Last time

- More on magnetic force
- Differences between electric and magnetic force
- Magnetic field lines
- Gauss's law for magnetism
- Cyclotron motion
- Hall effect

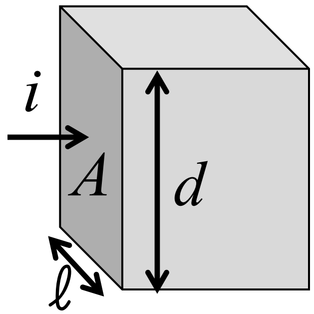
This time

- Helical paths and Aurora
- Spiral paths and particle physics
- Magnetic bottle
- Velocity selector
- Mass spectrometers
- High vacuum leak detector
- Force on a current carrying conductor

The Hall Effect

We have just found that the voltage established across a conductor carrying a current in a magnetic field is

$$\Delta V_H = v_d B d$$



We previously related the drift speed to the current via

$$v_d = \frac{i}{neA}$$ where $A = \ell d$ and n is a material property

We can then relate the Hall voltage to known quantities:

$$\Delta V_H = \frac{i}{ne\ell \cancel{d}} B\cancel{d} = \frac{iB}{ne\ell}$$

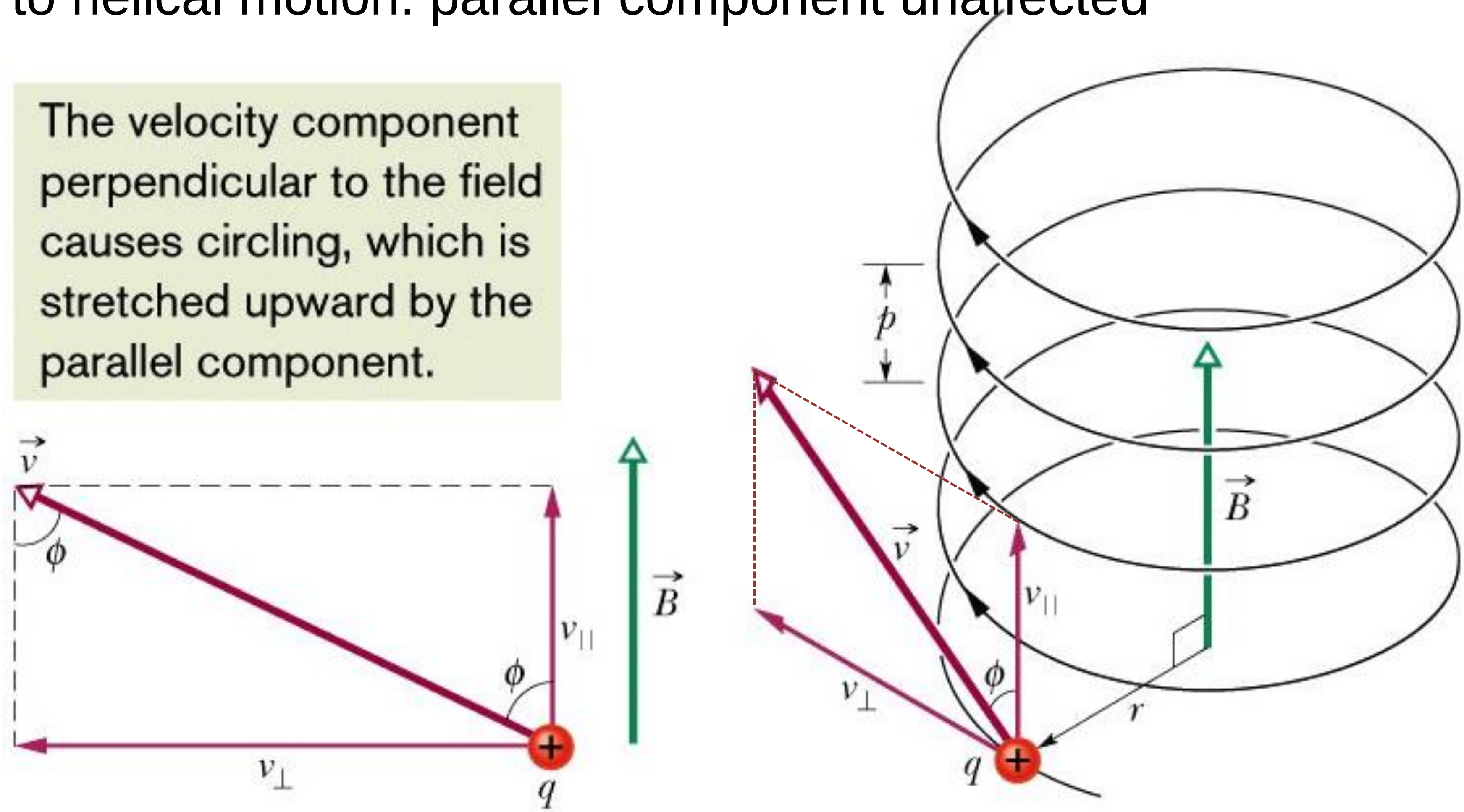
In practical applications, you measure ΔV_H to find B:

