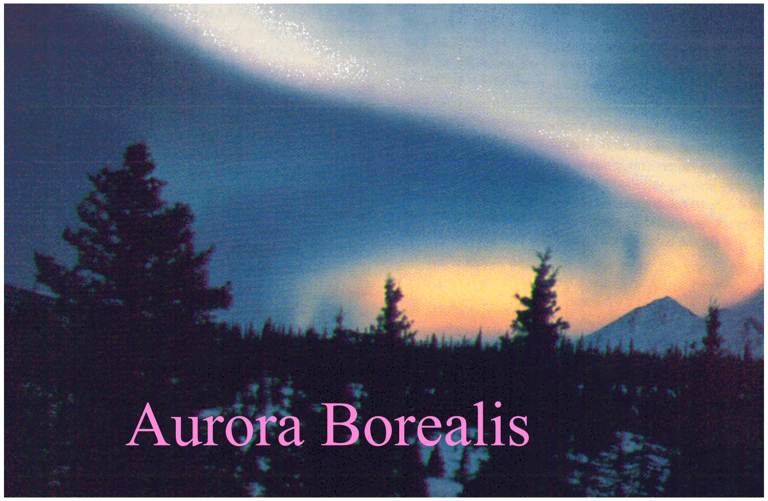
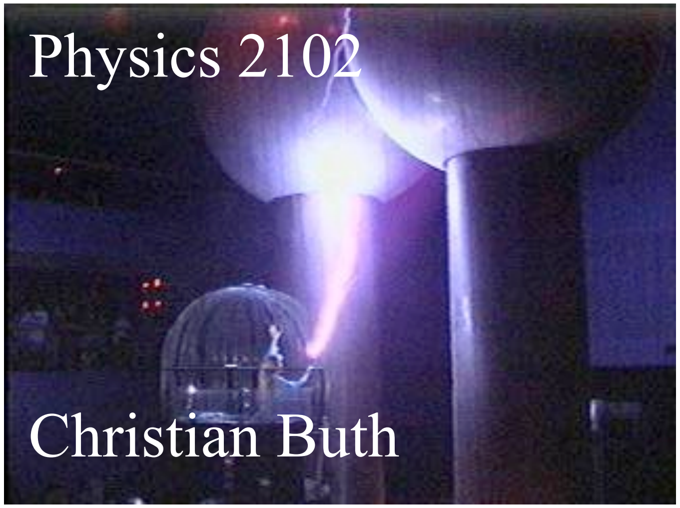




Physics 2102
Lecture 18
Magnetic fields 1

Version: 02/27/2009

Review

• Technique to **solve multiloop circuits**

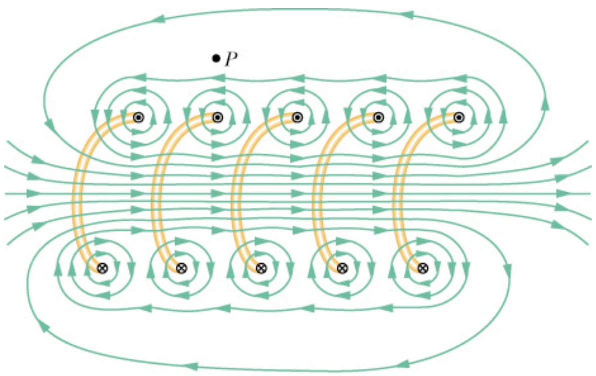
1. Simplify "compile" circuits
2. Apply loop rule and junction rule
3. Equations to unknowns

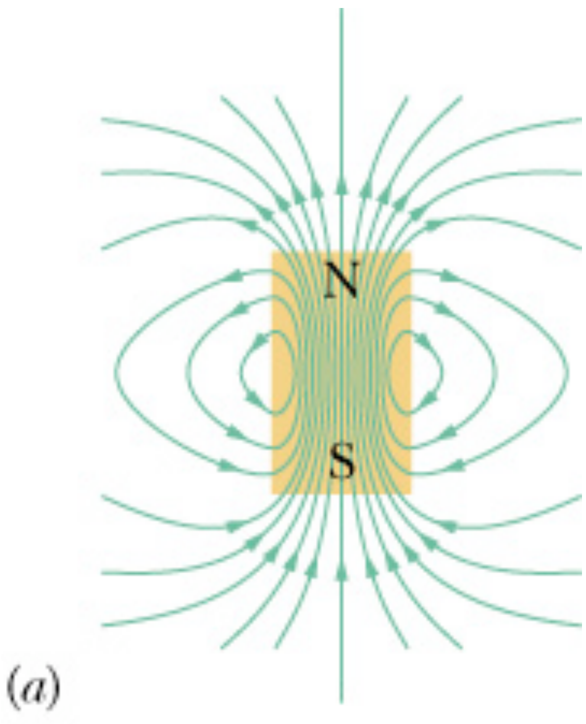
• **RC circuits**: simple circuit with time-varying current; time constant is $\tau = RC$

