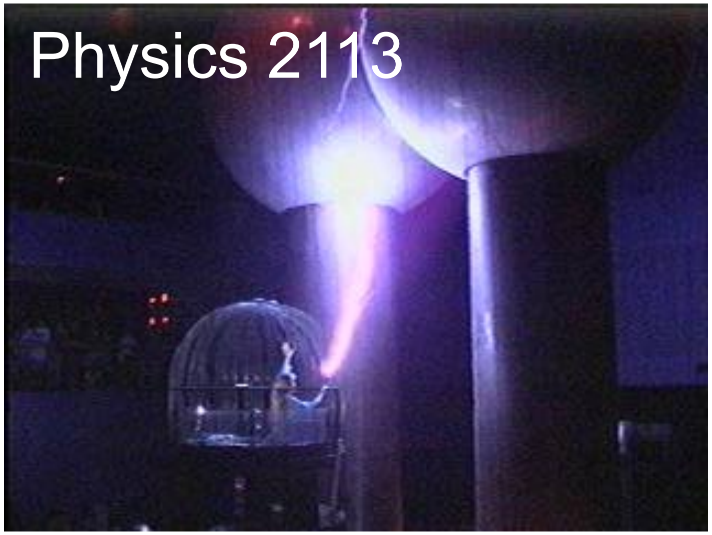


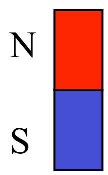
Physics 2113
Lecture 22: MON 20 OCT

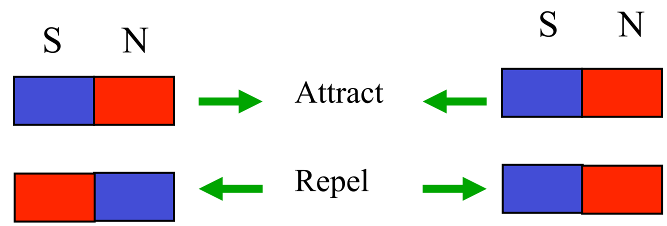
CH28: Magnetism

Magnetism is a familiar concept. Mankind has been using magnets since time immemorial.

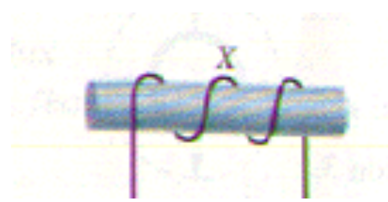
We know that magnetism through our experience with two kinds of objects:

Magnets:





Electromagnets:



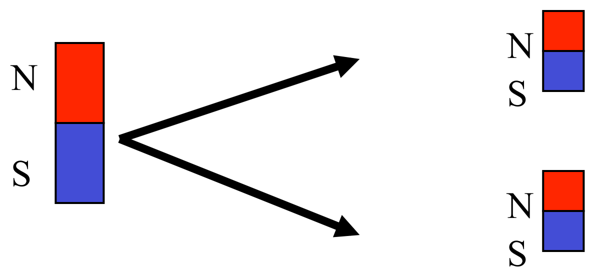
The basic idea is that static charges interact through electrostatic forces, like the ones we studied in the course up to now. Charges that move generate this new type of force called magnetism.

In magnets, the moving charges are the electrons in the atoms that make the materials. In electromagnets, they are the charges that make up the current in the wire.

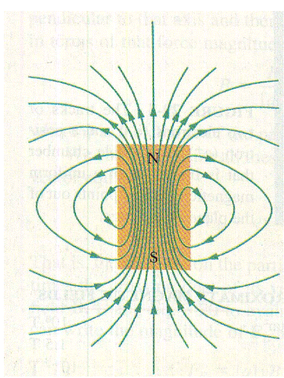
So the situation is very similar to electrostatics, if we substitute “poles” where we used to say “charge”.

However, a key difference is that no isolated poles occur in nature. They all occur in pairs. It’s like if one imagined a world without isolated charges, just dipoles.