$$\boxed{B = \frac{ne\ell}{i}\Delta V_H}$$

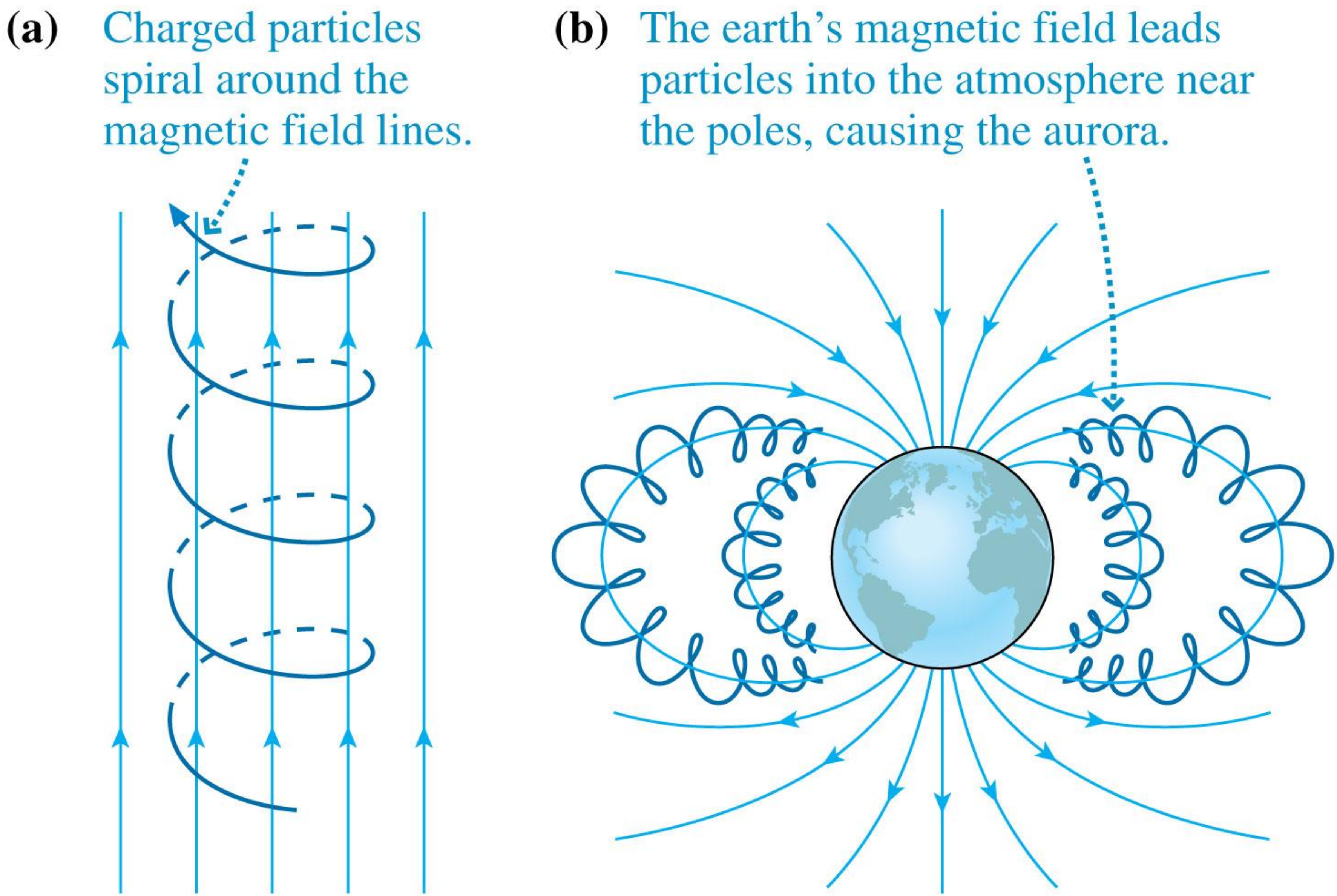
How the B-field probe used in the next lab works

Helical Paths Through a B-field

Splitting up the velocity into a component parallel to B-field and a component perpendicular to B-field immediately leads to helical motion: parallel component unaffected

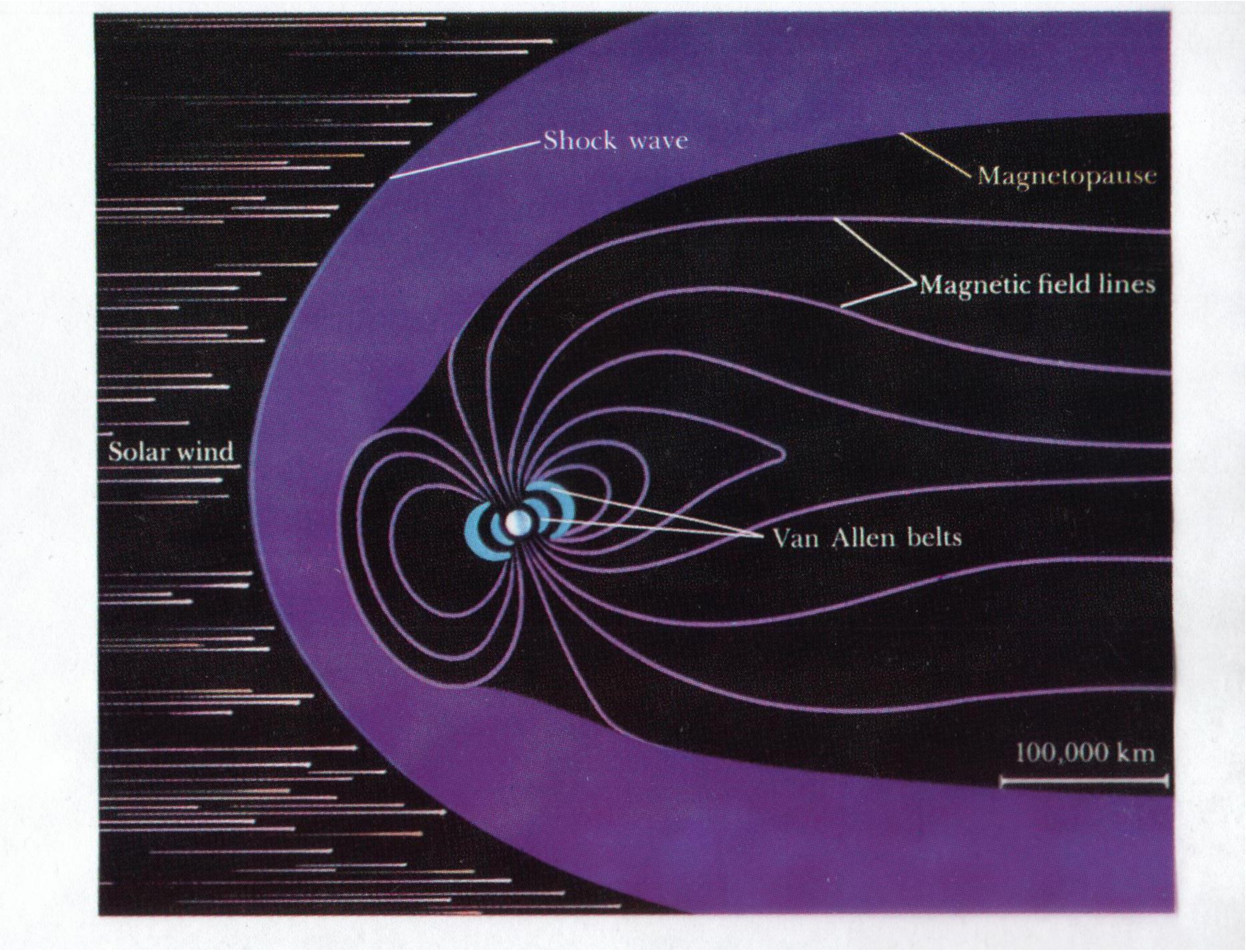


Solar wind and magnetic field of earth



Aurora

Magnetic field of earth is responsible for preventing the harmful solar wind particles from reaching the lower atmosphere.



