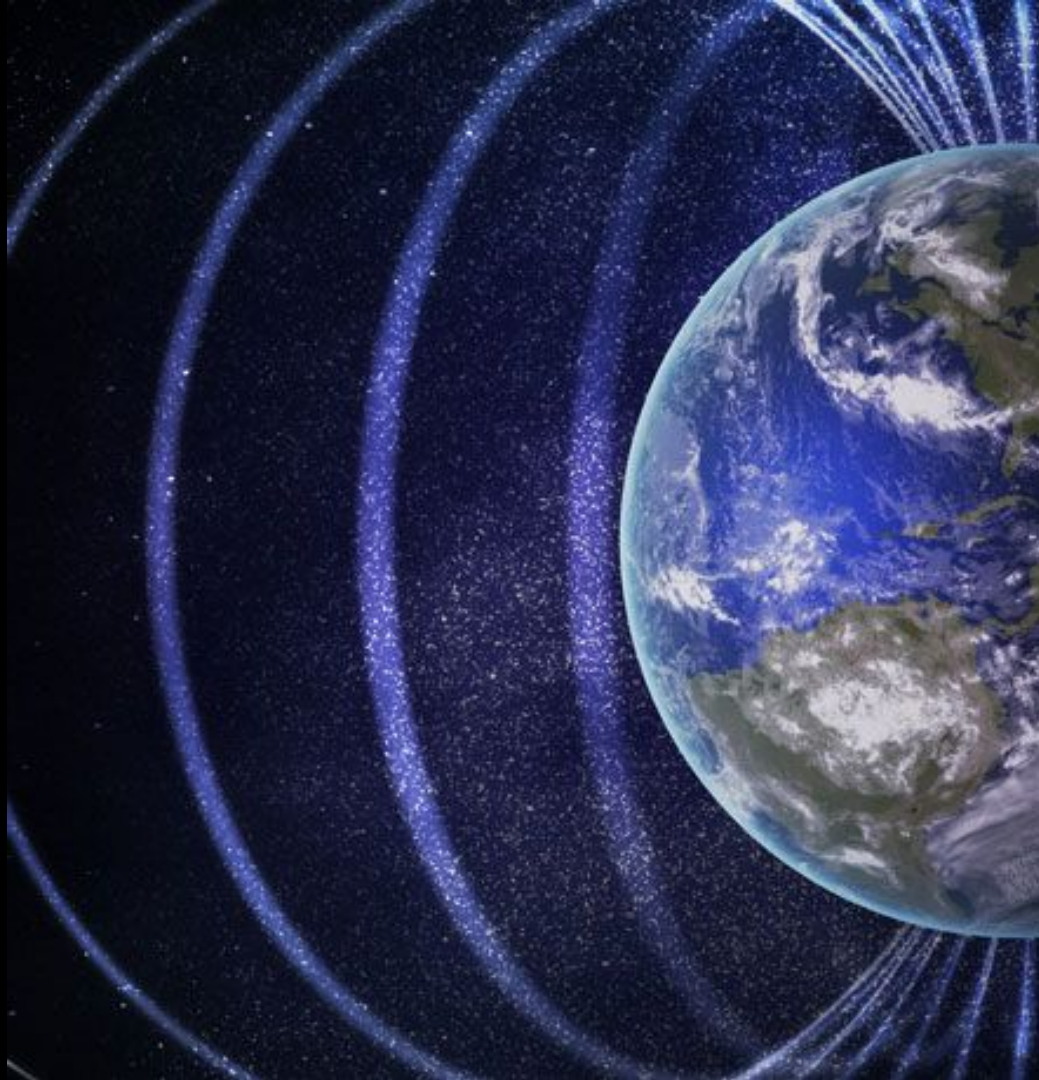
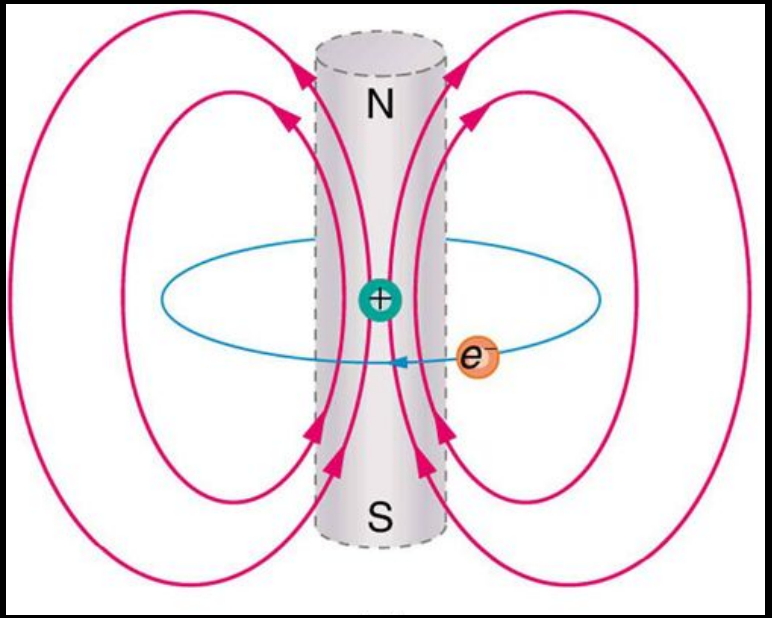
Magnets

How do they work???



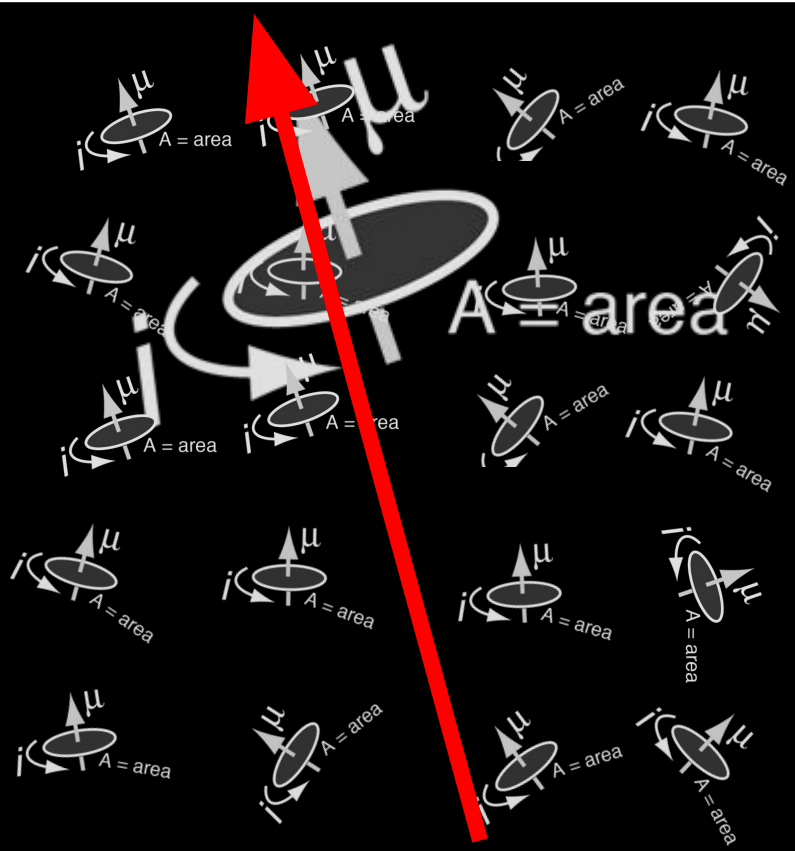
Electric Current is the Source of all Magnetism

