Lecture 19

Physics II

Chapter 29

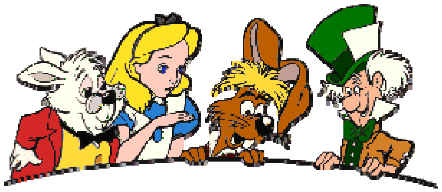
Cyclotron motion

Course website:
http://faculty.uml.edu/Andriy_Danylov/Teaching/PhysicsII

Department of Physics and Applied Physics

Today we are going to discuss:

Chapter 29:



- *Section 29.7 (Skip the Hall effect)*
- *Section 29.8*
- *Section 29.5 Skip*

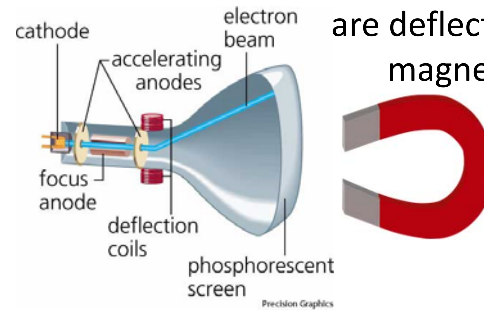
Applications

$$\vec{F}_{\text{on } q} = q\vec{v} \times \vec{B}$$

Magnetic Force in "Art"

$$\vec{F}_{\text{on } q} = q\vec{v} \times \vec{B}$$

Electrons in a kinescope are deflected by a magnetic field



Nam June Paik's Magnet TV (1965) at the truly amazing new Whitney Museum of American Art.

Nam June Paik
(a Korean-American artist)

Magnet TV
1965/99

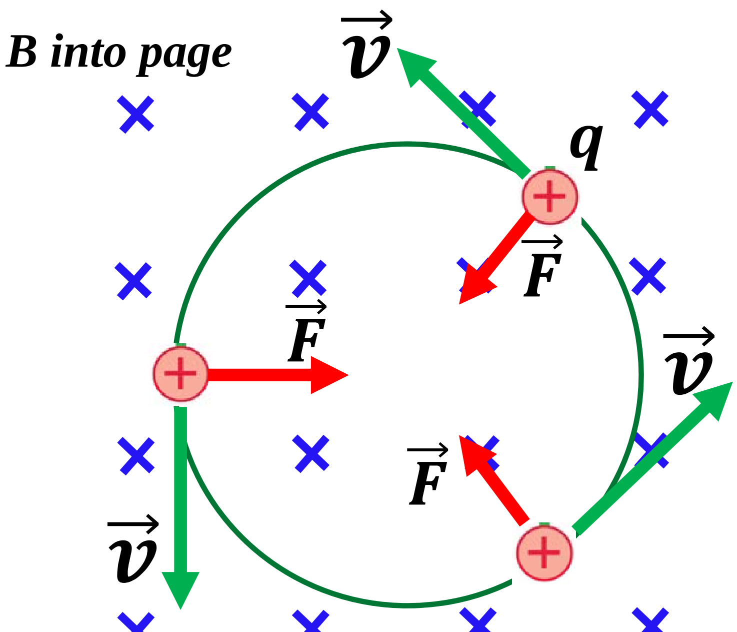
There is an amazingly beautiful application of $\vec{F}_{\text{on } q} = q\vec{v} \times \vec{B}$

Cyclotron Motion

Many important applications of magnetism involve the motion of charged particles in a perpendicular magnetic field

Cyclotron motion

The figure shows a positive charge moving in a plane that is perpendicular to a ***uniform*** magnetic field.