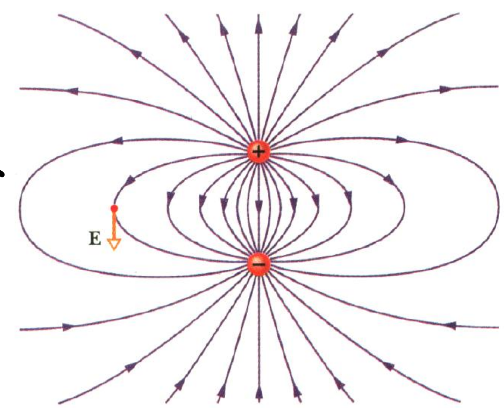
Cut a magnet in half, you still have two magnets with two poles each!



Fields:



Very much like that of electric dipole:



Magnetic versus electrostatic forces:

An important difference in electric and magnetic fields is how they act on charges.

For electrostatic forces : $\vec{F} = q\vec{E}$

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

Charges that do not move, do not feel magnetic forces.

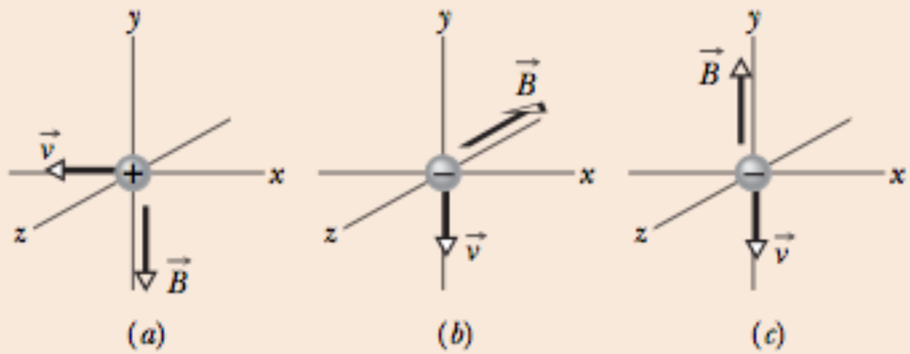
Magnetic forces are perpendicular to both the velocity of charges and to the magnetic field (electric forces are parallel to the field).

Since magnetic forces are perpendicular to the velocity, they do no work!

Speed of particles moving in a magnetic field remains constant in magnitude, the direction changes. Kinetic energy is constant (no work).

CHECKPOINT 1

The figure shows three situations in which a charged particle with velocity $\vec{v}$ travels through a uniform magnetic field $\vec{B}$. In each situation, what is the direction of the magnetic force $\vec{F}_B$ on the particle?



Magnetic force on a moving charged particle

A uniform magnetic field $\vec{B}$, with magnitude 1.2 mT, is directed vertically upward throughout the volume of a laboratory chamber. A proton with kinetic energy 5.3 MeV enters the chamber, moving horizontally from south to north. What magnetic deflecting force acts on the proton as it enters the chamber? The proton mass is 1.67×10^{-27} kg. (Neglect Earth's magnetic field.)

KEY IDEAS

Because the proton is charged and moving through a magnetic field, a magnetic force $\vec{F}_B$ can act on it. Because the initial direction of the proton's velocity is not along a magnetic field line, $\vec{F}_B$ is not simply zero.

Magnitude: To find the magnitude of $\vec{F}_B$, we can use Eq. 28-3 ($F_B = |q|vB \sin\phi$) provided we first find the proton's speed v. We can find v from the given kinetic energy because $K = \frac{1}{2}mv^2$. Solving for v, we obtain

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{(2)(5.3\text{ MeV})(1.60 \times 10^{-13}\text{ J/MeV})}{1.67 \times 10^{-27}\text{ kg}}}$$
$$= 3.2 \times 10^7 \text{ m/s}.$$

Equation 28-3 then yields

$$\begin{aligned} F_B &= |q|vB \sin\phi \\ &= (1.60 \times 10^{-19}\text{ C})(3.2 \times 10^7\text{ m/s}) \\ &\quad \times (1.2 \times 10^{-3}\text{ T})(\sin 90°) \\ &= 6.1 \times 10^{-15}\text{ N}. \qquad \text{(Answer)} \end{aligned}$$