- Electrons orbit atoms
- This angular moment generates a magnetic dipole moment
- This is like a tiny current loop, or a magnetic dipole
- There aren’t any magnetic monopoles...in the observable universe



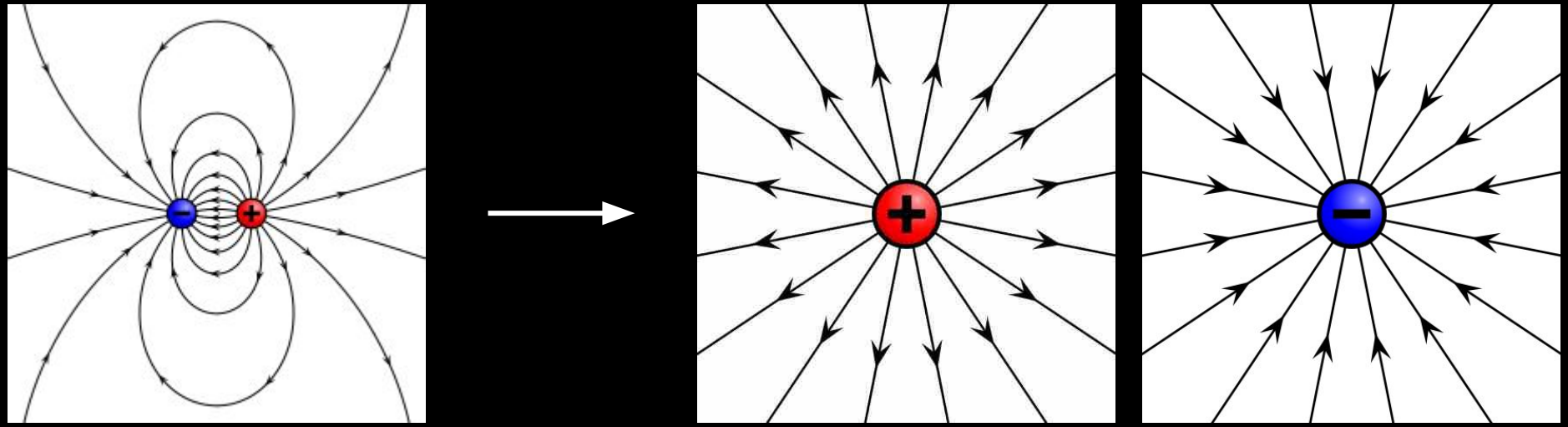
Electric Current is the Source of all Magnetism