The magnetic force is always perpendicular to $\vec{v}$, causing the particle to move in a circle.

$$\vec{F}_{\text{on } q} = q\vec{v} \times \vec{B}$$

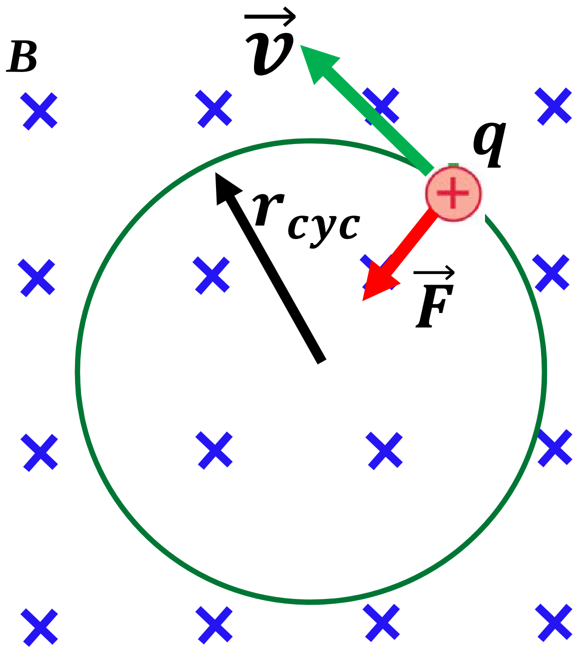
Since ***F*** is always perpendicular to ***v***, ***F*** changes the direction of the velocity, but not it is magnitude.

It means ***q*** experiences only the centripetal acceleration

Thus, the charge undergoes **uniform circular motion.**

This motion is called the **cyclotron motion** of a charged particle in a magnetic field.

Cyclotron radius



Newton's second law for a radial direction,

$$F = ma_r$$

$$F = |q\vec{v} \times \vec{B}| = qvB \qquad a_r = \frac{v^2}{r}$$

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

The radius of the cyclotron orbit:

$$r_{cyc} = \frac{mv}{qB}$$

If B=0, then $r_{cyc}=\infty$, which is a straight line

The period of the cyclotron motion:

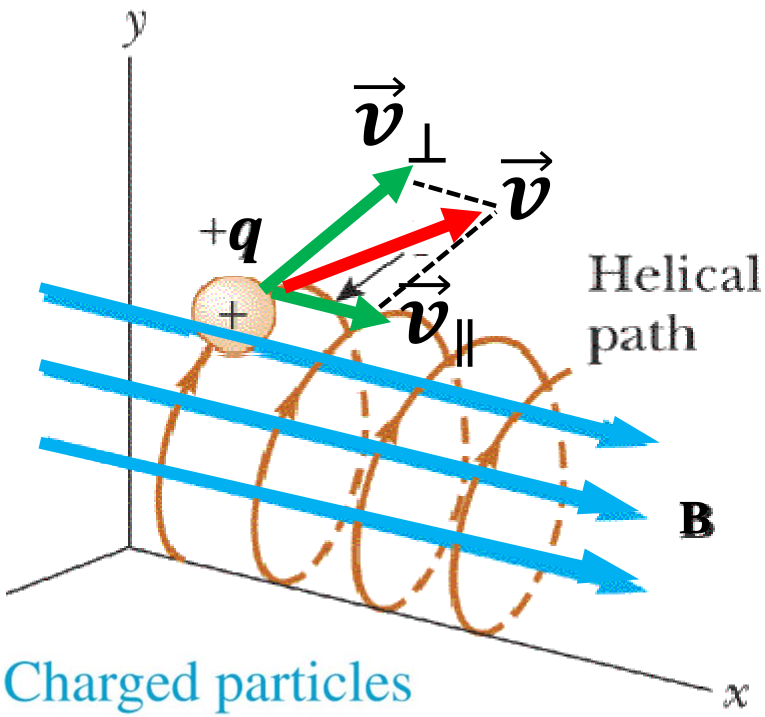
$$T_{cyc} = \frac{2\pi r_{cyc}}{v} = \left(\frac{2\pi}{v}\right)\left(\frac{mv}{qB}\right) = \frac{2\pi m}{qB}$$

The frequency of the **cyclotron motion**.

$$f_{cyc} = \frac{1}{T_{cyc}} = \frac{qB}{2\pi m}$$

Note! The cyclotron frequency does not depend on v.