Application: Cyclotron

In the gap between the dees, charges are accelerated by E-field:

$$\Delta K_{gap} = -\Delta U_{gap} = q\Delta V$$

After N times through the gap:

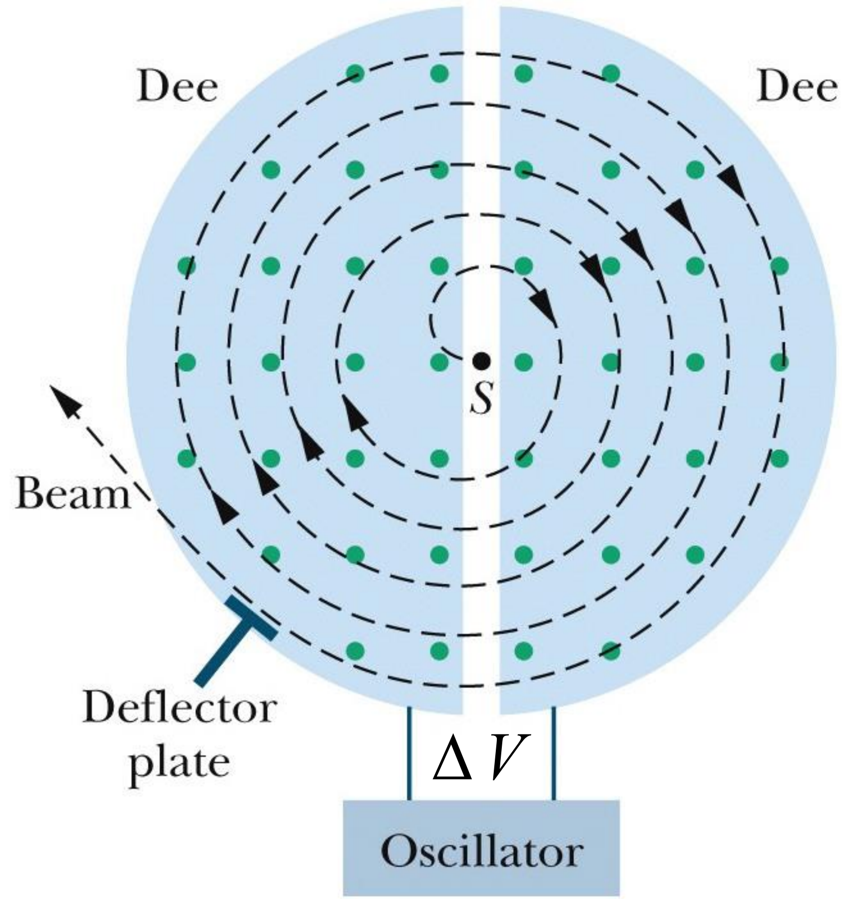
$$\frac{1}{2}mv^2 = Nq\Delta V$$

$$v = \sqrt{\frac{2Nq\Delta V}{m}}$$

$$r = \frac{mv}{qB} = \frac{m}{qB}\sqrt{\frac{2Nq\Delta V}{m}}$$

$$\boxed{= \sqrt{\frac{2Nm\Delta V}{qB^2}}}$$

The protons spiral outward in a cyclotron, picking up energy in the gap.



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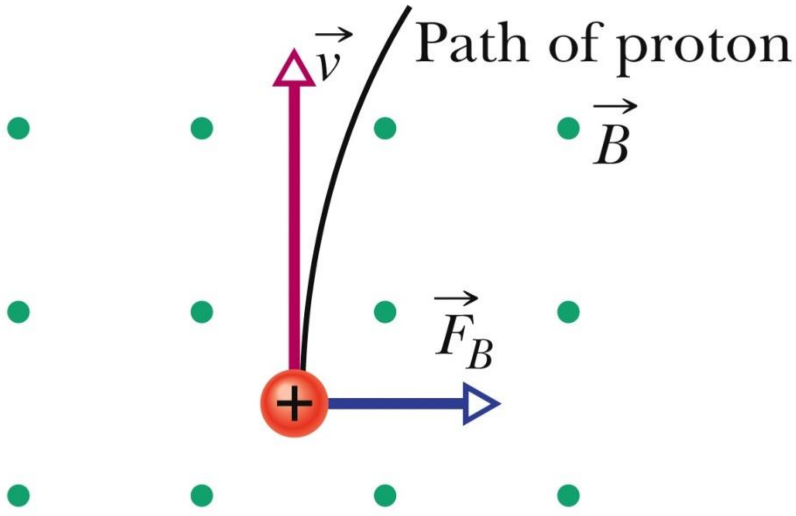
Motion of charges in B-field



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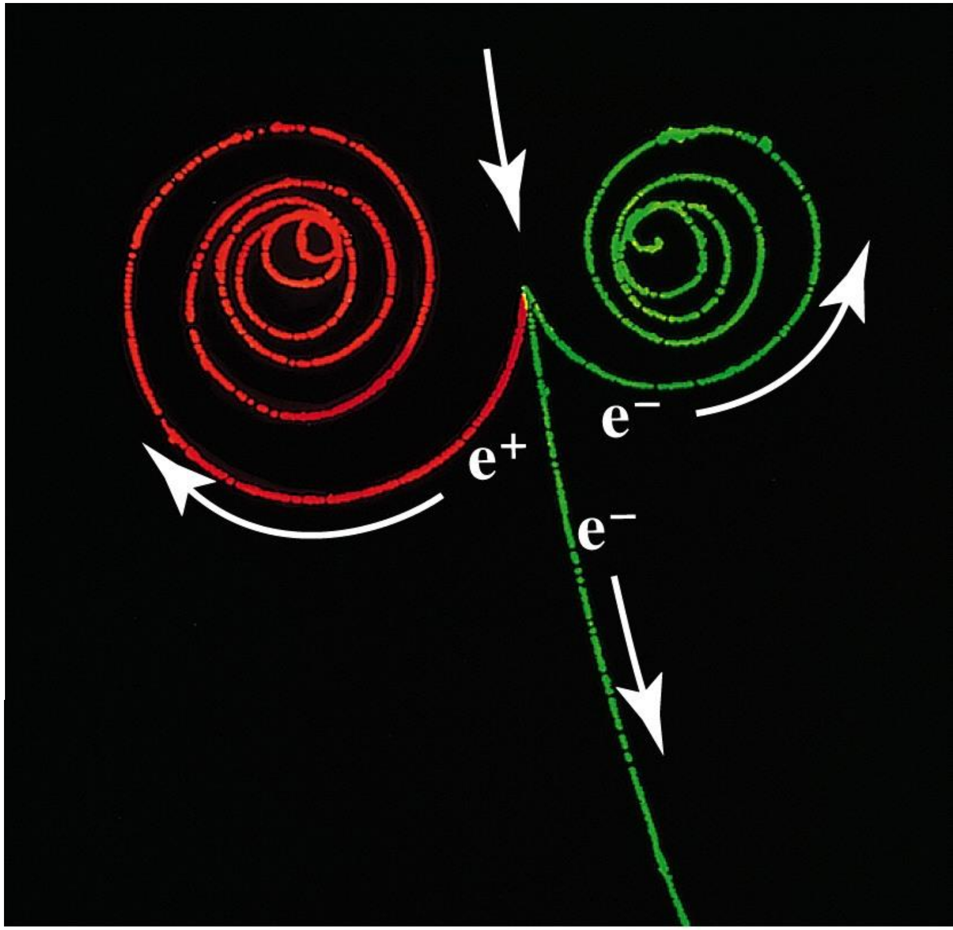