We can line up a bunch of these to get a macroscopic magnetic material



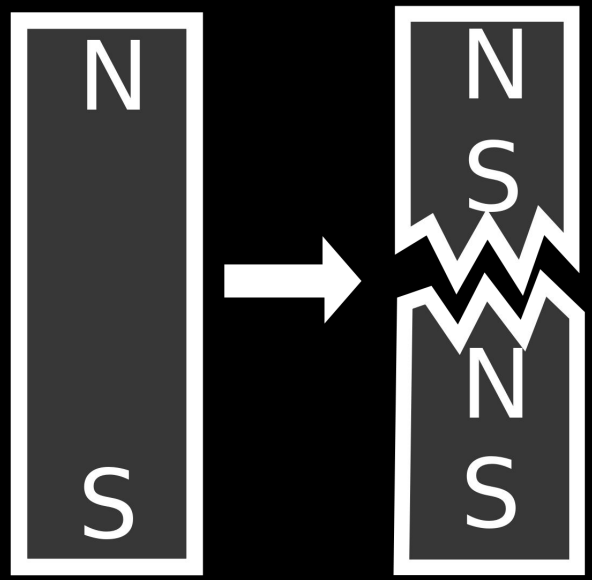
Drawing Parallels is Dangerous

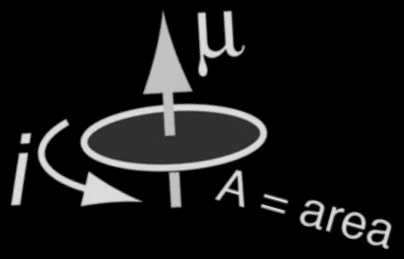
- Electric Dipoles can be split up



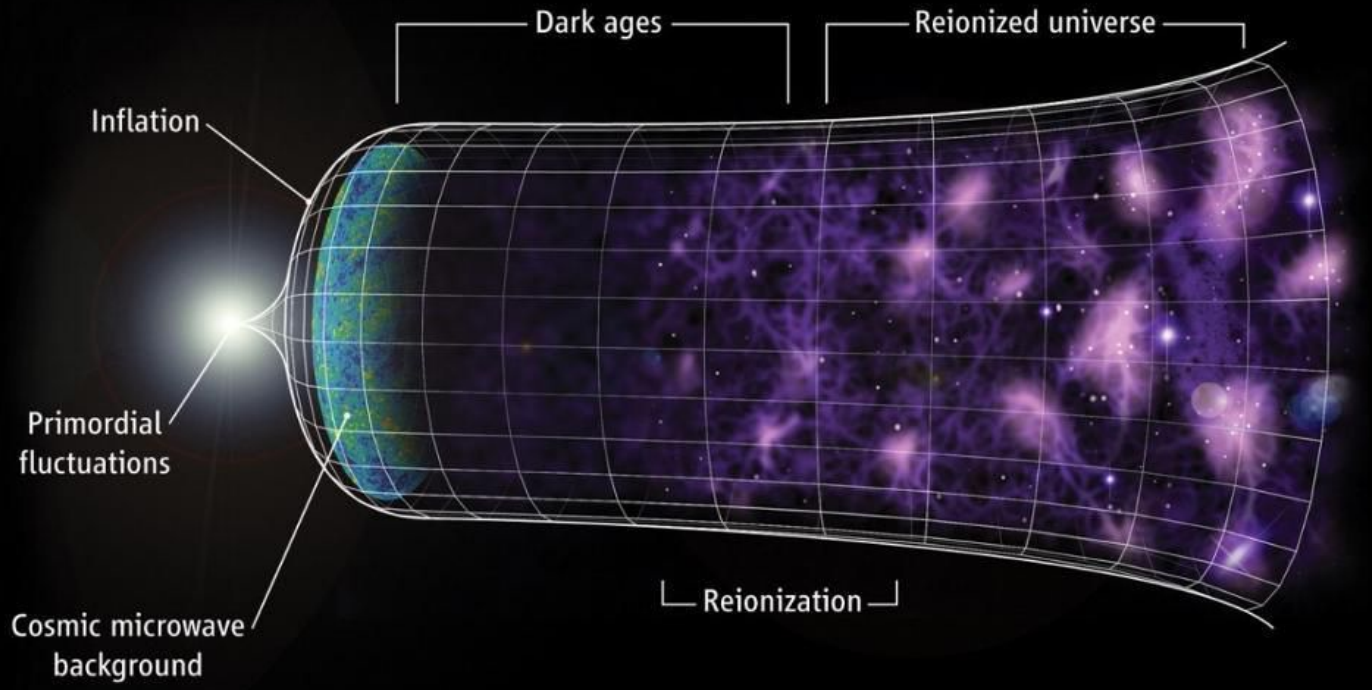
Drawing Parallels is Dangerous

- But magnetic dipoles cannot



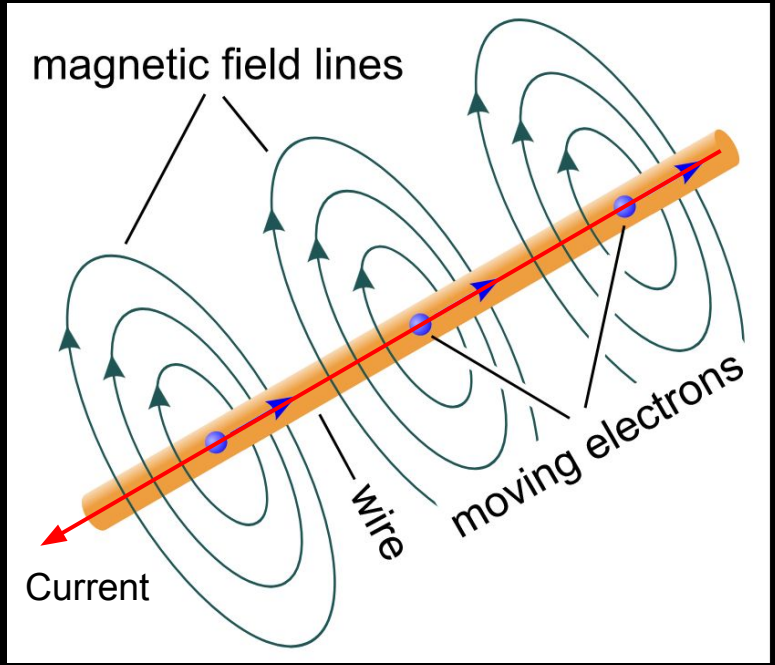


Inflation in the Early Universe



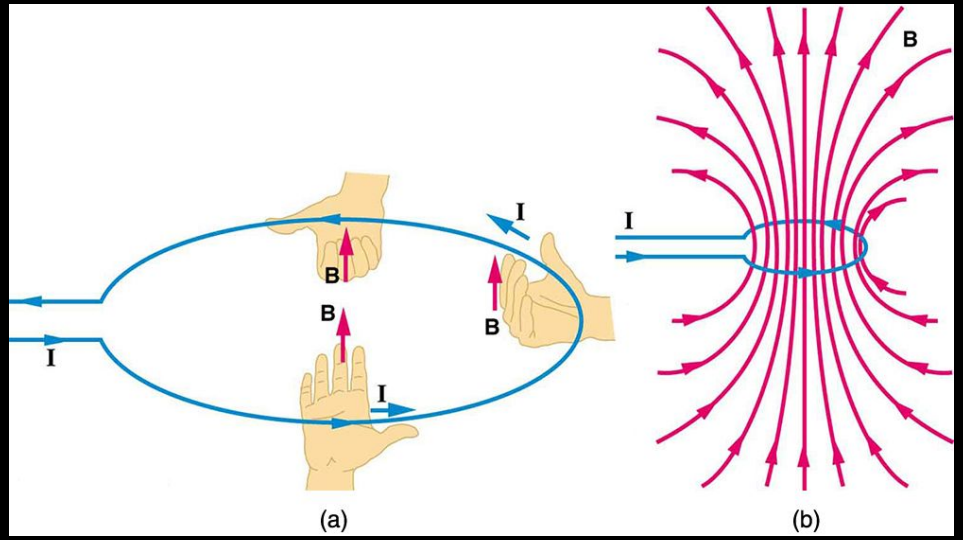
How do we pick a direction?

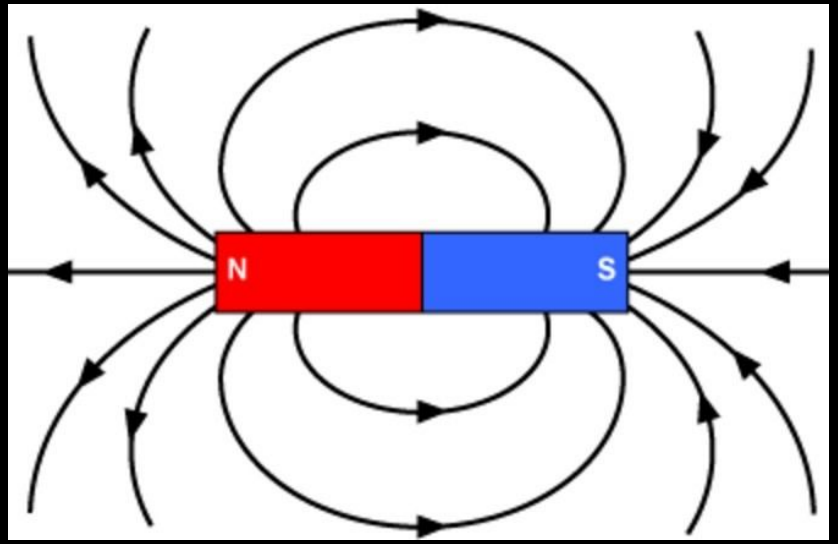
- Right-hand rule!
- Current travels the opposite direction that electrons move
- Point thumb in the direction of the current
- Fingers wrap around in the direction of the magnetic field



