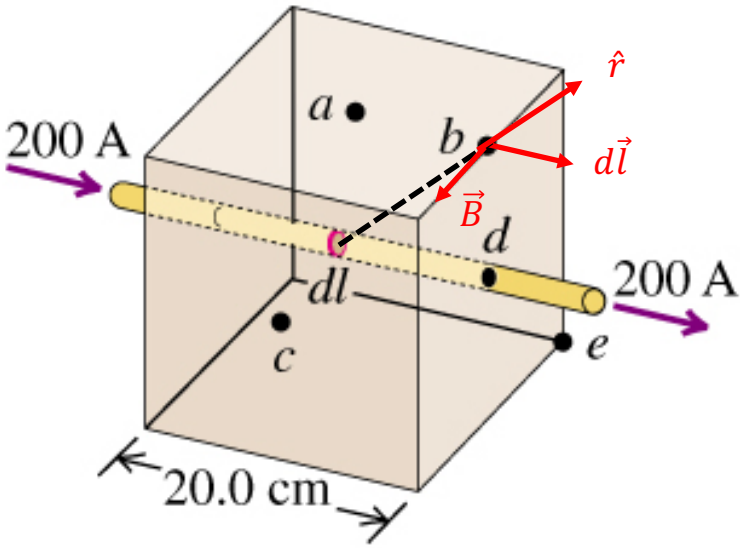

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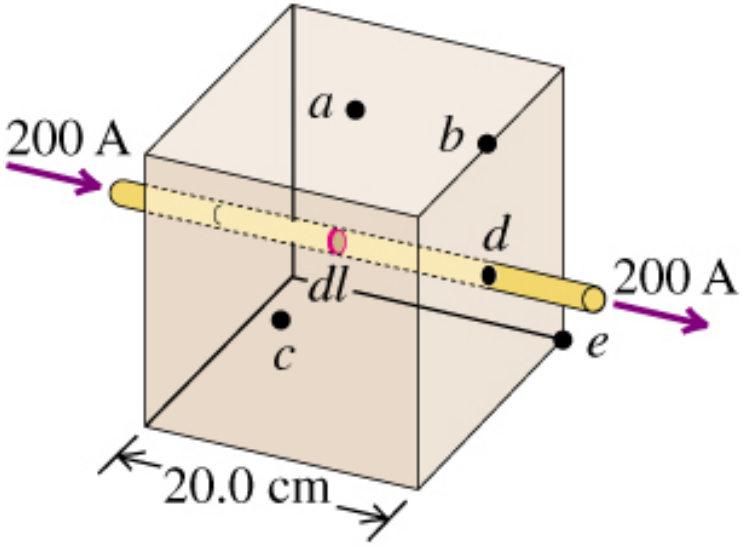

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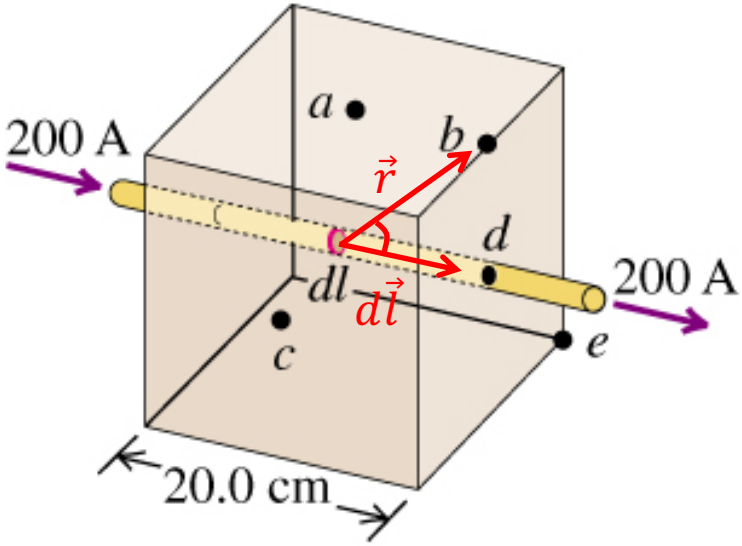

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$\mu_0 = 4\pi\times10^{-7}\ Tm/A$

$dl = 0.100\times10^{-2}\ m$

$I = 200\ A$

$r =$

$\theta =$

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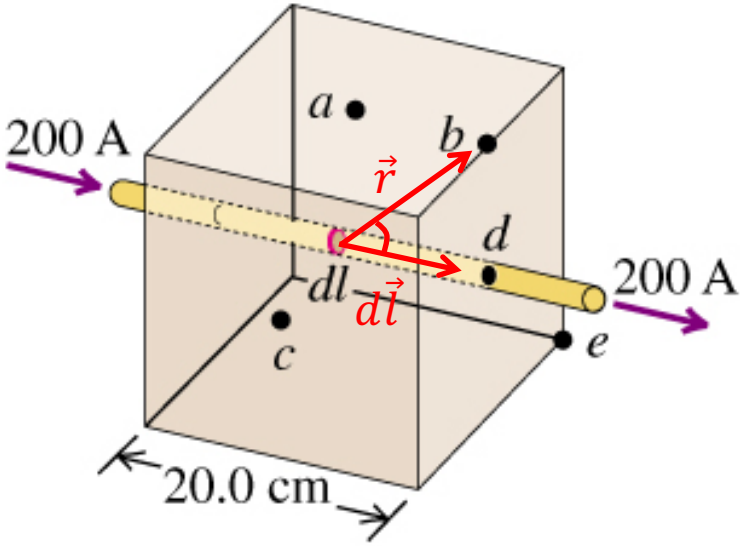