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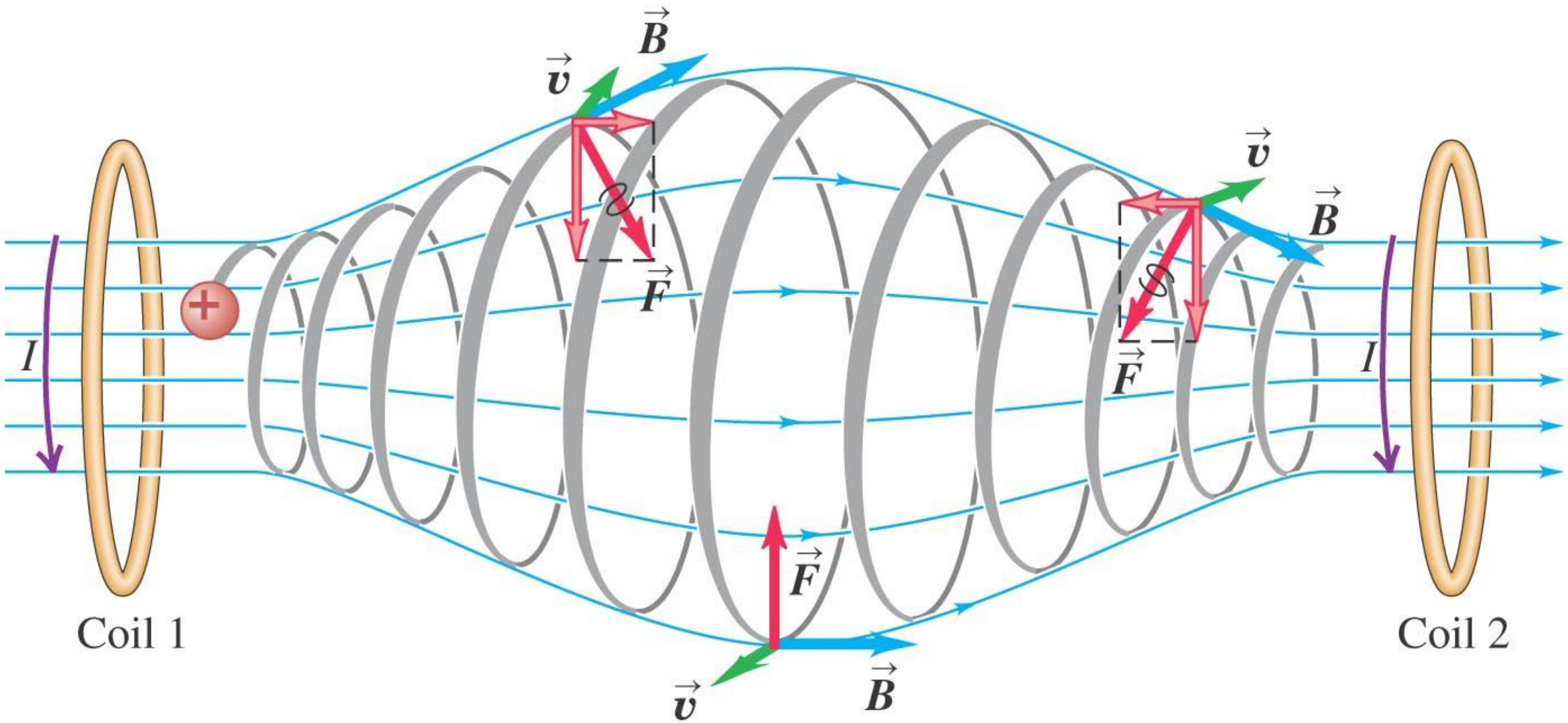
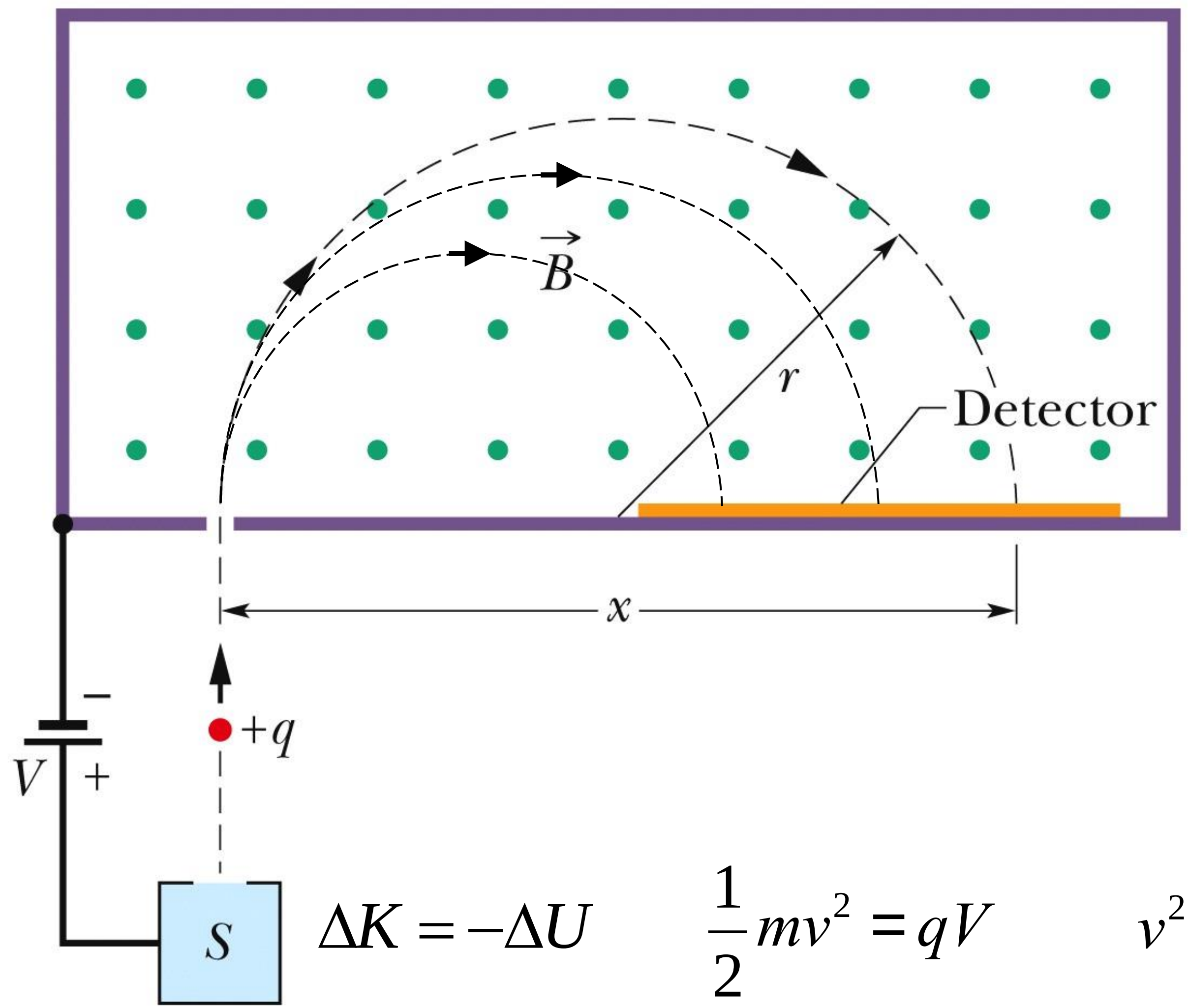
Magnetic Ion Trap