Magnetic Field Loops

- Form a closed loop - they have no start/end
- Come from North, go to South

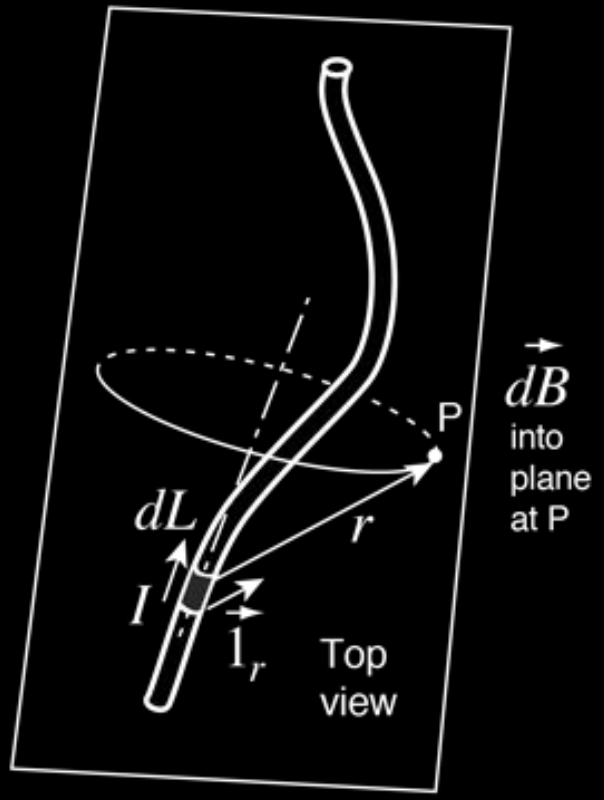




How to calculate a magnetic field

Biot-Savart Law

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



We don’t have to worry about that
:)

Magnetic Fields from Different Geometries

- Infinite Wire

$$\vec{B}(\vec{r}) = \frac{\mu_0 I}{2\pi r}$$

- Half Infinite Wire

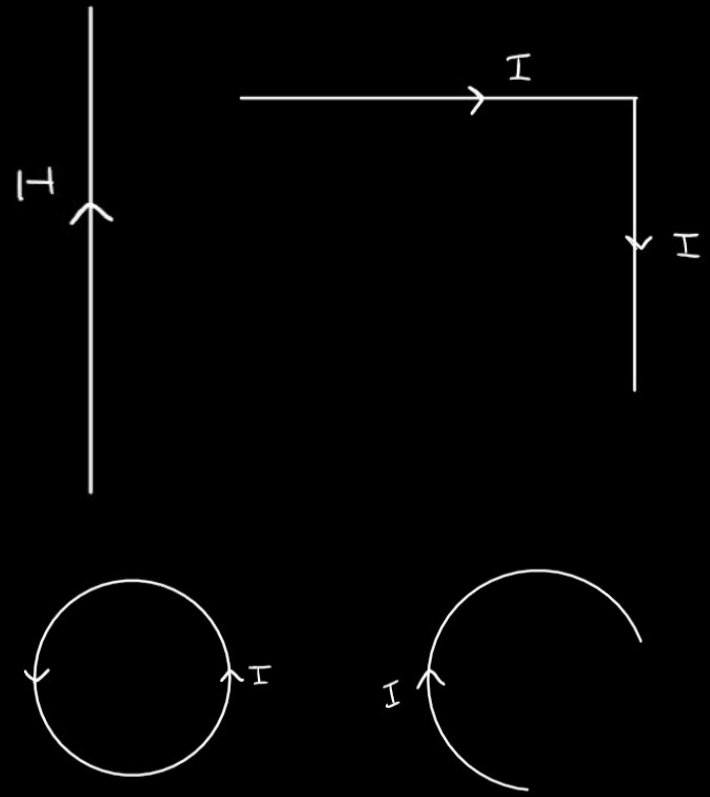
$$\vec{B}(\vec{r}) = \frac{\mu_0 I}{4\pi r}$$

- Circle

$$\vec{B}(\vec{r}) = \frac{\mu_0 I}{2R}$$

- Partial Circle

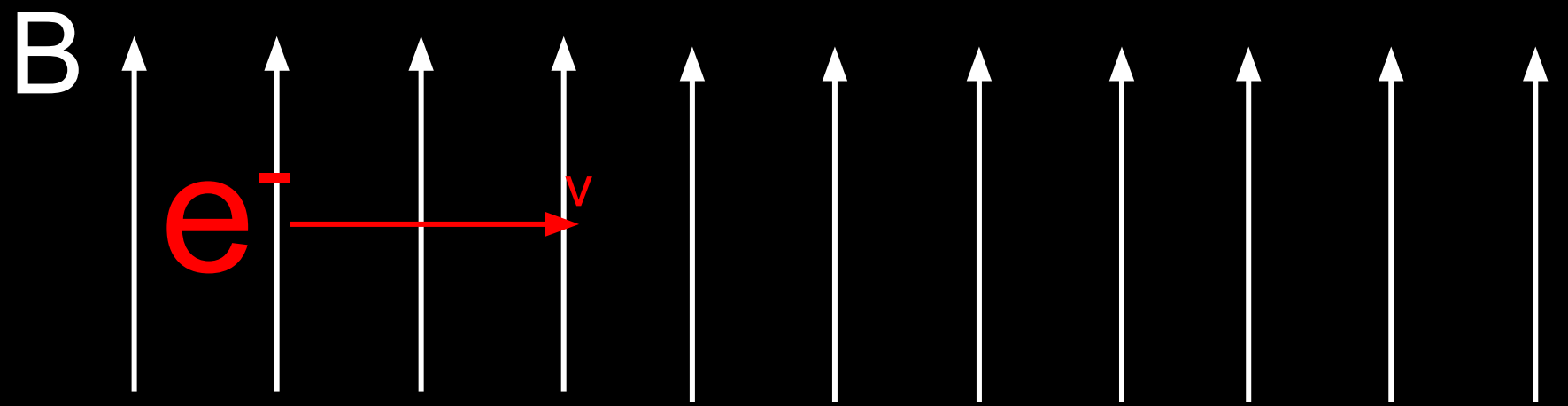
$$\vec{B}(\vec{r}) = \frac{\mu_0 I}{2R}\frac{\theta}{2\pi}$$