• **Charging** a capacitor: $q(t) = CE(1-e^{-t/RC})$

• **Discharging** a capacitor: $q(t)=CEe^{-t/RC}$

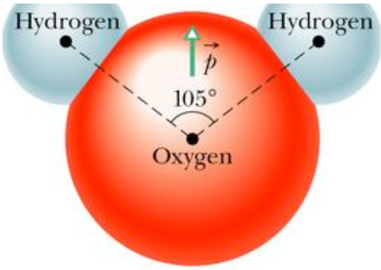
How Do You Use Magnetic Fields in Your Everyday Life!?





What Produces a Magnetic Field

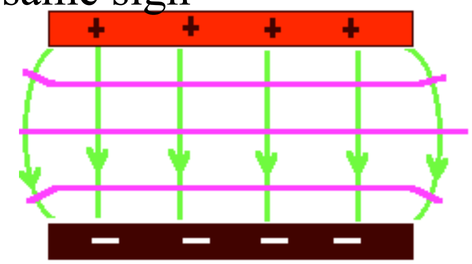
- Two classes of **magnets**:
  - a current through a wire is an **electromagnet**
  - a magnetic material is a **permanent magnet**
- Magnets **attract** iron pieces
- Magnets align in **North-South** direction
- Magnets create a **magnetic field *B*** which manifests by a **magnetic force**
- Force will serve to define ***B***



Electric vs. Magnetic Fields

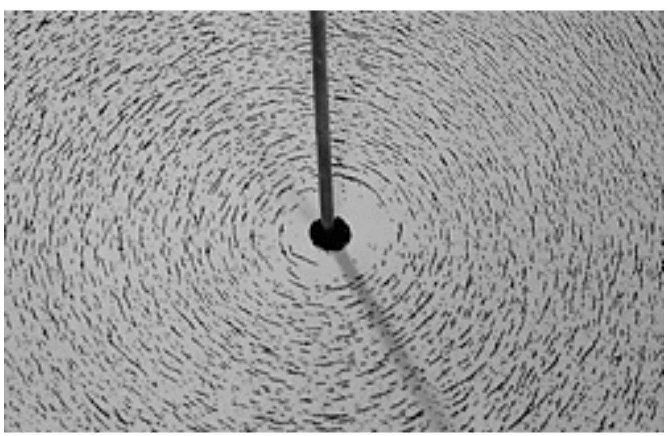
Electric fields are created:

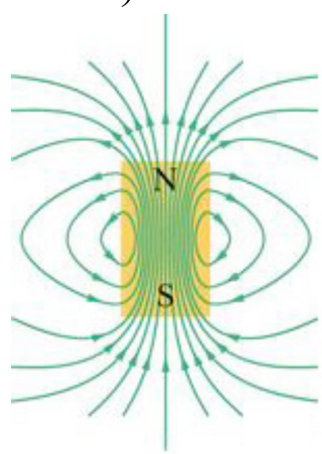
• *microscopically*, by electric charges (fields) of elementary particles (electrons, protons)
• *macroscopically*, by adding the field of many elementary charges of the same sign



Magnetic fields are created :

• *microscopically*, by magnetic "moments" of elementary particles (electrons, protons, neutrons)
• *macroscopically*, by
    • adding many microscopic magnetic moments (magnetic materials); or by
    • electric charges that move (electric currents)



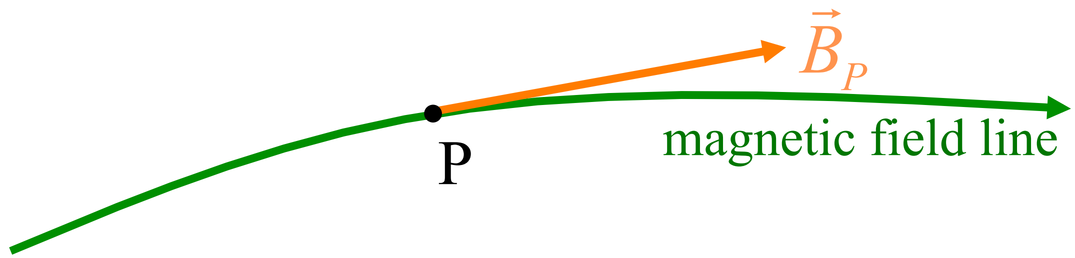


(*b*)

