Last time we learned that an electron wave in an atom is defined by a set of QUANTUM NUMBERS. In addition to the principal quantum number \( n \), there are the orbital and magnetic quantum numbers \( l \) & \( m \) which determine:

\[
L = \hbar \sqrt{l(l+1)}
\]

\[
L_z = m \hbar
\]

TOTAL ANGULAR MOMENTUM

\( z \)-component of angular momentum

Each of these states has the same energy — until a magnetic field is applied.
41.2 **Zeeman Effect**

Spectral lines split in a magnetic field.

**WHY?**

Pieter Zeeman, 1896

Magnetic moment

\[
\vec{\mu} = I \vec{A} \\
U = -\vec{\mu} \cdot \vec{B}
\]

\[
\mu = IA = \left( \frac{e}{t} \right) \pi r^2 = \frac{e}{(2\pi r/\nu)} \pi r^2
\]

\[
= \frac{evr}{2}
\]

But \( L = mvr \)

\[
\mu = \frac{e}{2m} L
\]
When $L = \hbar$, as in the Bohr model, $M = M_B$

\[ M_B = \frac{e\hbar}{2m} \]  

**BOHR MAGNETON**

This is the basic unit of magnetic moment. 

\( M_B = 5.788 \times 10^{-5} \text{eV/T.} \)

In a field along the $z$-axis

\[ U = -M_z B \]

But \( M_z = -\frac{e}{2m} L_z = -\left(\frac{e}{2m} \right) m_e \hbar = -M_B m_e \)

So

\[ U = m_e (M_B B) \]

It is this shift that creates spectral lines. 

\[ \Delta E = M_B B \]
Electrons like to lower their energy $\Rightarrow \mu$ parallel to $B$, angular momentum opposite to $B$

\[ l=0 \quad l=1 \quad l=2 \]

\begin{align*}
 n=4 & & & & n_0 & & & & n_1 \\
 n=3 & & & & n_0 & & & & n_1 \\
 n=2 & & & & n_0 & & & & n_1 \\
 n=1 & & & & n_0 & & & & n_1 \\
\end{align*}

**Selection Rules for Photon Emission**

\[ \Delta l = \pm 1 \]

\[ \Delta m_\ell = -1, 0, +1 \]

3 Lines

(Photon has angular momentum $l=1$)

\[ \Delta E = n_0B \]
Calculate the frequency shift associated with the Zeeman effect in a 10T field.

\[ \Delta \nu = \frac{m_e B}{h} = \frac{h \Delta f}{\hbar} \]

\[ \Delta f = \frac{m_e B}{h} = \frac{(5.788 \times 10^{-5} \text{ eV/T}) \times 10 \text{T}}{4.14 \times 10^{-15} \text{ eV s}} \]

\[ = 1.398 \times 10^4 \text{ Hz} \]

\[ = 0.14 \text{ GHz} \]

What is the change in the photon energy associated with the two satellites?

\[ \Delta E = m_e B = 5.788 \times 10^{-5} \text{ eV/T} \times 10 \text{T} \]

\[ = 5.788 \times 10^{-4} \text{ eV} \]

\[ = 0.6 \text{ meV} \]