Coils are used to create a magnetic field.

Application: Mass Spectrometer



$$r = \frac{mv}{qB} = \frac{x}{2}$$

$$m^2 = \frac{q^2B^2x^2}{4v^2}$$

$$m^2 = \frac{q^2B^2x^2}{4}\frac{m}{2qV}$$

$$\boxed{m = \frac{qB^2x^2}{8V}}$$

$$\Delta K = -\Delta U \qquad \frac{1}{2}mv^2 = qV \qquad v^2 = \frac{2qV}{m}$$

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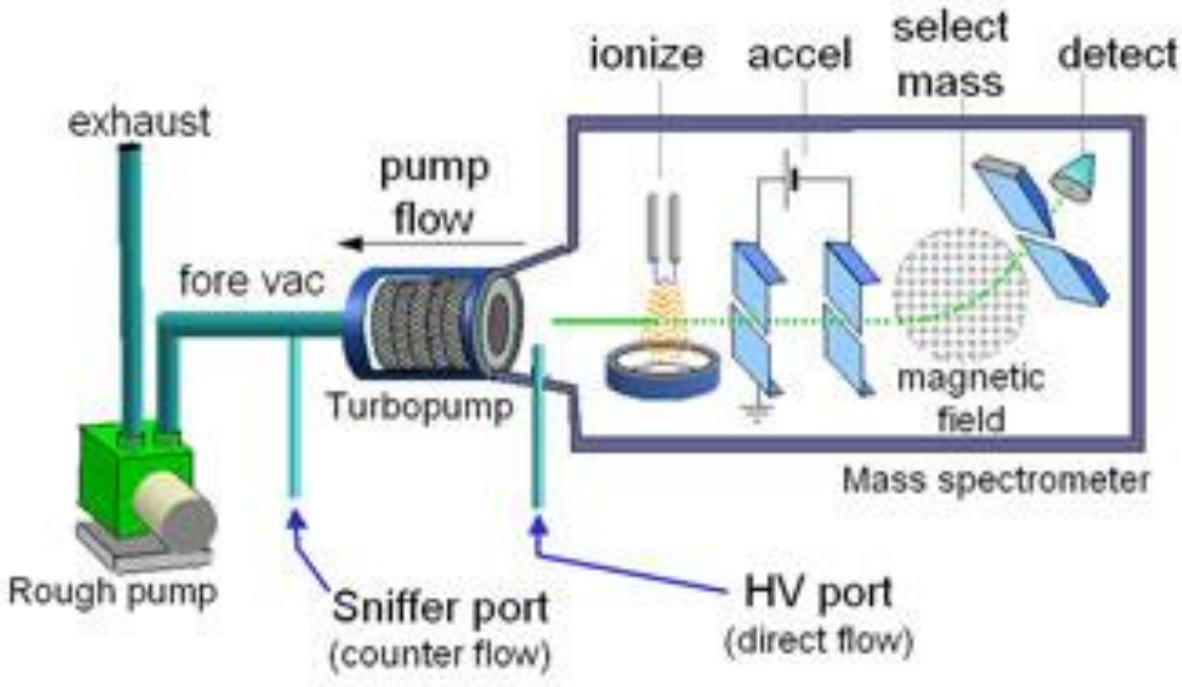
Mass spectrometer tuned to atomic mass unit of four (Helium high vacuum leak detector)

It detects microscopic cracks and holes in high vacuum chambers to prevent air from leaking into the chamber.