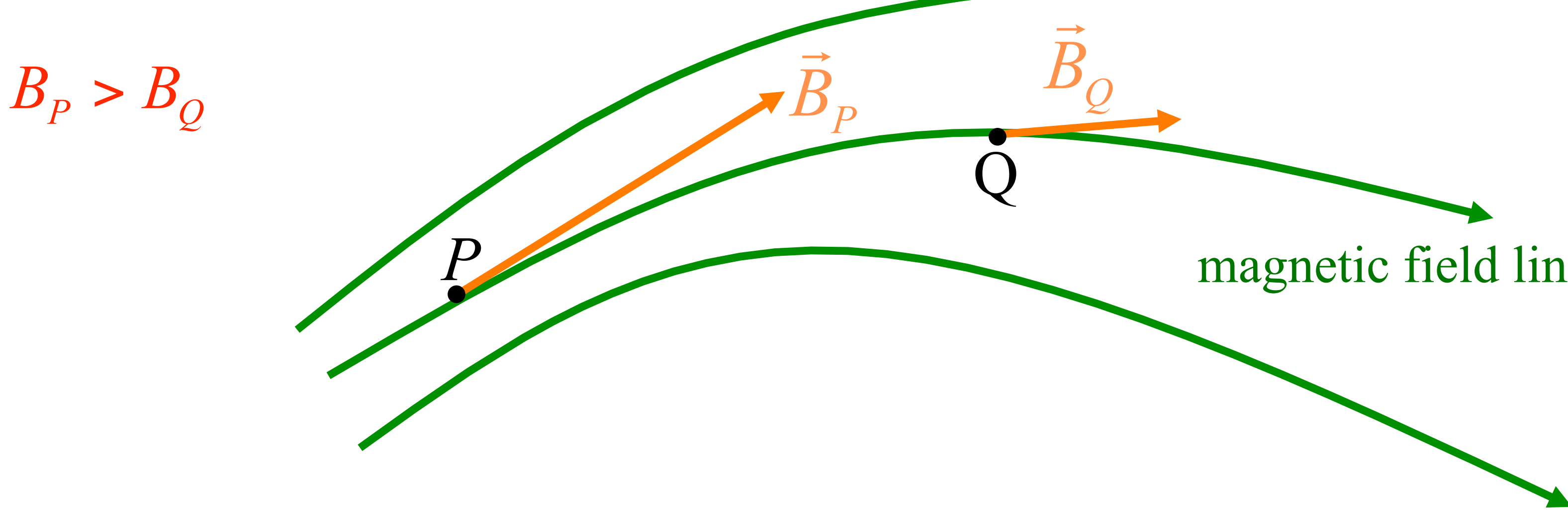
Magnetic Field Lines : In analogy with the electric field lines we introduce the concept of magnetic field lines, which help visualize the magnetic field vector $\vec{B}$ without using equations.

In the relation between the magnetic field lines and $\vec{B}$:

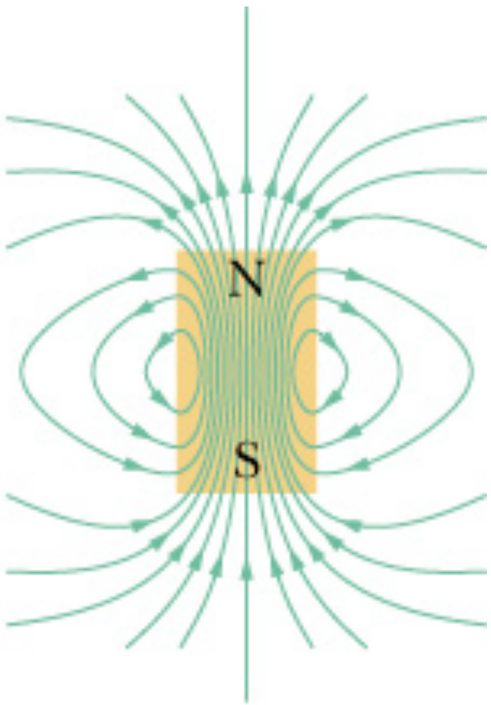
1. **At any point P the magnetic field vector $\vec{B}$ is tangent to the magnetic field lines.**