Cyclotron motion *(general situation)*

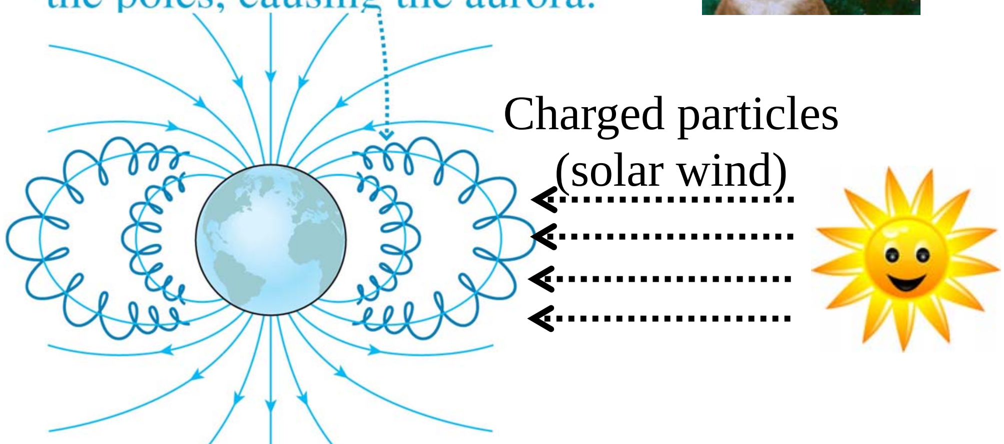


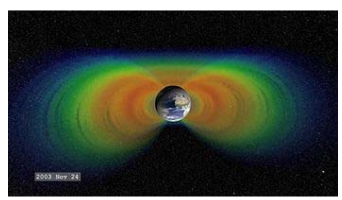
Charged particles spiral around the magnetic field lines.

- The figure shows a more general situation in which the charged particle's velocity is not exactly perpendicular to B.
- The component of v parallel to B is not affected by the field, so the charged particle spirals around the magnetic field lines in a helical trajectory.
- The radius of the helix is determined by $v_\perp$, the component of v perpendicular to B.

Aurora (Northern lights)

The earth's magnetic field leads particles into the atmosphere near the poles, causing the aurora.