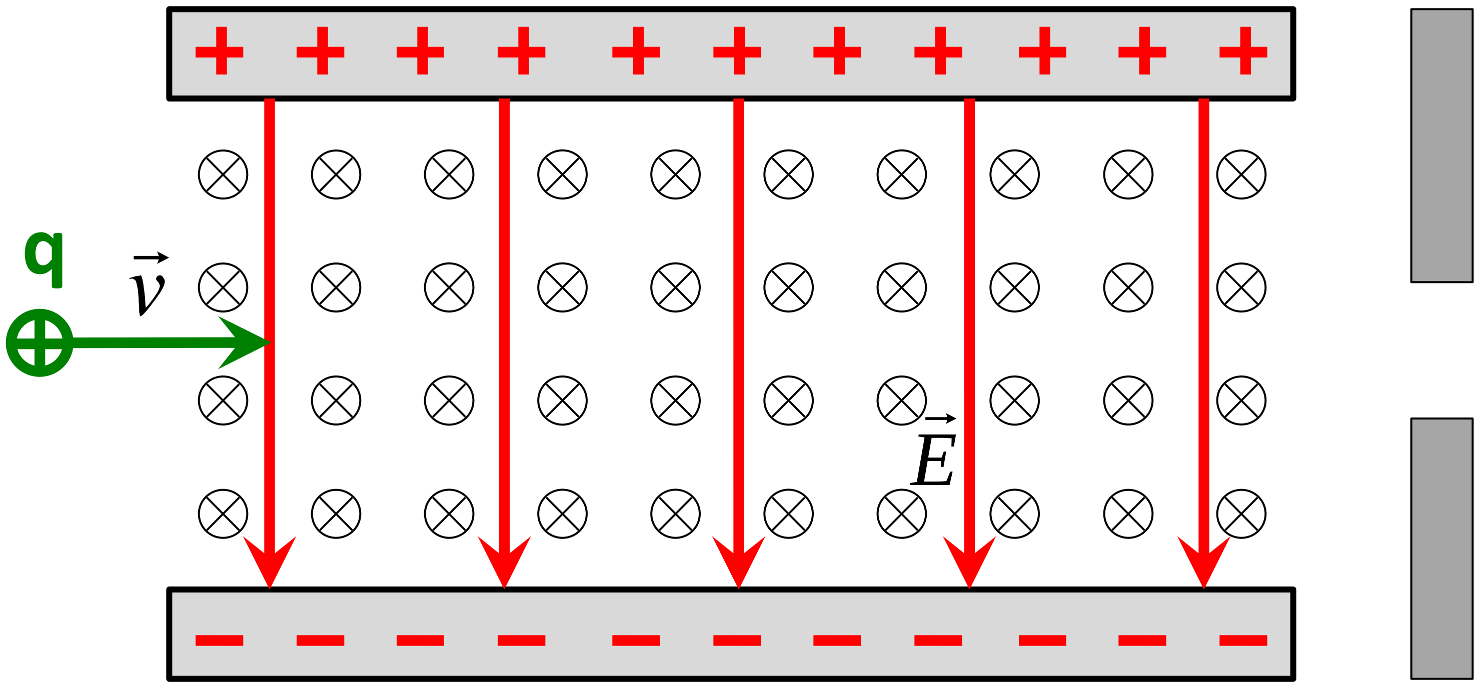
Helium high vacuum leak detector



High vacuum chamber

Relies on back diffusion of helium gas which is light.

Similar concept: velocity selector

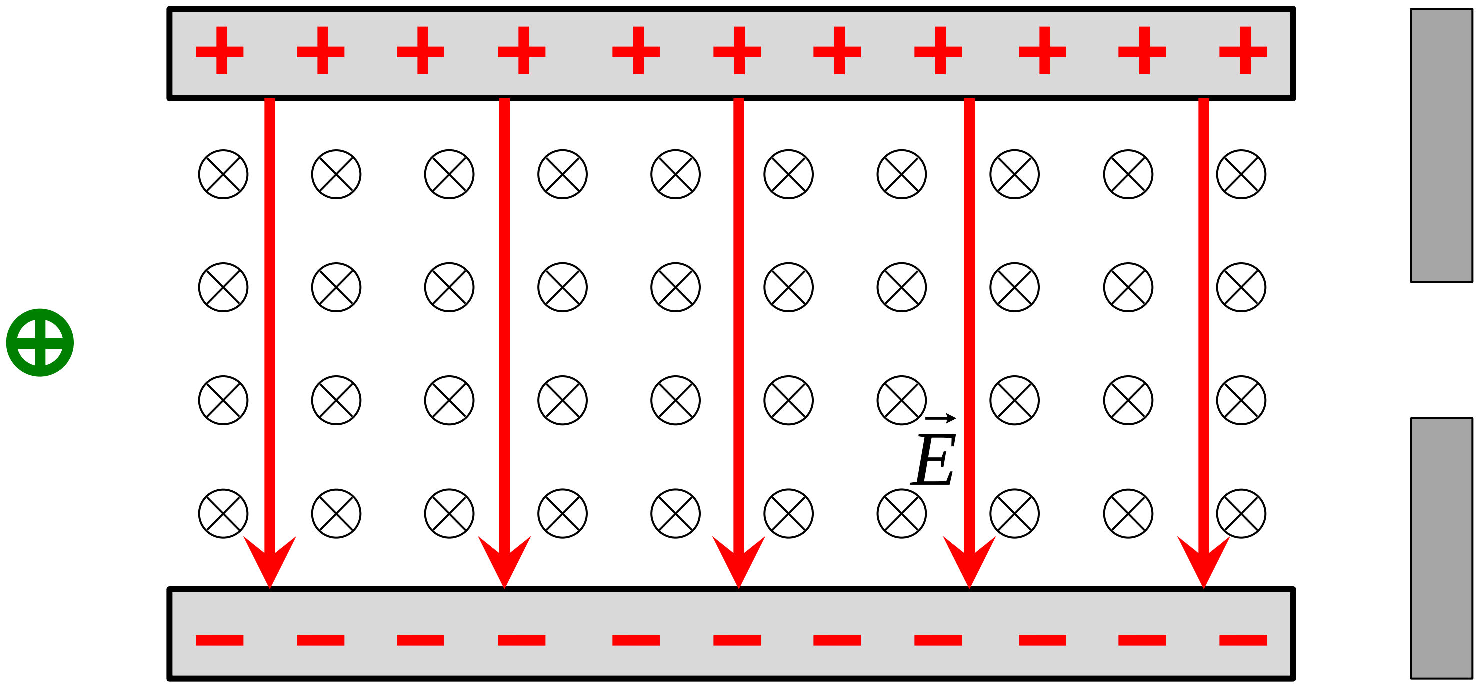


In a velocity selector, you send a charge through a region with crossed E and B fields, which leads to electric and magnetic forces:

$$\vec{F}_e = q\vec{E} \qquad \vec{F}_B = q\vec{v} \times \vec{B} \qquad qE = qvB \qquad v = \frac{E}{B}$$