This may seem like a small force, but it acts on a particle of small mass, producing a large acceleration; namely,

$$a = \frac{F_B}{m} = \frac{6.1 \times 10^{-15}\text{ N}}{1.67 \times 10^{-27}\text{ kg}} = 3.7 \times 10^{12}\text{ m/s}^2.$$

Direction: To find the direction of $\vec{F}_B$, we use the fact that $\vec{F}_B$ has the direction of the cross product $q\vec{v} \times \vec{B}$. Because the charge q is positive, $\vec{F}_B$ must have the same direction as $\vec{v} \times \vec{B}$, which can be determined with the right-hand rule for cross products (as in Fig. 28-2*d*). We know that $\vec{v}$ is directed horizontally from south to north and $\vec{B}$ is directed vertically up. The right-hand rule shows us that the deflecting force $\vec{F}_B$ must be directed horizontally from west to east, as Fig. 28-6 shows. (The array of dots in the figure represents a magnetic field directed out of the plane of the figure. An array of **X**s would have represented a magnetic field directed into that plane.)

If the charge of the particle were negative, the magnetic deflecting force would be directed in the opposite direction—that is, horizontally from east to west. This is predicted automatically by Eq. 28-2 if we substitute a negative value for q.

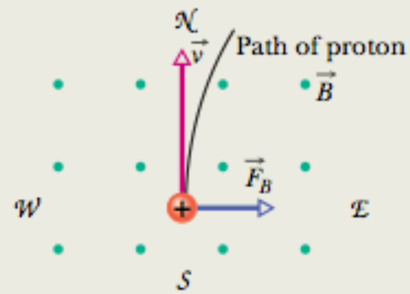


Fig. 28-6 An overhead view of a proton moving from south to north with velocity $\vec{v}$ in a chamber. A magnetic field is directed vertically upward in the chamber, as represented by the array of dots (which resemble the tips of arrows). The proton is deflected toward the east.

Cathode ray tube   (TV tube)

