Magnetism (Part II)

In this lecture

- ★Magnetic field
- ★Magnetic force on a moving charge
- ★Magnetic Field Lines
- ★Magnetism for MRI

Magnetic Field

Just as there is a field associated with electric charge there is a field associated with a magnet

<u>Electric Field, E</u>

- Collection of electric charge at rest creates an *electric field*, E
- Field exerts force F=q X E on other charge, q

Magnetic Field

Just as there is a field associated with electric charge there is a field associated with a magnet

<u>Magnetic Field, B</u>

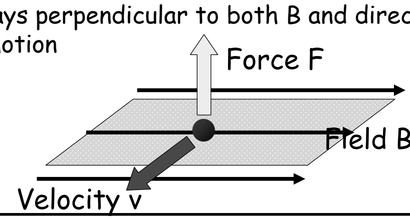
- A moving charge (or current) creates a *magnetic field*, B
- Field exerts force on any other moving charge in the field

Moving Charges in a B-Field

- Characteristics of force on a charge moving in a magnetic field
- Magnitude of force proportional to
  1. Size of charge
  2. 'Strength' of magnetic field
  3. Speed of moving charge!

Moving Charges in a B-Field

- Characteristics of force on a charge moving in a magnetic field
- Direction of force
  - Always perpendicular to both B and direction of motion



Moving Charges in a B-Field

- Magnitude of force is proportional to the component of velocity perpendicular to the B field

$$F = q \times v_{\perp} \times B$$

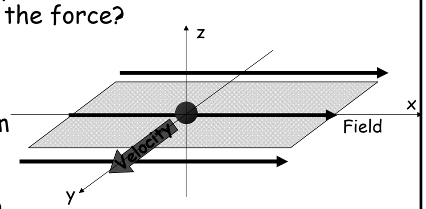
- When that component is zero (i.e. v and B are parallel of anti-parallel) the force is zero

Magnetic Field Strength

- SI units of magnetic field strength is the Tesla (T)
- One Tesla = 1 N/A m
- Older unit: gauss (G)
- One Tesla = 10,000 gauss
- Earth's magnetic field strength:
  - Approximately 50μT at equator & 100μT at poles
  - (Magnetic door latch ~100 mT)

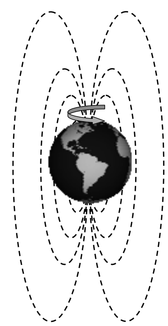
Example

- A beam of protons moves through a uniform magnetic field of 2T, directed alone the x-axis. The protons are travelling along the y-axis at with a velocity of 3×10^{5} ms^{-1}. What is the magnitude of the force?
- What would change if an electron beam was used instead of a proton beam?



Magnetic Field Lines

- As with electric field magnetic field can be represented by field lines
- Unlike electric field lines, they do NOT point in the direction of the force on a charge
- They point along the direction that a compass needle would point
- Density of lines proportional to field strength
- Field lines never intersect!



Magnetic Field Lines

- Common sources of magnetic fields
- Permanent bar magnet
- Solenoid
- Iron core electromagnet
- Straight wire
- Loop of wire

MRI (Magnetic Resonance Imaging)

<u>N</u>uclear <u>M</u>agnetic <u>R</u>esonance (NMR)

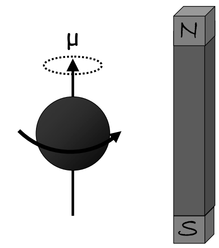
Protons in a Magnetic Field

- Not all nuclei exhibit NMR
- Must have odd number of nucleons and therefore exhibit magnetic component or a MAGNETIC MOMENT