If the forces balance ($F_{net} = 0$) the charge makes it through the slit

Similar concept: velocity selector

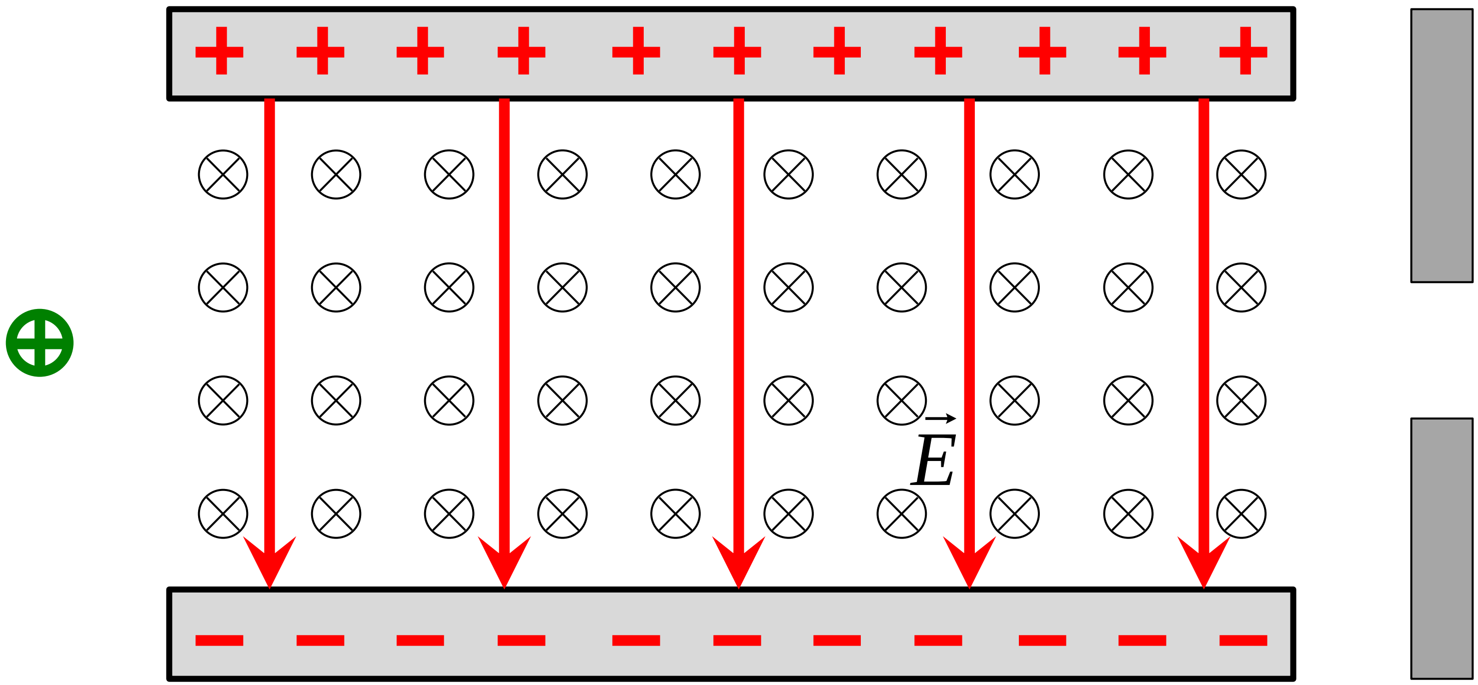


If the forces don't balance the charge hits the wall.

$$qE - qvB = ma$$

We pick the E and B magnitudes to select the speeds we want.

Similar concept: velocity selector



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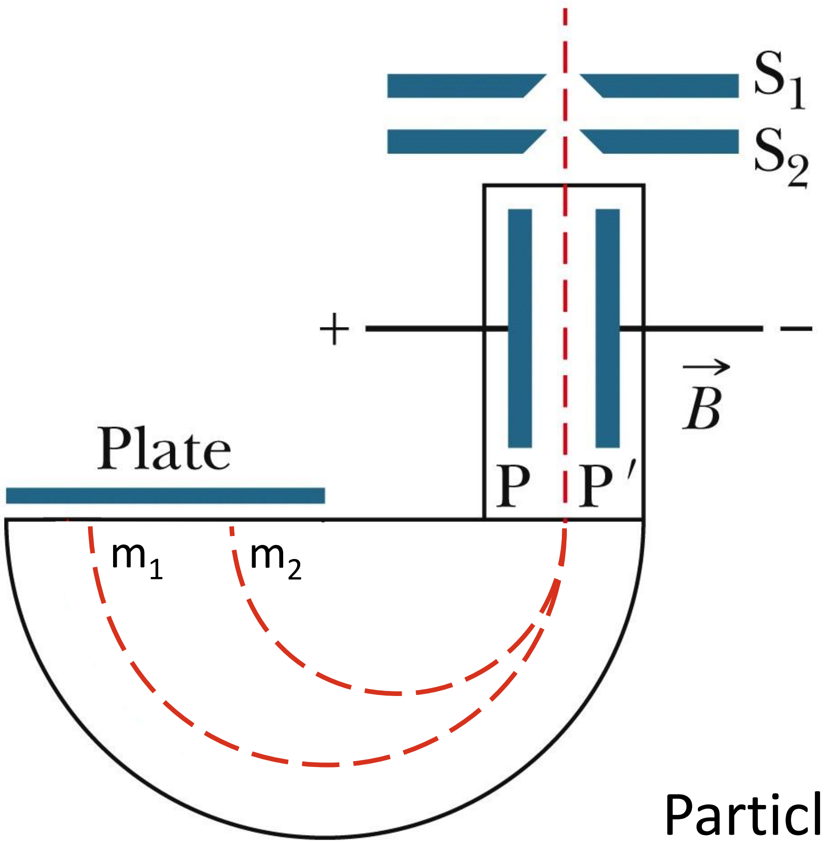
Bainbridge Mass Spectrometer

Accelerate charges through ΔV so they all have similar Kinetic Energy.



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The slits S_1 and S_2 ensure the beam of particles is collimated.

The beam enters a region of crossed E and B-fields.

A narrow slit ensures only particles with a specific speed enter, velocity selector.