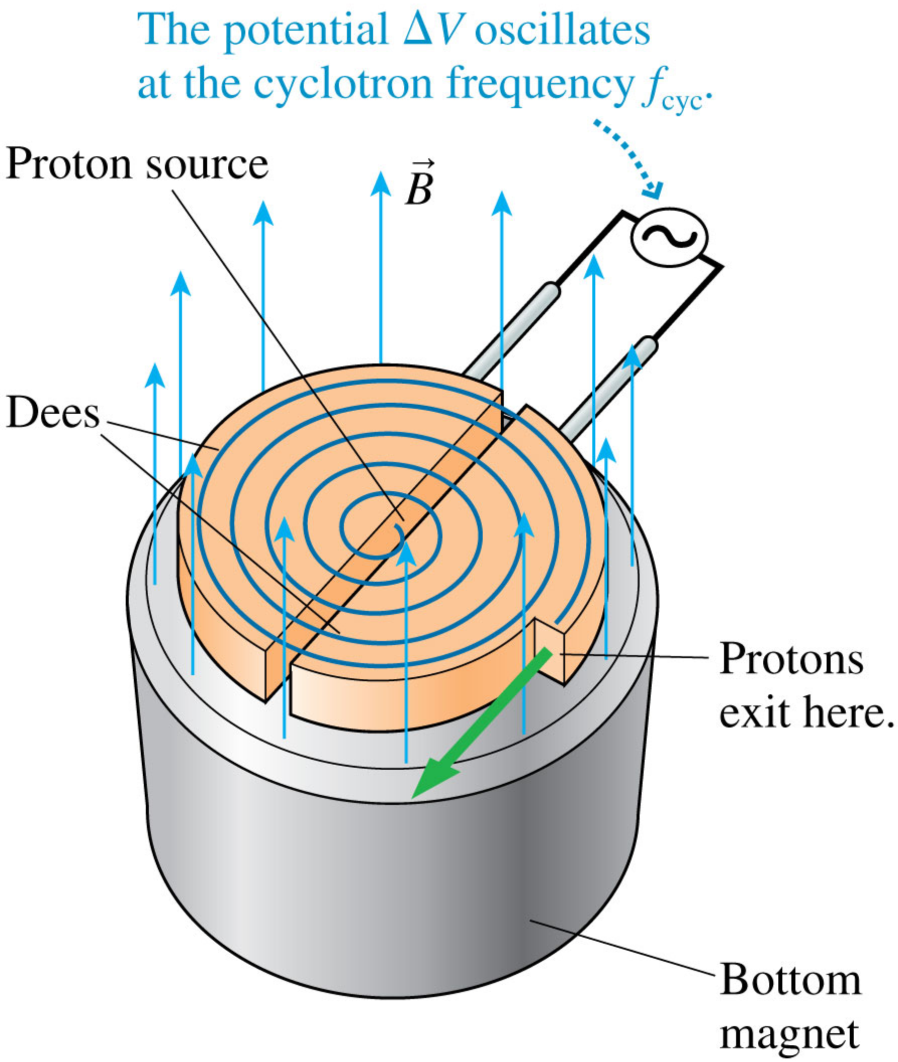




Van Allen radiation belt

https://en.wikipedia.org/wiki/Van_Allen_radiation_belt

The Cyclotron



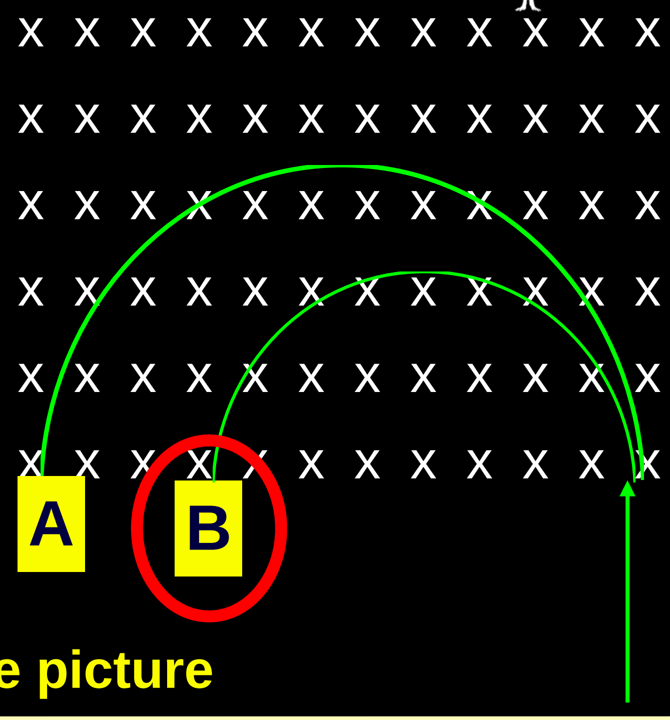
The first practical particle accelerator, invented in the 1930s, was the **cyclotron.**

Cyclotrons remain important for many applications of nuclear physics, such as the creation of radioisotopes for medicine.

$$r_{cyc} = \frac{mv}{qB}$$

ConcepTest **Mass Spectrometer**

Two particles of the *same mass* enter a magnetic field with the *same speed* and follow the paths shown. Which particle has the *bigger charge*?



C) both charges are equal

D) impossible to tell from the picture

$r_A > r_B$

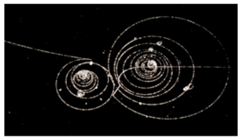
so since m, v, B are the same, then $q_A < q_B$

The relevant equation for us is: $r_{cyc} = \frac{mv}{qB}$

According to this equation, the bigger the charge, the smaller the radius.

Follow-up: What is the sign of the charges in the picture?