2. **The magnitude of the magnetic field vector $\vec{B}$ is proportional to the density of the magnetic field lines.**



Field Lines of a Permanent Magnet



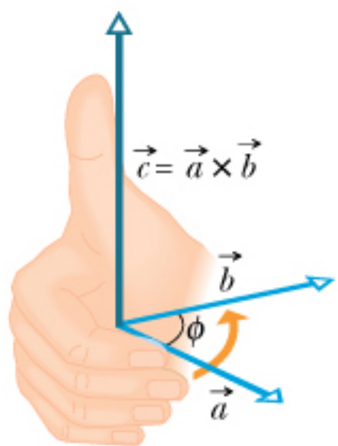
(a)

- Lines pass though body and form **closed** loops
- Lines emerge (**north pole**) at some point
- Lines enter (**south pole**) at another
- Poles cannot be separated; they form a **magnetic dipole**

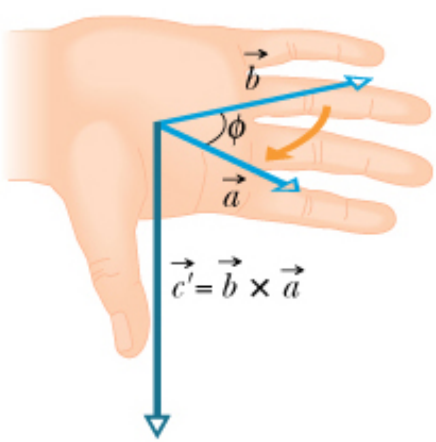
Definition of *B*

- **Magnetic field vector** defined from force $\boldsymbol{F}_B$ on a particle with velocity $\boldsymbol{v}$ and charge q
- Particle **injected** with different directions
- **Parallel** with ***B*** no force on particle
- For all other directions: $F_B = |q| vB \sin\phi$
- Magnetic force vector: $\vec{F}_B = q\vec{v} \times \vec{B}$
- **SI unit** of ***B***: 1 tesla = 1 T = 1 N / (A m) = 10^4 gauss

Vector Product of Two Vectors



(*a*)



(*b*)

- The **vector product** (cross product): ***c*** = ***a*** x ***b***
- The **magnitude** of ***c*** is $c = a\,b \sin \phi$
- The **direction** of ***c*** is **perpendicular** to the plane by the vectors ***a*** and ***b***
- **Right-hand rule**:
  - ***a***, ***b*** **tail to tail**
  - Rotate ***a*** in the plane along **shortest angle** to coincide with ***b***
  - **Rotate fingers** of the right hand in same direction
  - Thumb of **right hand** in direction of ***c***

The Vector Product $\vec{c} = \vec{a} \times \vec{b}$ in Terms of Vector Components

$$\vec{a} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k},\ \vec{b} = b_x\hat{i} + b_y\hat{j} + b_z\hat{k},\ \vec{c} = c_x\hat{i} + c_y\hat{j} + c_z\hat{k}$$

The vector components of vector $\vec{c}$ are given by the equations

$$c_x = a_y b_z - a_z b_y\ ,\quad c_y = a_z b_x - a_x b_z\ ,\quad c_z = a_x b_y - a_y b_x$$

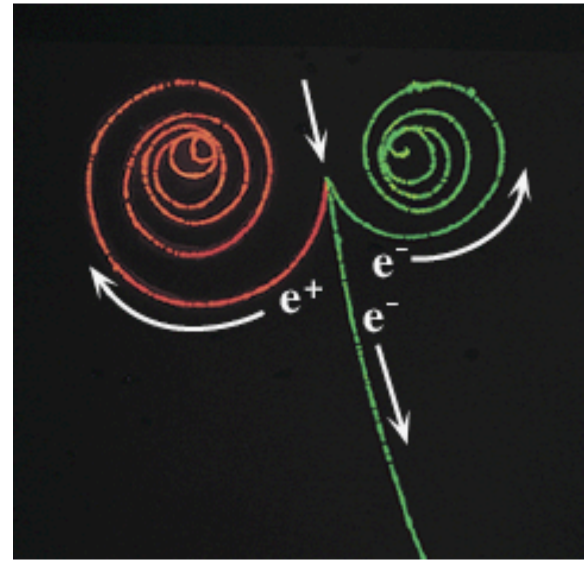
Note: Those familiar with the use of determinants can use the expression

$$\vec{a} \times \vec{b} = \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ a_x & a_y & a_z \\ b_x & b_y & b_z \end{vmatrix}$$