Particles with same KE but different masses and charges will have different radius in B field

TopHat Question

When a charged particle moves through a magnetic field, the trajectory of the particle at a given point is

A. parallel to the magnetic field line that passes through that point.

B. perpendicular to the magnetic field line that passes through that point.

C. neither parallel nor perpendicular to the magnetic field line that passes through that point.

D. any of the above, depending on circumstances

$$\vec{F}_B = q\vec{v} \times \vec{B}$$

TopHat Question

Under what circumstances is the total magnetic flux through a closed surface *positive?*

A. if the surface encloses the north pole of a magnet, but not the south pole

B. if the surface encloses the south pole of a magnet, but not the north pole

C. if the surface encloses both the north and south poles of a magnet

D. none of the above

TopHat Question

A charged particle moves through a region of space that has both a uniform electric field and a uniform magnetic field. In order for the particle to move through this region at a constant velocity,

A. the electric and magnetic fields must point in the same direction.

B. the electric and magnetic fields must point in opposite directions.

C. the electric and magnetic fields must point in perpendicular directions.

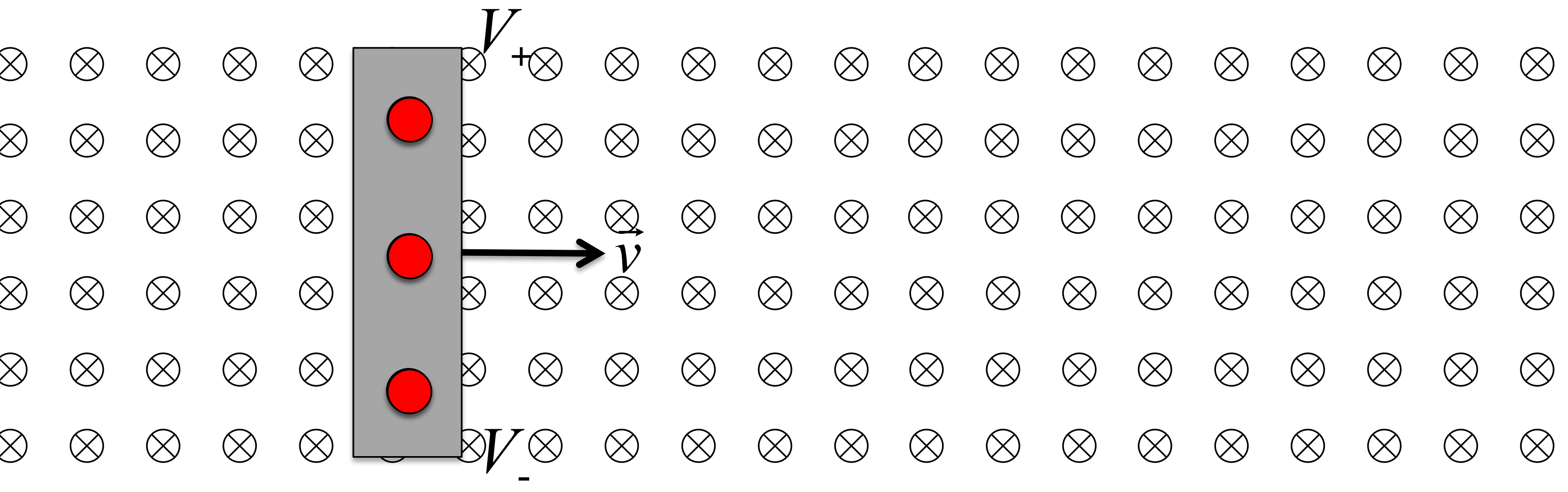
D. The answer depends on the sign of the particle's electric charge.

Conductors moving in B-fields

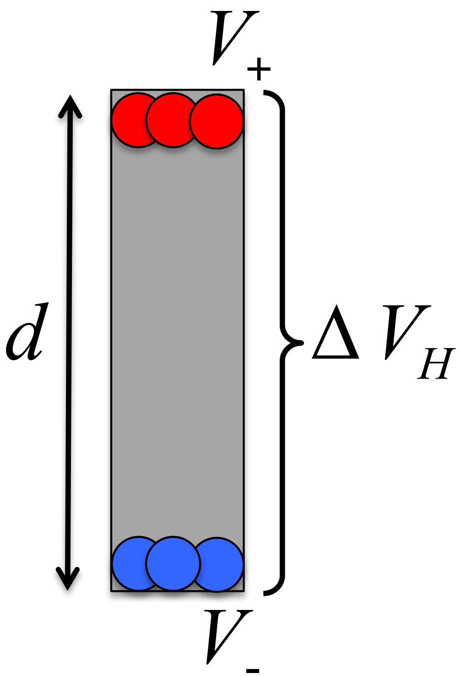
We've seen that free charges moving in a B-field feel a force perpendicular to the field and the charge's velocity:

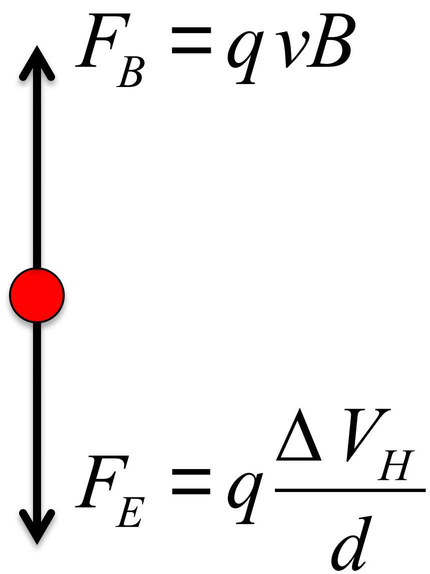
$$\vec{F}_B = q\vec{v}\times\vec{B}$$

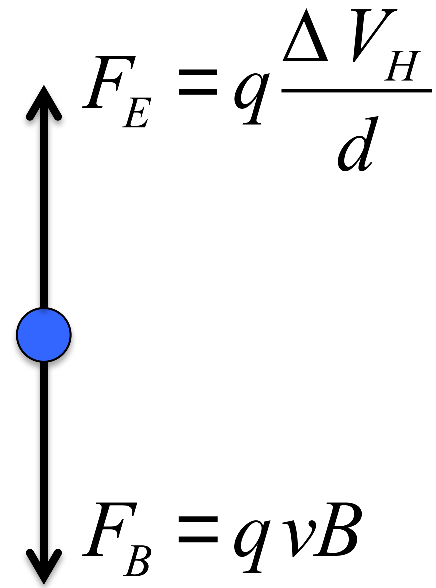
Conductors are full of charges that are free to move around (yet they have to stay confined to the conductor itself). If a conductor moves in a magnetic field, these charges also feel a magnetic force



Conductors moving in B-fields







In equilibrium, forces balance, leading to a constant voltage

$$q\frac{\Delta V_H}{d} = qvB$$

$$\boxed{\Delta V_H = vBd}$$

Forces on Current-Carrying Wires

Current in wires is nothing ordered flow of charges. It doesn't matter if we consider $-q$ moving opposite i or $+q$ moving in the same direction as i.

In a magnetic field, these charges feel a force and get deflected from their normal straight path. For a single charge: $\vec{F}_B = q\vec{v}_d \times \vec{B}$

For N charges moving through the wire:

$$Nq\vec{v}_d = \left(nAq\vec{v}_d\right)\ell = i\vec{\ell}$$

$$\boxed{\vec{F}_B = i\vec{\ell} \times \vec{B}}$$

Length of wire, the same direction as i