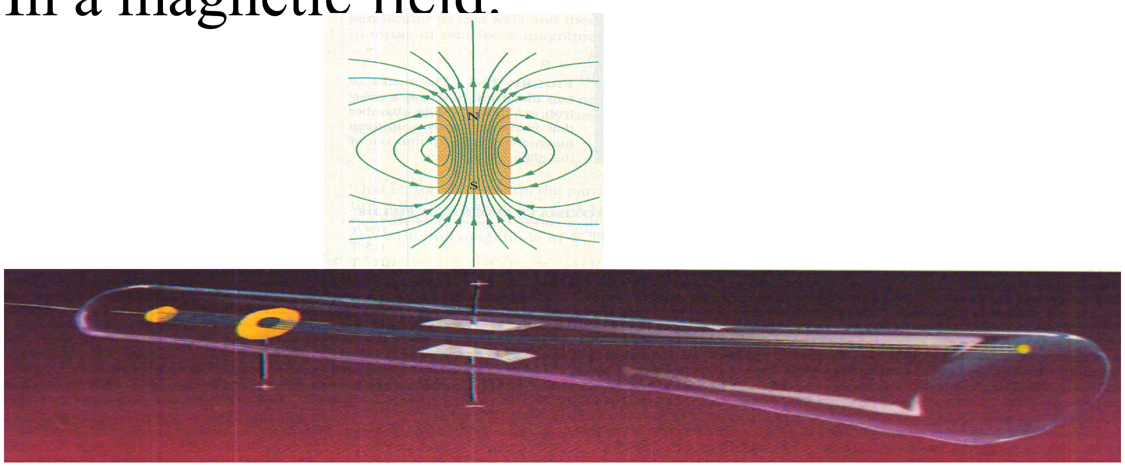
Hot cathode emits electrons

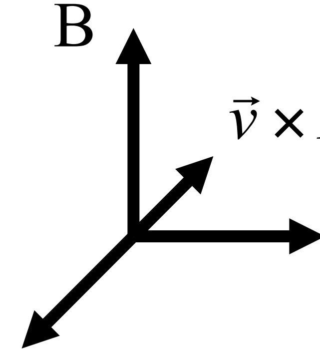
Get accelerated by positive plate

Might be deflected using plates

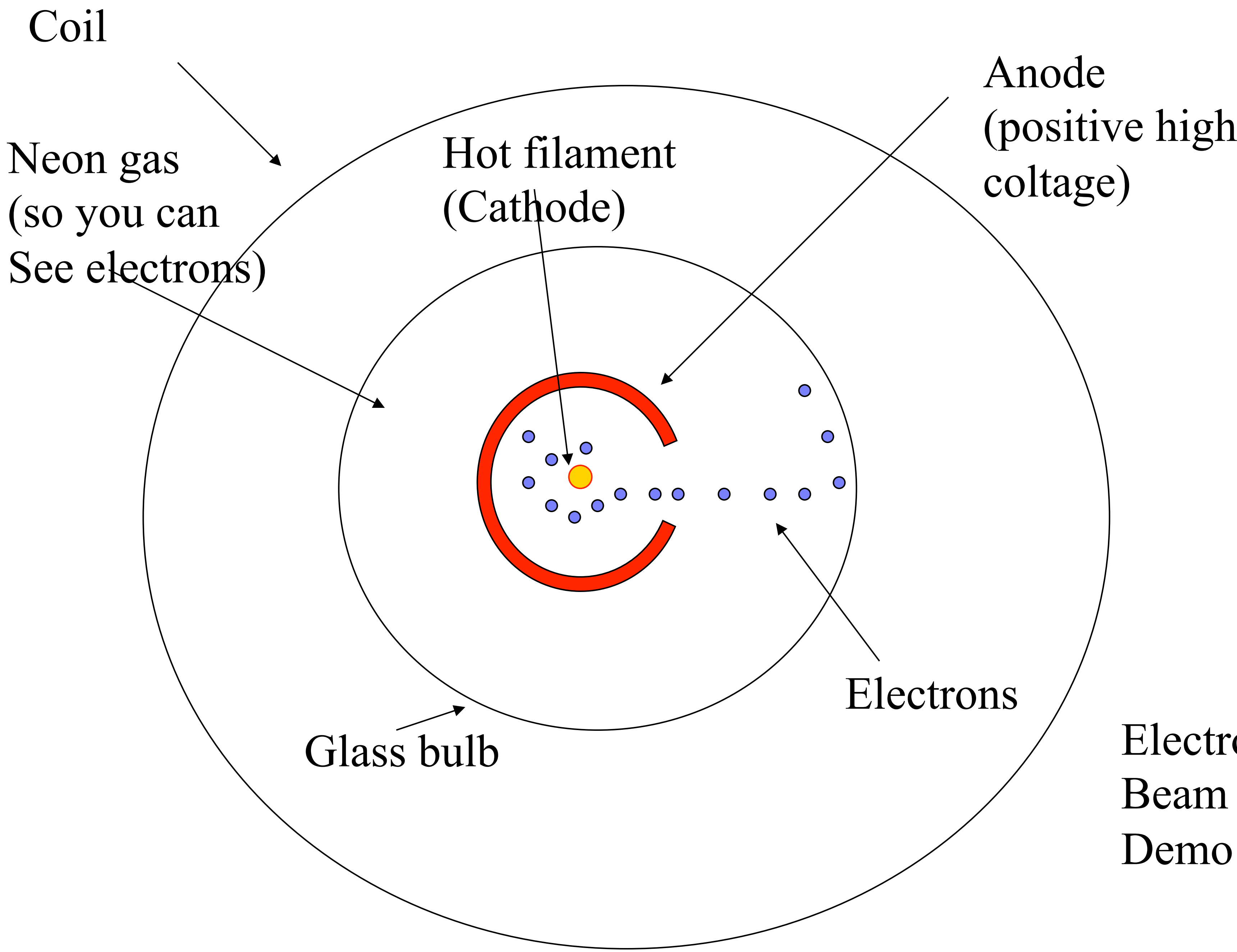
Produce point of light on screen.