Force from a Magnetic Field

Think of a point charge moving through a magnetic field

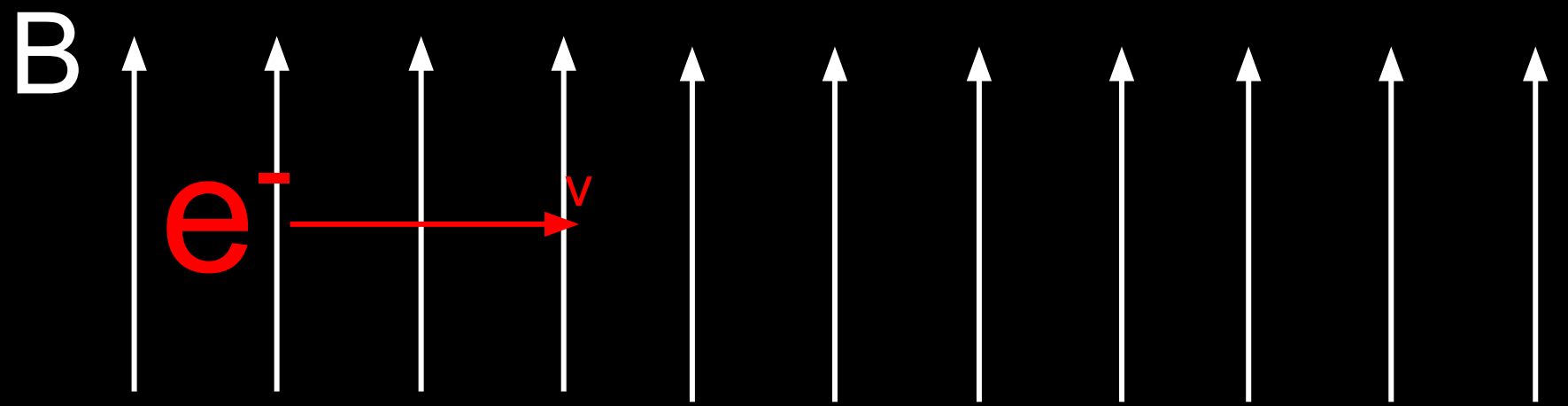
$$\vec{F} = q\vec{v} \times \vec{B}$$



Force from a Magnetic Field

The geometric interpretation

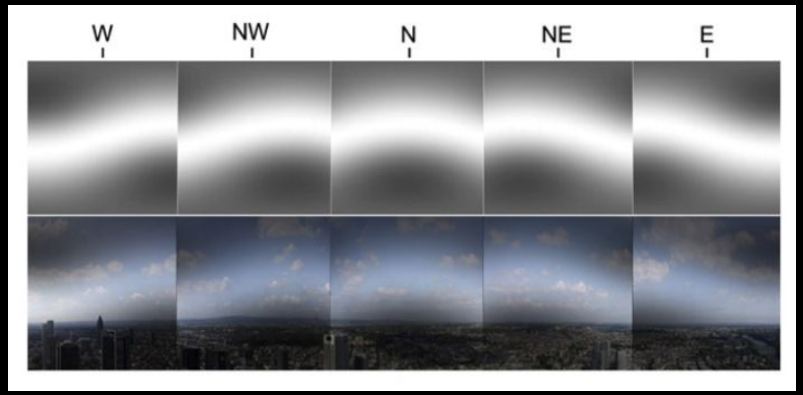
$$\vec{F} = q|\vec{v}||\vec{B}|sin\theta$$



Why it’s *cool*

Birds can *see* Magnetic Fields

- Scientific studies done on Zebra Finches and Robins to test how birds navigate during migration
- Protein in their eyes called Cry4, a cryptochrome (photoreceptor sensitive to blue light)
- Detect these fields with “magnetoreception”
- Studies show that avian magnetoreception depends on blue light
- Cry4 is clustered in the retinas
- Robins have increased Cry4 production during the migration season



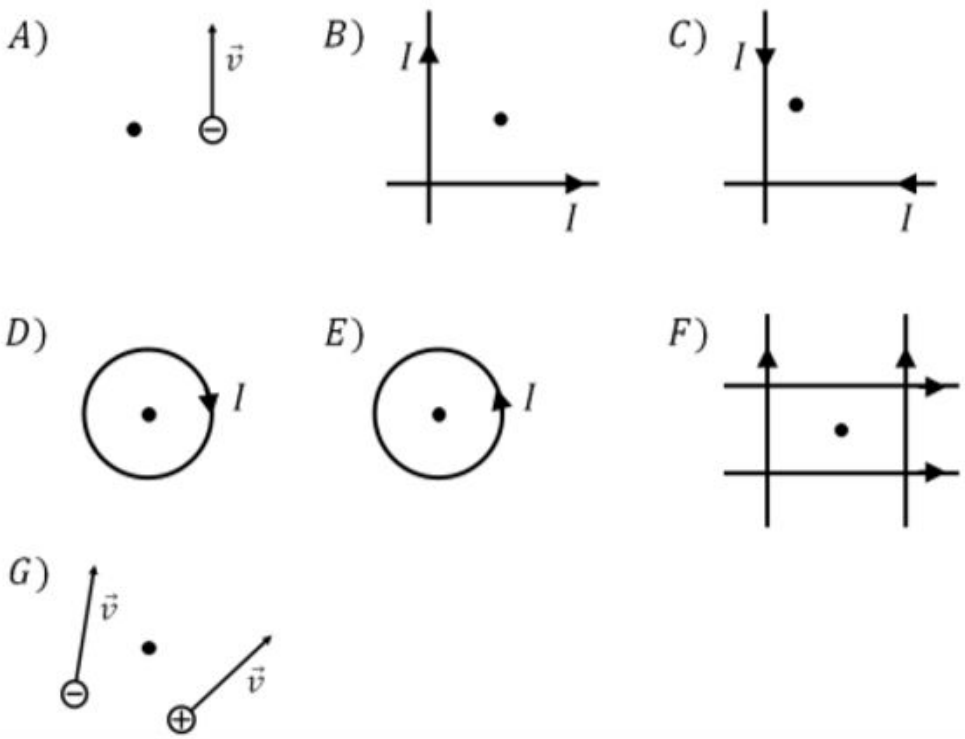
https://www.sciencealert.com/birds-see-magnetic-fields-cryptochrome-cry4-photoreceptor-2018

Putting it to Practice

S18 Final Exam

2. Which of the following situations will produce a magnetic field pointed out of the page?

- ☐ a)
- ☐ b)
- ☐ c)
- ☐ d)
- ☐ e)
- ☐ f)
- ☐ g)



