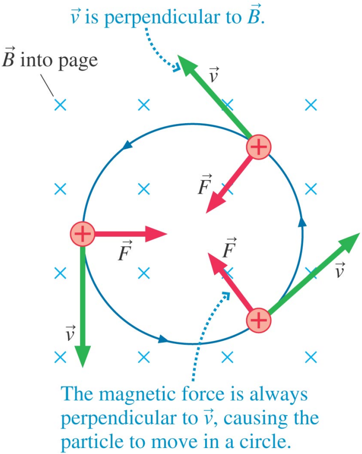
Cyclotron Motion



- We can also work-out the frequency of the cyclotron motion

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

- q/m is the particle's charge-to-mass ratio. Notice that the frequncy does not depend on the particle's velocity!!

Example 33.11

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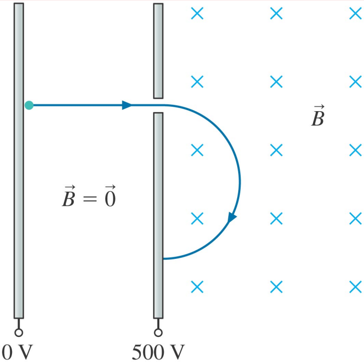
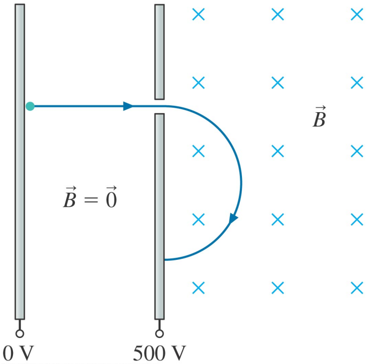


An electron is accelerated from rest through a potential difference of 500V, the injected into a uniform magnetic field. Once in the magnetic field it completes half a revolution in 2.0ns. What is the radius of the orbit?

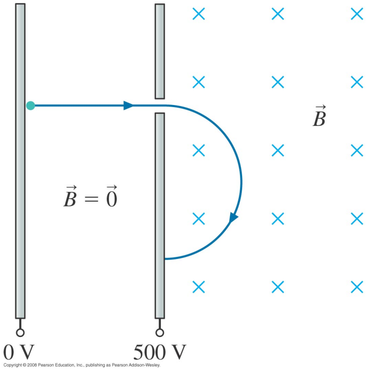
Example 33.11



- We can do the electric field part using conservation of energy:

$$
\begin{aligned}
K_f + qV_f &= K_i + qV_i \\
K_f + qV_f &= 0 + q(0) \\
\frac{1}{2}mv_f^2 + (-e)V_f &= 0 \\
v_f = \sqrt{\frac{2eV_f}{m}} &= 1.33 \times 10^7 m/s
\end{aligned}
$$

Example 33.11



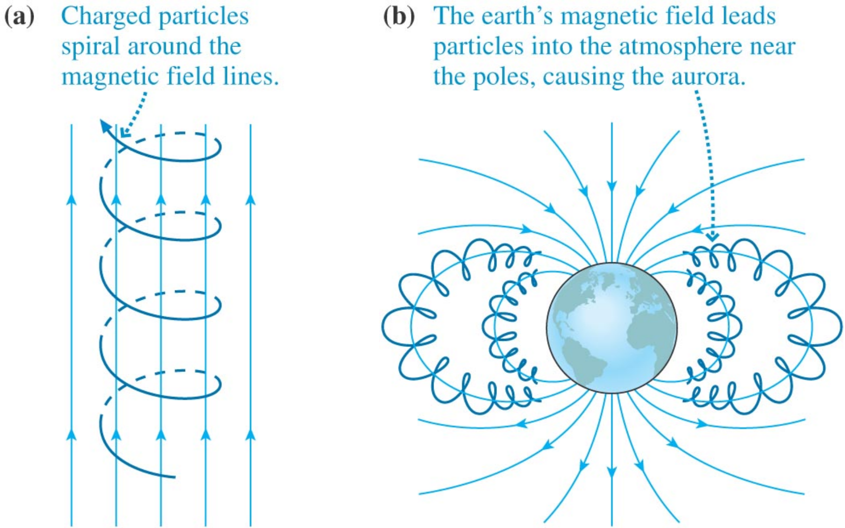
- We know that one orbit would take 4ns, therefore the frequency is

$$
\begin{aligned}
f &= \frac{1}{4ns} = 2.5 \times 10^{8} Hz \\
f &= \frac{qB}{2\pi m} \\
B &= \frac{2\pi m f}{e} = 8.94 \times 10^{-3} T
\end{aligned}
$$