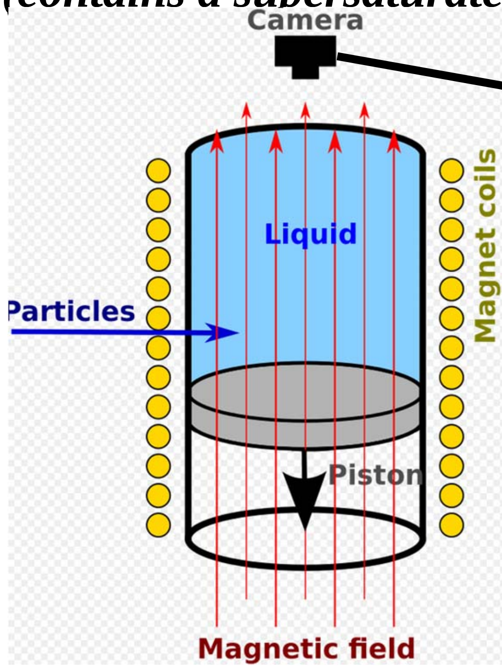
$\vec{F}_{\text{on } q} = q\vec{v} \times \vec{B}$ → *If $q > 0$, then the force is to the left (our case)*

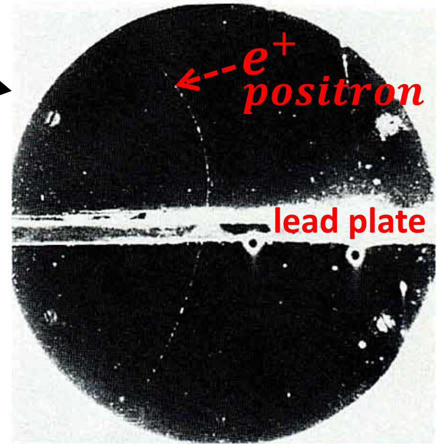


Cloud/Bubble chamber to detect charged particles

$$r_{cyc} = \frac{mv}{qB}$$

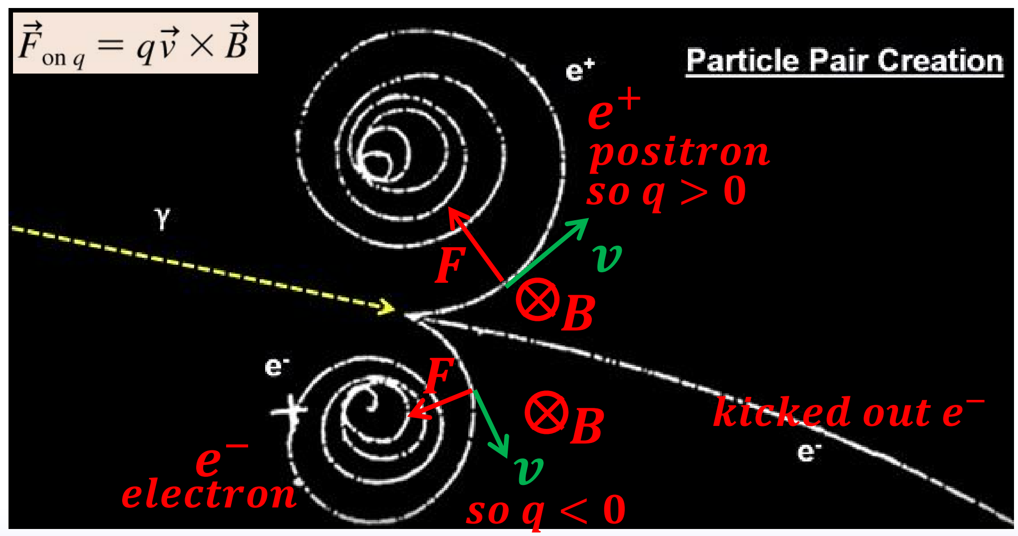
(contains a supersaturated vapor of water)





The photograph shows the track of an unusual **positively** charged particle with a mass about equal that of an electron slowed down by passing through a lead plate. It was among the earliest evidence of the existence of the <u>**positron**</u> found by C.D. Anderson in 1932, but predicted by Paul Dirac in 1928

A gamma photon kicks out an electron out of an atom and creates an electron-positron pair.




Thank you
Bye Bye For Now