Lecture 19

Chapter 29

Cyclotron motion

Messiah!?!... Miraculous appearance out of the blue.

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

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

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

**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 $\vec{F}$ is always perpendicular to $\vec{v}$, $\vec{F}$ changes the direction of the velocity, but not its 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,

\[ F = m \alpha_r \]

\[ F = |q \mathbf{v} \times \mathbf{B}| = q \nu B \]

\[ \alpha_r = \frac{\nu^2}{r} \]

The frequency of the cyclotron motion:

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

The radius of the cyclotron orbit:

\[ r_{cyc} = \frac{mv}{qB} \]

The period of the cyclotron motion:

\[ T_{cyc} = \frac{2\pi r_{cyc}}{\nu} = \left( \frac{2\pi}{\nu} \right) \left( \frac{mv}{qB} \right) = \frac{2\pi m}{qB} \]

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

Note! The cyclotron frequency does not depend on \( v \).
Cyclotron motion \textit{(general situation)}

- The figure shows a more general situation in which the charged particle’s velocity is not exactly perpendicular to B.

- The component of $\vec{v}$ 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 $\vec{v}$ perpendicular to B.
**Aurora (Northern lights)**

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

Charged particles
(solar wind)

Van Allen radiation belt
https://en.wikipedia.org/wiki/Van_Allen_radiation_belt
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.

\[ r_{cyc} = \frac{mv}{qB} \]
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?

If \( q > 0 \), then the force is to the left (our case).
Cloud/Bubble chamber to detect charged particles

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 positron 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.

\[ r_{cy} = \frac{mv}{qB} \]
Thank you
Bye Bye For Now