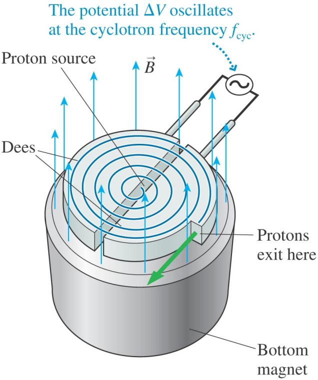
- The radius is then

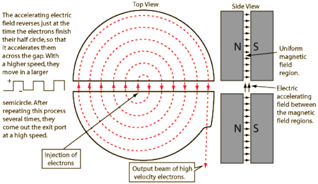
$$r = \frac{mv}{qB} = 8.5mm$$

Example 33.11



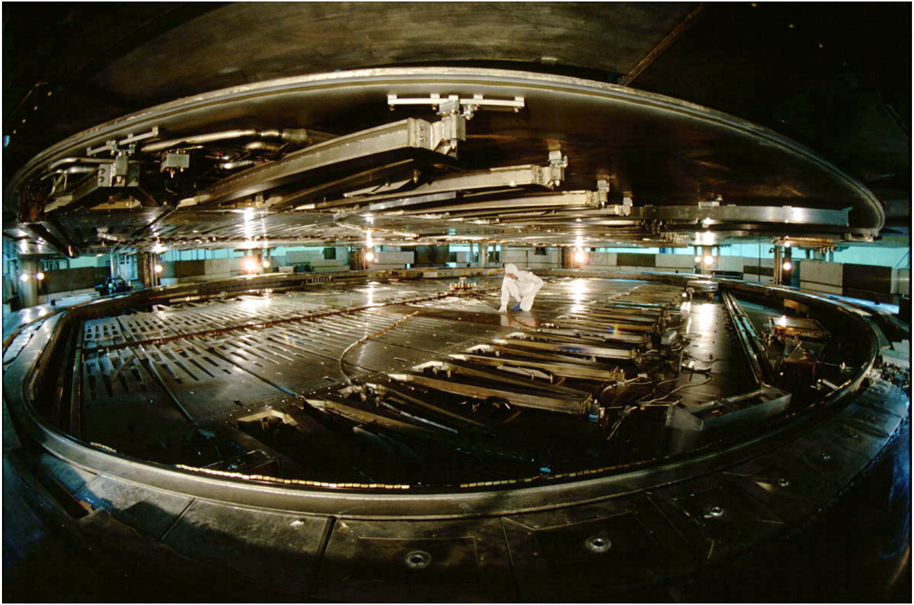
The Cyclotron





- A cyclotron is useful for nuclear, particle and CM physics experiments (and creation of medical isotopes).
- Exploit that the cyclotron frequency does not depend on particle velocity.
- Create a powerful magnetic field and inject charged particles at the center of the device.
- Accelerate them using electric fields across gaps between the “dees”. Switch the sign of the potential difference at exactly the right moment to keep accelerating.
- Increase the radius until the particles escape.

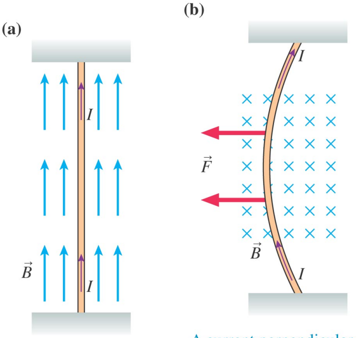
The World's Largest Cyclotron - TRIUMF



TRIUMF Cyclotron Tidbits

- First beam December 15, 1974
- 18m diameter magnet, about 0.6 Tesla
- 18500A current
- 520MeV (particle speed is 225000km/s)
- accelerates 600 trillion particles (protons) per second

Magnetic Forces on Current-Carrying Wires (33.8)

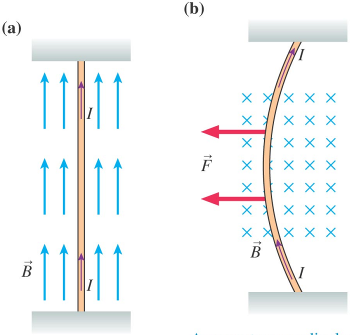


There's no force on a current parallel to a magnetic field.