Note: The order of the two vectors in the cross product is important:

$$\vec{b} \times \vec{a} = -\left(\vec{a} \times \vec{b}\right).$$

Magnetic vs. Electric Forces



We know that an electric fields exists because it accelerates electric charges, with a force independent of the velocity of the charge, proportional to the electric charge: $\boldsymbol{F}_E = q\boldsymbol{E}$

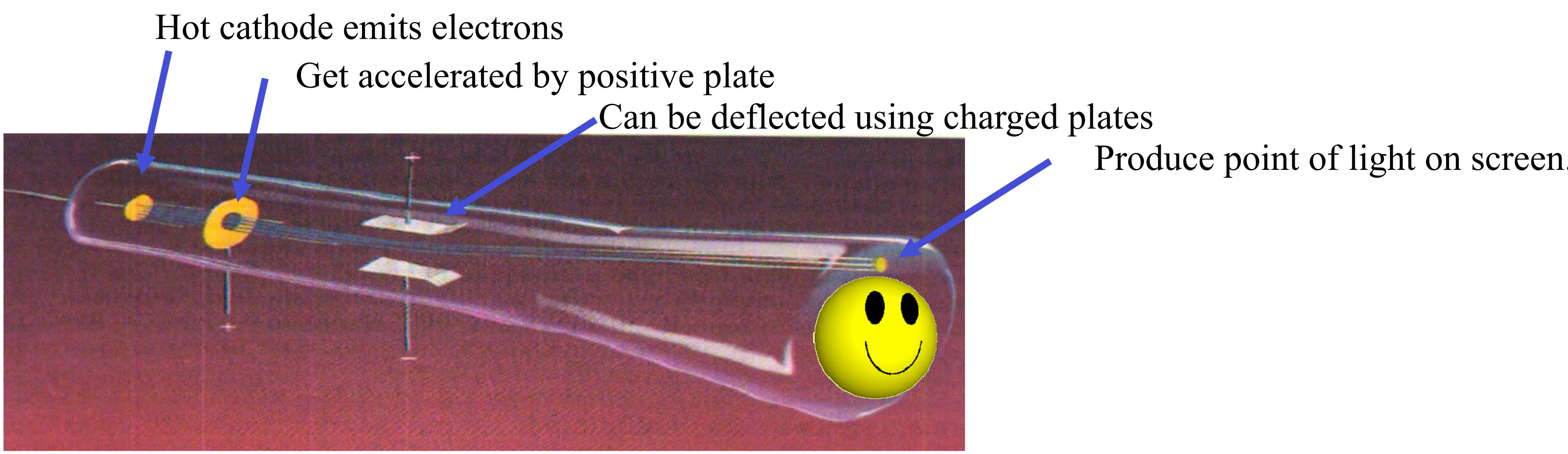
We know that a magnetic field exists because it accelerates electric charges in a direction perpendicular to the velocity of the charge, with a magnitude proportional to the velocity of the charge and to the magnitude of the charge: $\boldsymbol{F}_B = q\,\boldsymbol{v} \times \boldsymbol{B}$

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

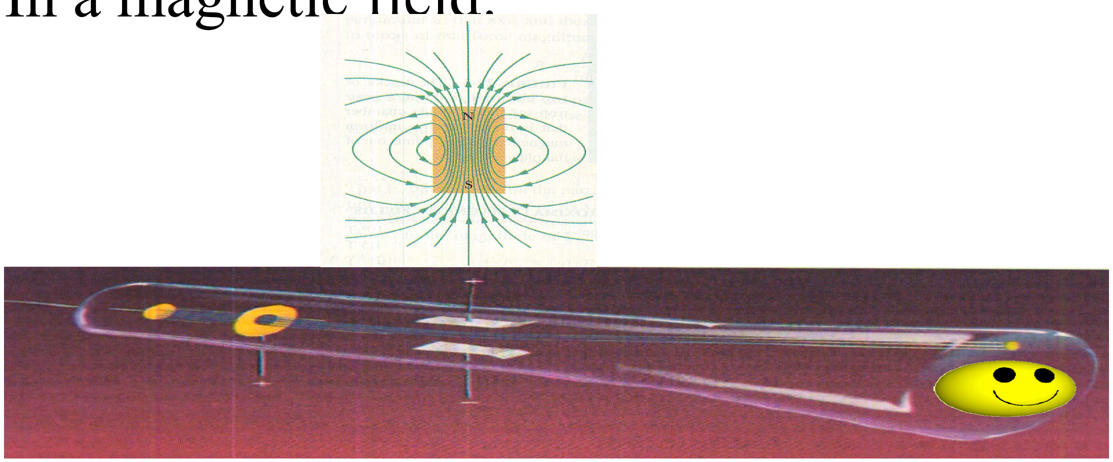
Since magnetic forces are perpendicular to the velocity, they do **no work**! $(W=\boldsymbol{F} \cdot \boldsymbol{r})$