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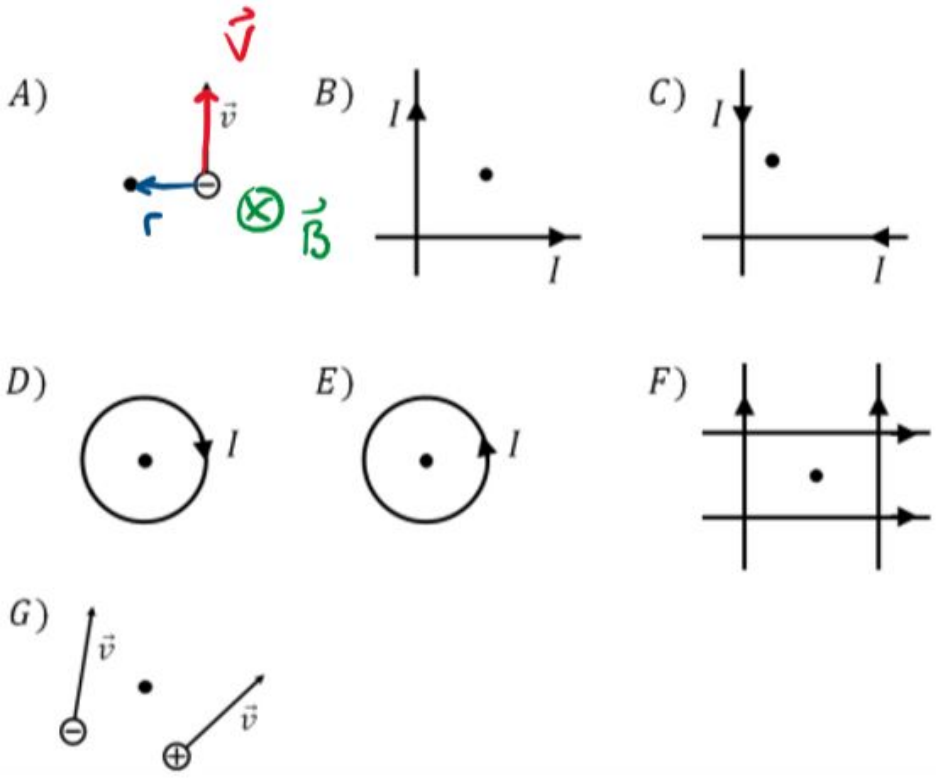

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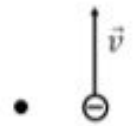
- ☐ f)
- ☐ g)

$r_1 = r_2$

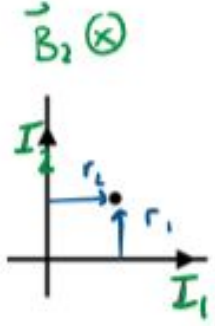
$\vec{B}_1 + \vec{B}_2 = \frac{\mu_0 I}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$

opposite signs bc opposite directions

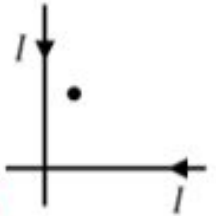
A)



B)



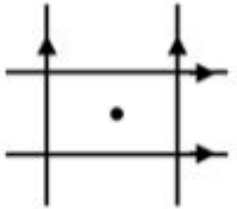
C)



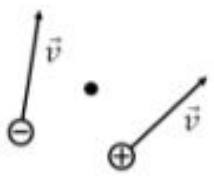
D)

E)

F)



G)



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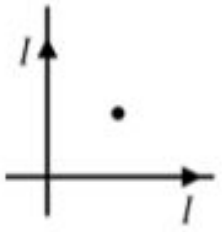
- ☐ e)
- ☐ f)
- ☐ g)

Into page →

A)

B)



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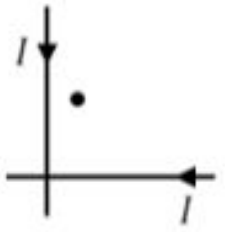
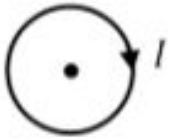
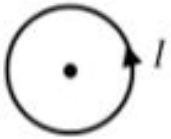


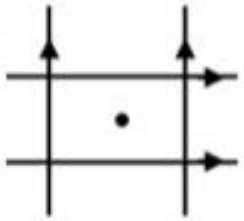
D)



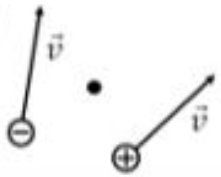
E)



F)



G)



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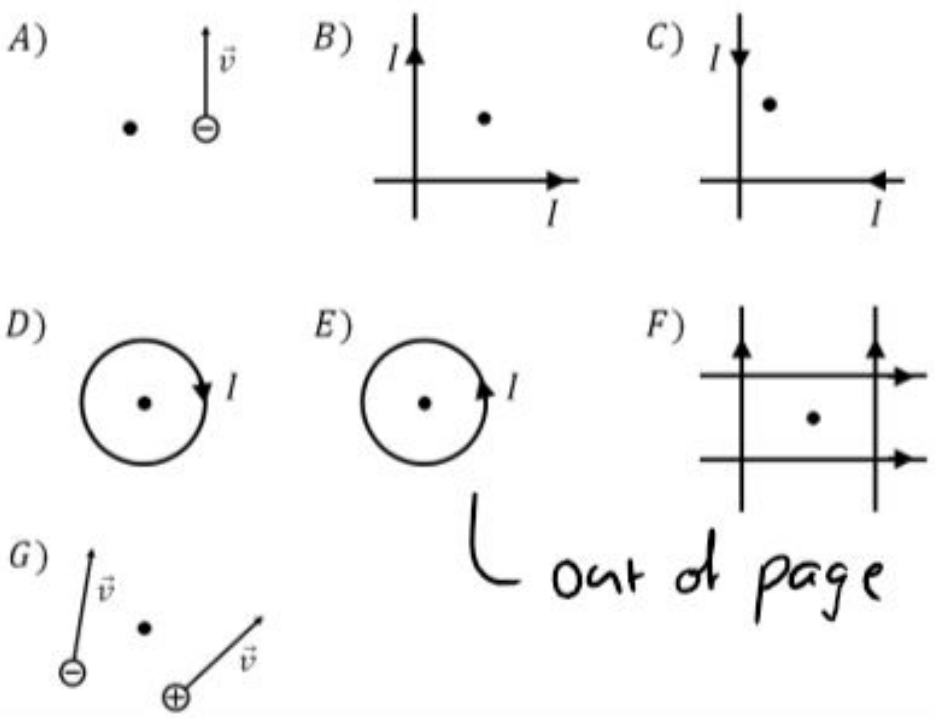
- ☐ g)