In a magnetic field:



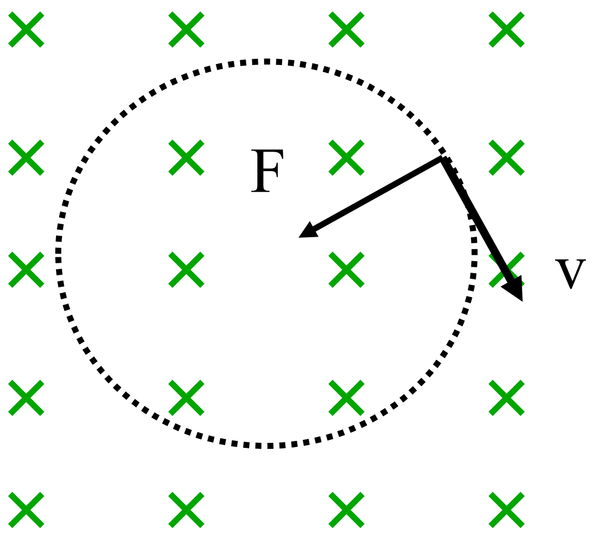


Dot shifts sideways.



Electron
Beam
Demo

Circular motion:



B into blackboard.

Since magnetic force is transverse to motion, the natural movement of charges is circular.

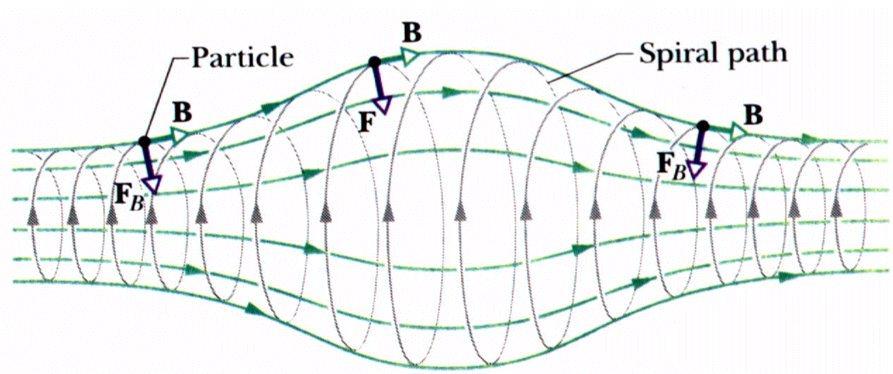
$$F = ma = m\frac{v^2}{r} \text{ for circular motion}$$

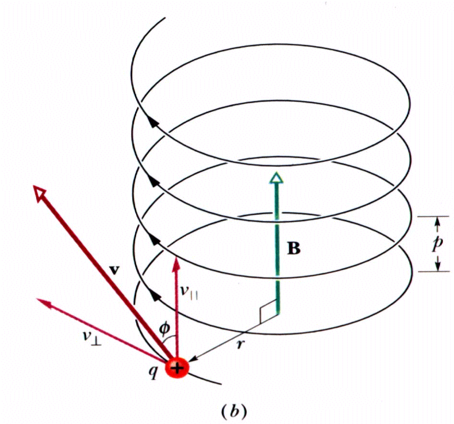
Therefore $$qvB = \frac{mv^2}{r}$$

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

Period $$T = \frac{2\pi r}{v} = \frac{2\pi}{v}\frac{mv}{qB} = \frac{2\pi m}{qB}$$