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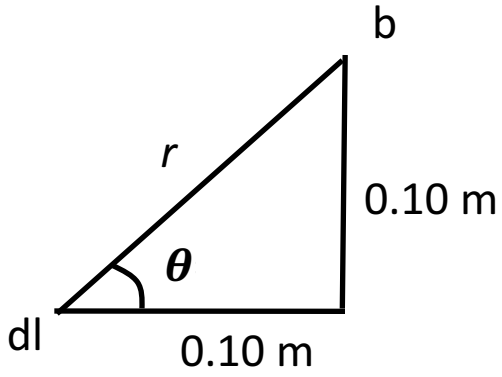

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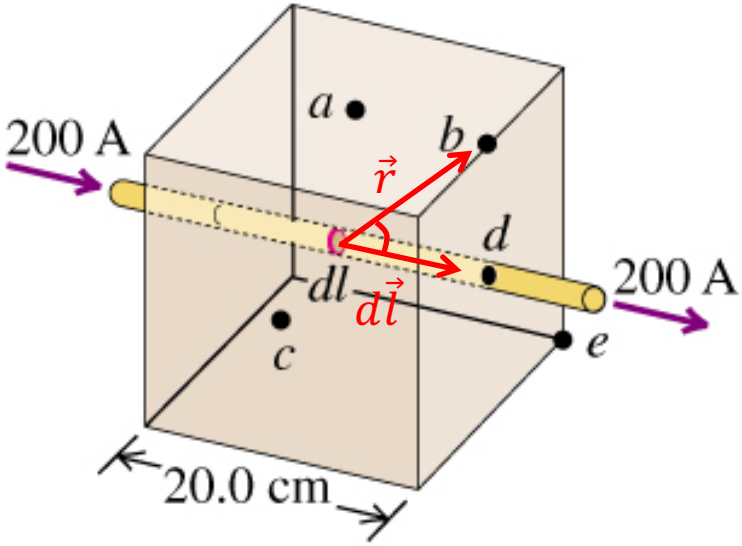

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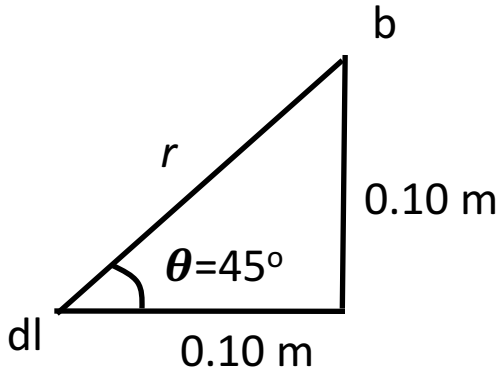
$r =$

$\theta = 45°$



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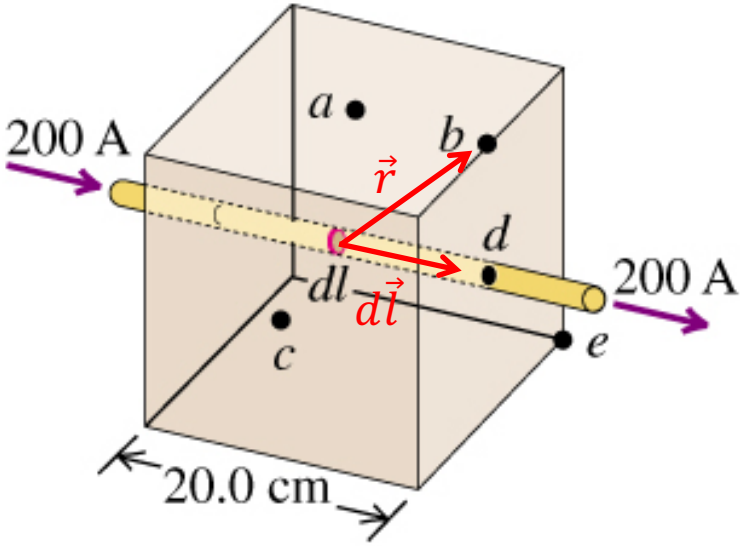