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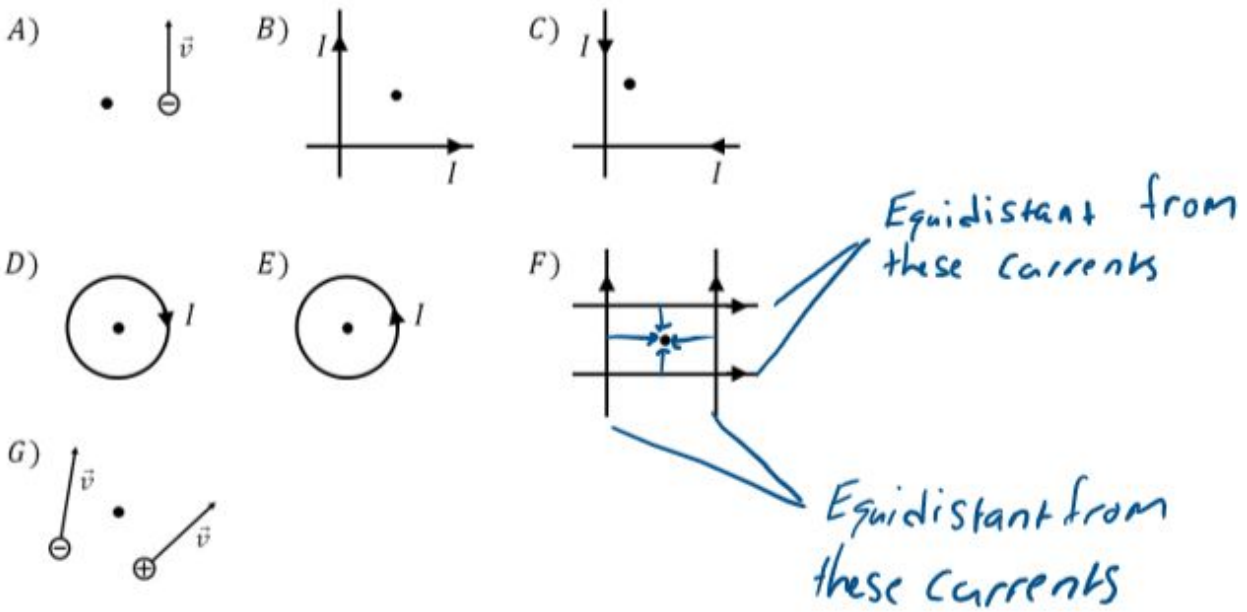
- ■ c)
- ☒ d)
- ■ e)
- ☐ f)
- ☐ g)



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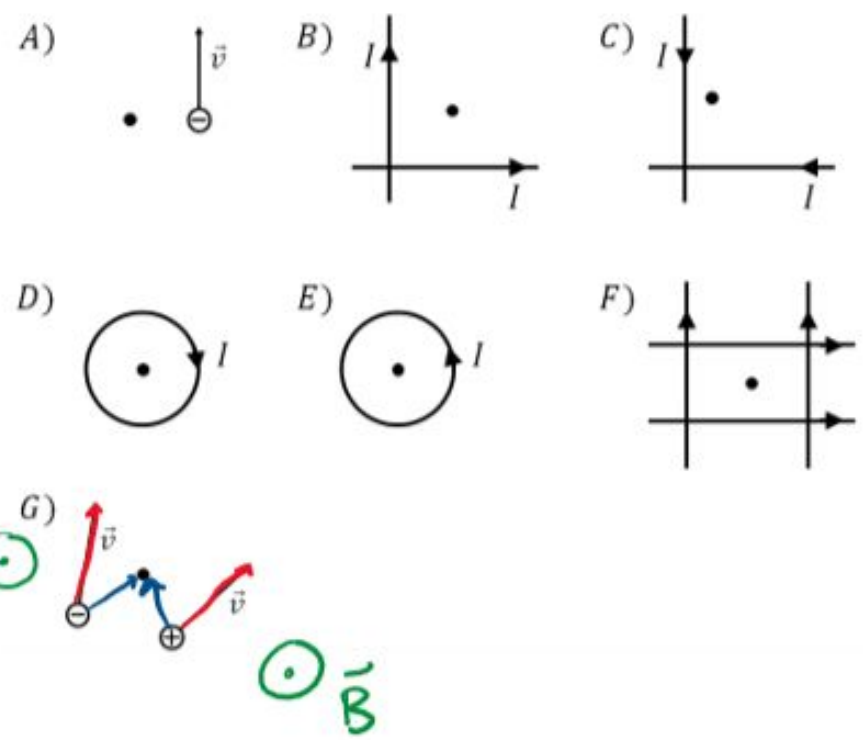
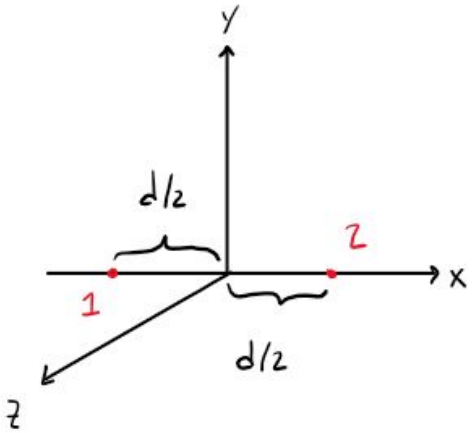
- ■ g)



S18 Final Exam

11. (8 points) Two negative particles are travelling in the +y direction with identical velocities and y coordinates. Particle 1 is a distance $\frac{d}{2}$ in the $-x$ direction from the y axis, particle 2 is a distance $\frac{d}{2}$ in the $+x$ direction from the y axis.

a) (2 points) In what direction is the electric force on particle 1? Explain.



They have identical velocities

They are both negative

They are travelling in the y-direction

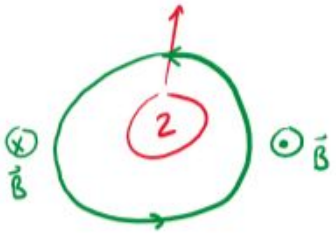
They are separated by a distance d

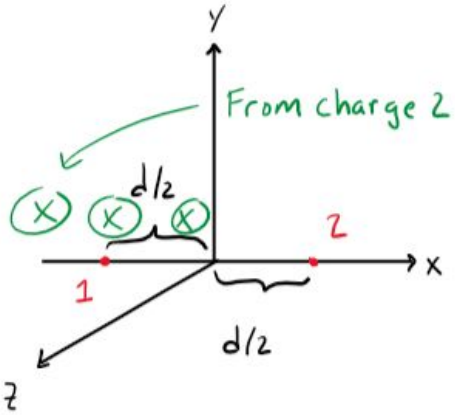
$$\vec{F}_{12}^{\,E} = \frac{k|q||q|}{|d|^2} = |F_{12}^{E}|\,(-\hat{x})$$

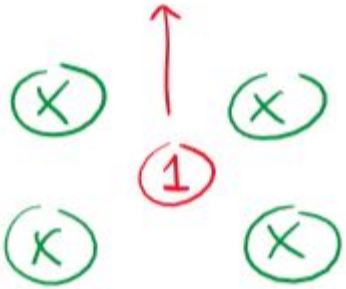
They repel

S18 Final Exam

b) (4 points) In what direction is the magnetic force on particle 1? **Explain.**



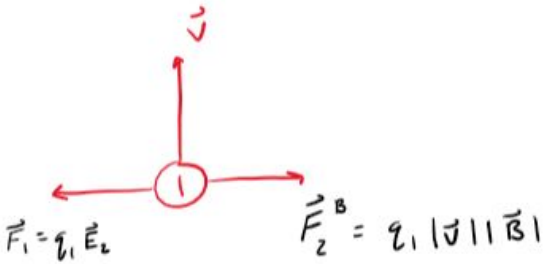




$$F_B = q\,\vec{v} \times \vec{B}$$
$$= \hat{y} \times z$$
$$= \hat{x}$$

S18 Final Exam

c) (2 points) If the particles are in (dynamic) equilibrium, how fast must they be travelling? (Ignoring relativity, you should be able to give a numerical answer! Notice anything interesting about the value of the speed?)