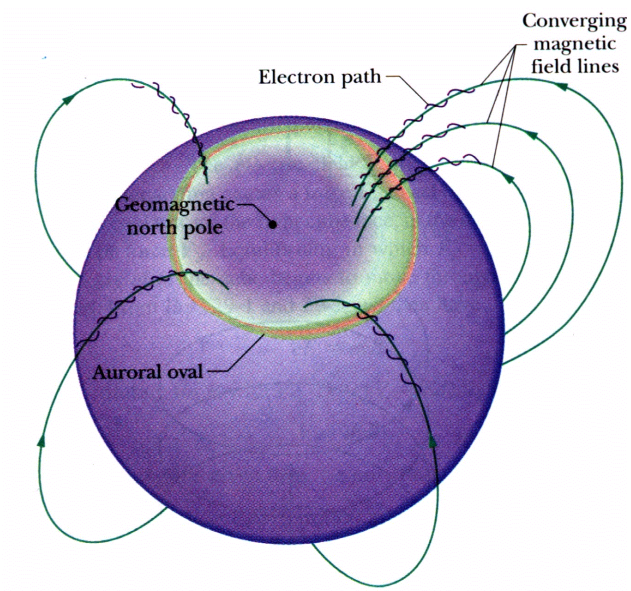
Angular frequency $$\omega = \frac{2\pi}{T} = \frac{qB}{m}$$





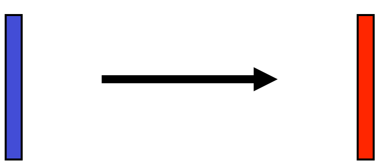
In general, path is a helix (component of v parallel to field is unchanged).

Example: aurora borealis

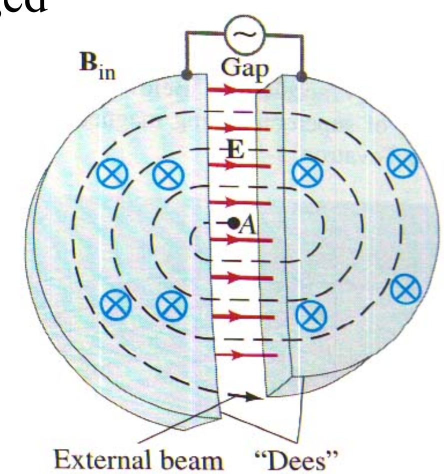


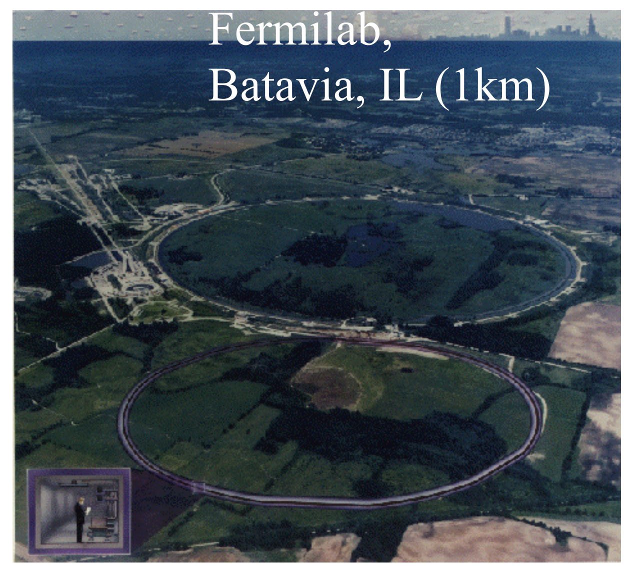
Example: synchrotron

Suppose you wish to accelerate charged particles as fast as you can.



Linear accelerator (long).





Units of B

[F] = [q] [v] [B], therefore Newton = Coulomb m/s [B]

$$\text{So, } [B] = \frac{N}{C\frac{m}{s}} = \frac{N}{m\,A} = \frac{\text{Weber}}{m^2} = \text{Tesla}$$

Another widely used unit is the $\text{Gauss} = 10^{-4}\ \text{Tesla}$

K. F. Gauss (1777-1855)
W. Weber (1804-1891)

Nikola Tesla (1856-1943) USA

Summary:

- Magnetostatic forces operate very much like electrostatic forces, but…
- There are no isolated magnetic poles, the simplest magnetic field looks like a dipole.
- The force law has a vector product between velocity and field: no velocity, no force, and forces are perpendicular to the field.
- Moving charges spiral in magnetic fields, they do not gain kinetic enegy.