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$\mu_0 = 4\pi\times10^{-7}\ Tm/A$
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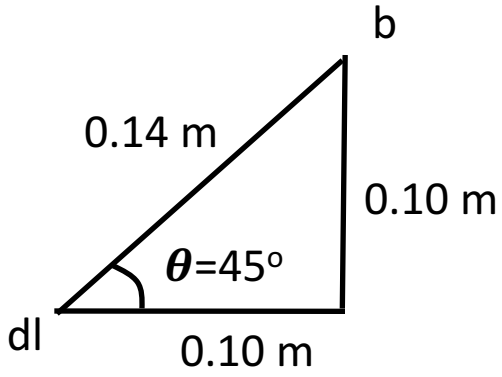

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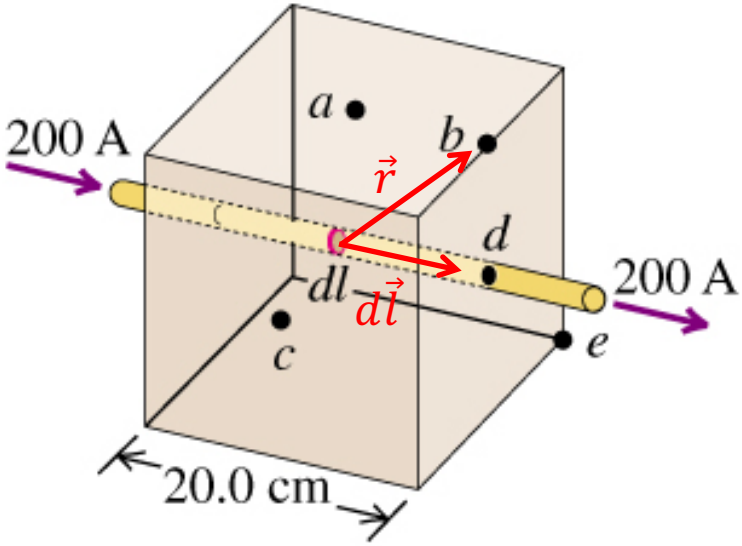

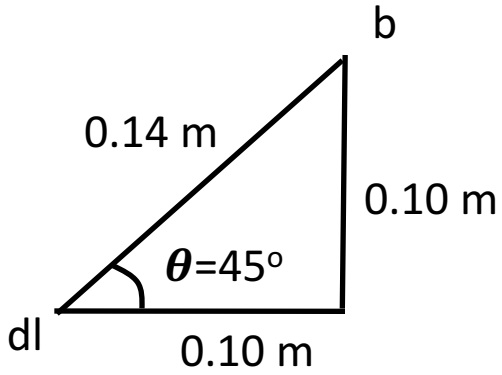

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{Id\vec{l}\times\hat{r}}{r^2}$$

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$$dl = 0.100\times10^{-2}\ m$$
$$I = 200\ A$$
$$r = 0.14\ m$$
$$\theta = 45°$$

$$|d\vec{B}| = \frac{\mu_0}{4\pi}\frac{(200)(0.001)\sin(45)}{(0.14)^2}$$

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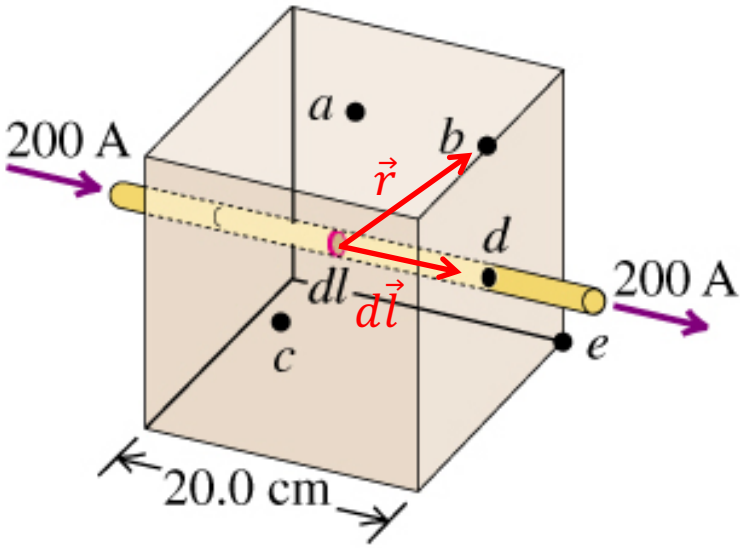

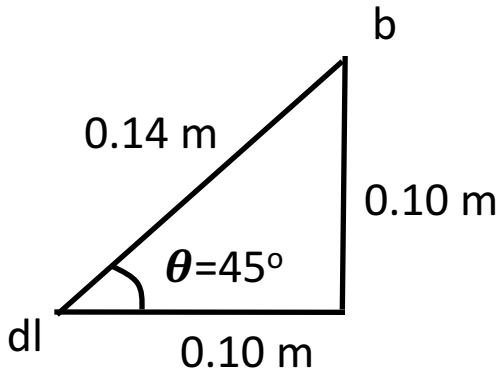

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$$\left|d\vec{B}\right| = 7.21\times10^{-7}\ B$$