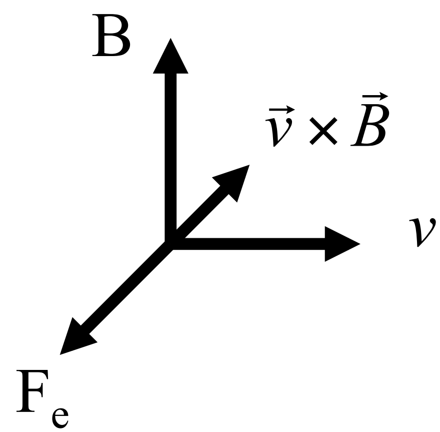
Speed of particles moving in a magnetic field remains constant in magnitude, ONLY the direction changes.
Kinetic energy is constant! (no work).

Cathode Ray Tube (Old TVs & Computer Monitors)



In a magnetic field:

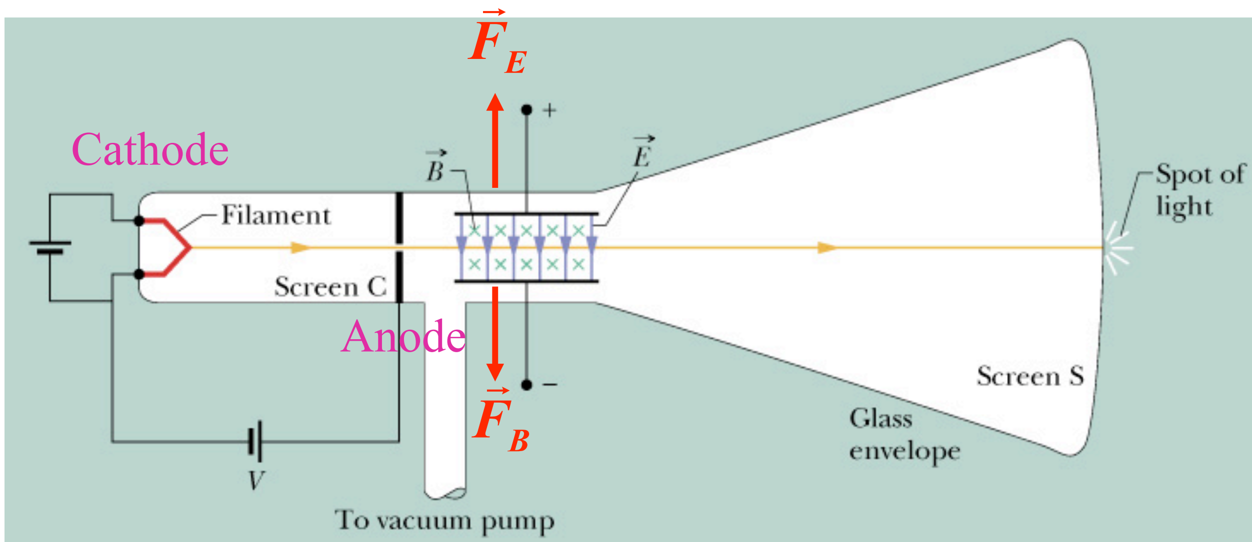




Dot shifts sideways.

Discovery of the Electron

- **Crossed** electric and magnetic fields
- Force from electric field $\vec{F}_E = q\vec{E}$
- Force from magnetic field $\vec{F}_B = q\vec{v} \times \vec{B}$
- Adjust ***B*** and ***E*** to exert **equal force in opposite direction**



Summary

- Magnetic fields **exert forces** on moving charges $\boldsymbol{F}_B = q\,\boldsymbol{v} \times \boldsymbol{B}$: the force is **perpendicular** to the field and the velocity
- Magnetic field lines are used to **visualize** magnetic fields
- Magnetic field $\boldsymbol{B}$ has SI unit **tesla**
- **Right hand rule** for vector products (cross products)
- **Cathode ray tube** crossed electric and magnetic fields; lead to discovery of electron