  ^{1}H - Hydrogen
  ^{13}C - Carbon
  ^{31}P – Phosphorous

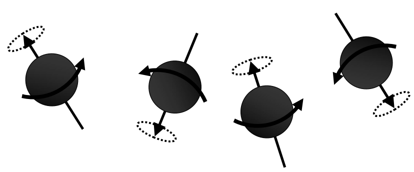
Protons in a Magnetic Field

- Hydrogen proton can be compared to a bar magnet
- Magnetic moment, μ



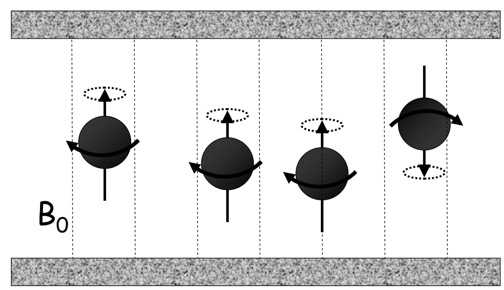
Protons in a Magnetic Field

- In the absence of B-field protons can adopt ANY orientation



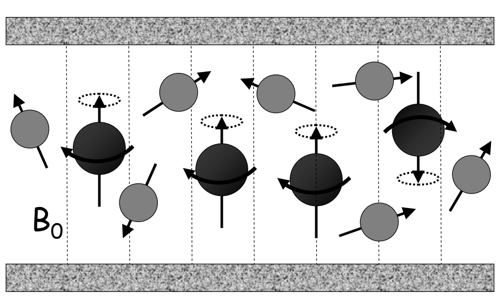
Protons in a Magnetic Field

- Switch on B-field



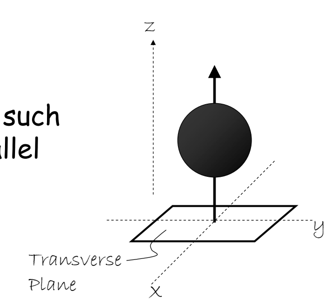
Protons in a Magnetic Field

- Switch on B-field



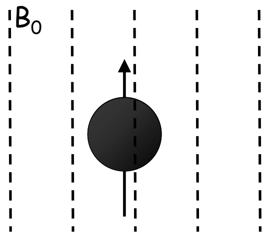
3-Dimensional Co-ordinate System

- Axes x, y, z
- Define axes such the z is parallel with B_0



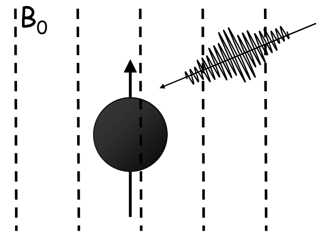
Precession

- Spins align with B-field



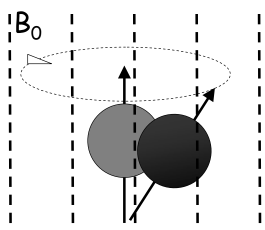
Precession

- Additional energy from RF pulse



Precession

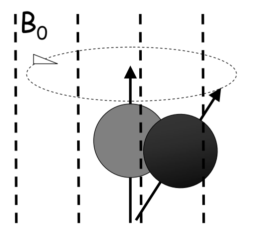
- Spins rotate about mean position
- Analogous to spinning top in gravitational field



Precession

$$\omega_L = \gamma B_o$$

- Frequency of rotation know as **Larmor frequency, ω_L**
- Governed by strength of magnetic field and property of spin called **gyromagnetic ratio, γ**



Precession

$$\omega = \gamma B_o$$

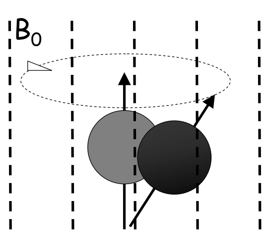
<u>Gyromagnetic Ratio</u>

$$\gamma = \frac{\textit{Magnetic Moment}}{\textit{Spin Angular Momentum}}$$

$$\gamma = \frac{\mu}{2\pi L}$$

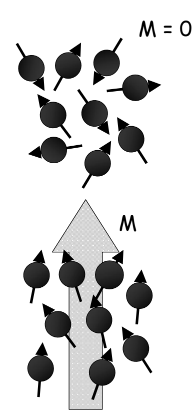
$$\gamma = \frac{1.41 \times 10^{-26}\, JT^{-1}}{2\pi \times 0.527 \times 10^{-34}\, Js^{-1}}$$

$$\gamma = 42.58\ MHzT^{-1}$$



Magnetisation Vector

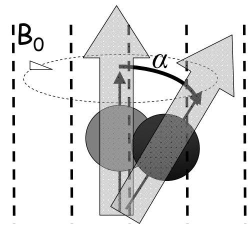
- Magnetisation Vector, M
- Represents the net magnetic moment or the 'sum behaviour' of all protons in sample



Magnetisation Vector

Flip Angle

- Depends upon pulse energy
- B_1 = B-field associated with pulse
- t_p = pulse duration
- Angle controlled by varying pulse time or amplitude

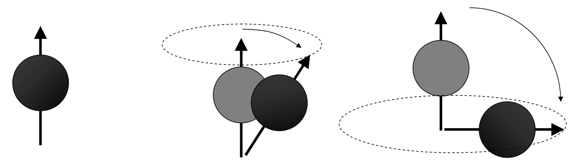


$$\alpha = \gamma B_1 t_p$$

- Magnetisation Vector is flipped
- Not protons

Magnetisation Vector

Proton in B_0	RF Pulse	Larger RF Pulse
Maximum M_z	M_z	Zero M_z
Zero $M_{x,y}$	M_{xy}	Maximum $M_{x,y}$



Summary

- ★Magnetic field
- ★Magnetic force on a moving charge
- ★Magnetic Field Lines
- ★Magnetism for MRI

Practice Questions

PAM2011: Lecture 8 Problem Sheet

1. Magnetic fields in excess of 5 gauss can interfere with cardiac pacemakers. How many mT is this?
2. A beam of protons moves through a uniform magnetic field of 4T, directed alone the positive x-axis. The protons are travelling along the y-axis at with a velocity of 1.5 X 10^5 ms^{-1}. What is the magnitude of the force and along which direction does the force act?
3. A beam of electrons moves through a uniform magnetic field of 1T, directed alone the positive x-axis. The protons are travelling at an angle of 30^o to the y-axis at with a velocity of 1 X 10^5 ms^{-1}. What is the magnitude of the force and along which direction does the force act?
4. An electron beam travelling at a velocity of $1X10^5$ ms^{-1} through a magnetic field of 1T experiences a force of 4 X 10^{-14}N. What is the angle between the direction of the electron beam and the magnetic field?