Charge 1: $\sum \vec{F}_x' = \vec{F}_B' - \vec{F}_E' = 0$

$$\vec{F}_E' = \frac{k q_1 q_2}{d^2}$$

$$\vec{F}_B' = q_1 v B = q_1 v \frac{\mu_0 q_2}{4\pi} \frac{v}{d^2}$$

$$\frac{k q_1 q_2}{d^2} = q_1 v \frac{\mu_0 q_2}{4\pi} \frac{v}{d^2}$$

$$\frac{k q_1 q_2}{q_1 q_2} = \frac{\mu_0 v^2 d^2}{4\pi d^2}$$

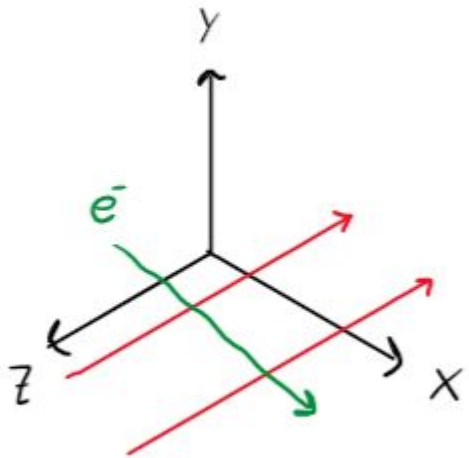
$$k = \frac{\mu_0}{4\pi} v^2$$

$$v = \sqrt{\frac{4\pi}{\mu_0} k} = \sqrt{\frac{4\pi}{4\pi \varepsilon_0 \mu_0}} = \sqrt{\frac{1}{\varepsilon_0 \mu_0}} = c$$

S18 Final Exam

10. (7 points) At t = 0, a particle with a charge of $-4.0\ C$ and mass $1.5\ \mu g$ is moving in the $+x$ direction with velocity $0.9\ m/s$ through a magnetic field of $1.0\ \mu T$ pointed in the $-z$ direction.

a) (2 points) What direction is the force on the particle?



$\vec{B} = 1.0\mu T\,(-\hat{z})$

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

$(-)\quad \hat{x} \quad -\hat{z}$

$= (-)\,\hat{x} \times (-\hat{z})$

$= \hat{x} \times z$

$= -\hat{y}$

The force is in the $-\hat{y}$ direction

S18 Final Exam

b) (1 point) What is the radius of the circle in which the particle travels?

$$\vec{F}_c = \frac{mv^2}{r}$$

$$\vec{F}_B = q|\vec{v}||\vec{B}|\sin\theta$$

$$= q|\vec{v}||\vec{B}|\sin 90$$

$$= q|\vec{v}||\vec{B}|$$

$$\frac{mv^2}{r} = qvB$$

$$r = \frac{mv^2}{qvB}$$

$$= \frac{mv}{qvB}$$

$$= \frac{(1.5\cdot 10^{-9}\,kg)(0.9\,m/s)}{(4C)(1.0\cdot 10^{-6}T)}$$

$$= 3.38\cdot 10^{-4}\,m$$

$$= \boxed{338\,\mu m}$$

S18 Final Exam

c) (2 points) How long does it take the particle to make one full circle?

From 202...

$$T = \frac{2\pi r}{v} = \frac{2\pi (338 \cdot 10^{-6}\ m)}{(0.9\ m/s)} = 2.36 \cdot 10^{-6}\ s$$

$$= \boxed{2.36\ \mu s}$$

S18 Final Exam

d) (2 points) If we average over a large period of time, we could say the particle travelling in a circle was a circular current. What is the magnitude of this current? (If you did not get part c, state this clearly, then solve for the current assuming it takes 2 seconds to make one full circle)

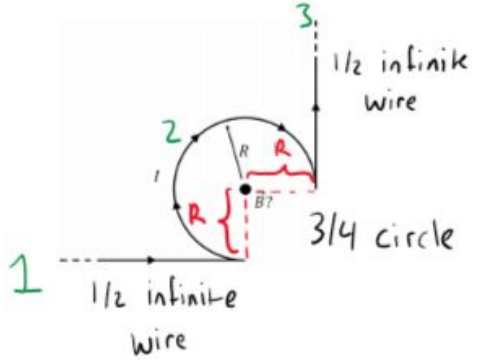
Current is just $I = \frac{\Delta q}{\Delta t}$

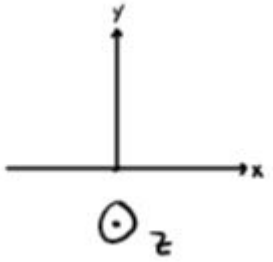
$$I = \frac{4\,C}{(2.36 \cdot 10^{-6}\,s)} = \boxed{1.7 \cdot 10^{3}\,A}$$

S18 Final Exam

8. (6 points) A very long wire is bent into the following shape. The circular portion has a radius R and the whole wire carries a current I.

What are the magnitude and direction of the magnetic field at the black dot in the center of the arc?





$$\vec{B}_1 = \frac{I\mu_0}{4\pi R}\,\hat{z}$$

$$\vec{B}_3 = \frac{I\mu_0}{4\pi R}\,\hat{z}$$

$$\vec{B}_2 = \frac{\mu_0 I}{2R}\left(\frac{3}{4}\right)(-\hat{z})$$

$$\vec{B} = \vec{B}_1 + \vec{B}_2 + \vec{B}_3$$

$$\vec{B} = \frac{I\mu_0}{4\pi R}(\hat{z}) + \frac{I\mu_0}{4\pi R}(\hat{z}) + \frac{\mu_0 I 3}{8R}(-\hat{z})$$

$$= \left[\frac{2I\mu_0}{4\pi R} - \frac{3I\mu_0}{8R}\right]\hat{z}$$

$$= \frac{I\mu_0}{2R}\left[\frac{3}{4} - \frac{1}{\pi}\right]\hat{z}$$