A current perpendicular to the field experiences a force in the direction of the right-hand rule.

- We have seen the effect of placing two current-carrying wires close to each other (likes attract, opposites repel).
- Now it is time to quantify this magnetic force.
- A magnetic field parallel to a current exerts no force, perpendicular fields exert maximum force - makes sense from our knowlegde of moving charges.

Magnetic Forces on Current-Carrying Wires



There's no force on a current parallel to a magnetic field.

A current perpendicular to the field experiences a force in the direction of the right-hand rule.

- Let's get the force in terms of current, instead of moving charges. The current in a segment of wire of length L is charge q moving through the wire divided by the time it takes Δt:

$$q = I\Delta t = I\frac{L}{v}$$

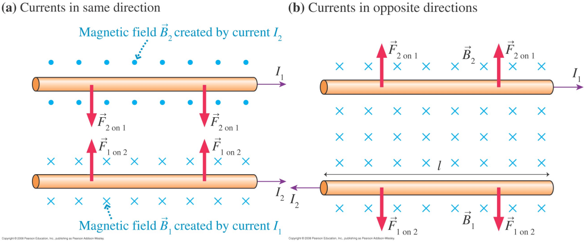
- This means that

$$IL = qv$$

- Substituting into the force equation gives

$$\vec{F}_{wire} = q\vec{v} \times \vec{B} = I\vec{L} \times \vec{B}$$

Force Between Two Parallel Wires

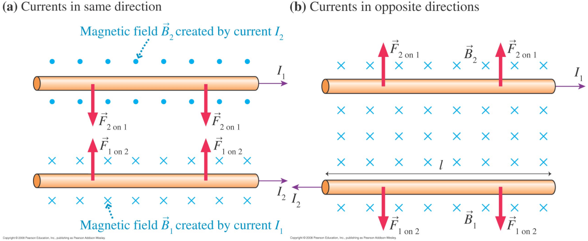


- For the specific case of two parallel wires spaced d apart, we know that the magnetic field from a “long” wire at distance d is

$$B = \frac{\mu_0 I}{2\pi d}$$

- A field of this strength is generated at the position of the second wire by the first and vice versa.

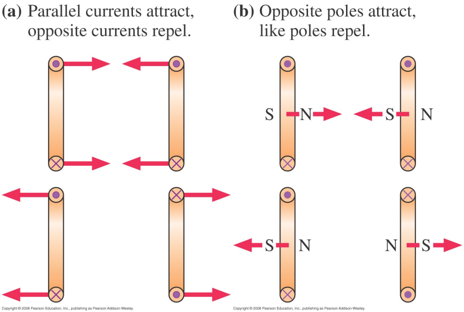
Force Between Two Parallel Wires



- Using the right-hand-rule (and some acrobatics) you can see why opposites repel and like directions attract.
- The field is the same everywhere along the parallel wires. The force on the upper wire is

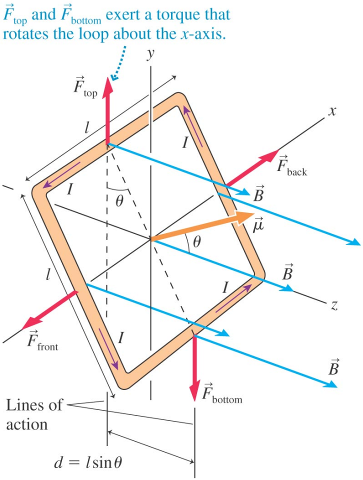
$$F = I_1 L B_2 = I_1 L \frac{\mu_0 I_2}{2\pi d} = \frac{\mu_0 L I_1 I_2}{2\pi d}$$

Forces and Torques on Current Loops (33.9)



- You could see current carrying wires as repelling or attracting because of the alignment of their poles.

Torque on a Current Loop



- Now consider a current loop in a uniform magnetic field.
- In this configuration the forces on front and back cancel. However, the loop is not perpendicular to the field, so the forces on top and bottom do not cancel - there is a torque:

$$\tau = Fd = (ILB)(L\sin\theta) = (IL^2)B\sin\theta$$

- But L^2 is the area, $\mu = IA$ so

$$\tau = \mu B\sin\theta$$
$$\vec{\tau} = \vec{\mu} \times \vec{B}$$

An Electric Motor