Magnetic Dipole moment

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Magnetic Dipole moment

Orbital angular momentum : L=lh/2π. L=0,1,2,3,4……..

Spin angular momentum :S=ms/2π, where ms=+1/2, or -1/2

Magnetic moment due to orbital angular moment: $\mu_l = - g_l(e/2m)L$

Where g is called lande 'g' factor =1 for orbital motion, g=2 for spin motion

Magnetic moment due to spin Angular moment: [$\mu s = - g_s(e/2m)S$]

Relation in orbital angular momentum and orbital magnetic moment

Relation in spin angular moment and spin magnetic moment

Bohr Magneton ($\mu_B = eh/4\pi m$)

Magnetic Dipole moment

Electricity is the movement of electrons, whether in a wire or in an atom, so each atom represents a tiny permanent magnet in its own right.

The circulating electron produces its own orbital magnetic moment, measured in Bohr magnetons (μ_B), and there is also a spin magnetic moment associated with it due to the electron itself spinning, like the earth, on its own axis (illustrated in figure).

In most materials there are resultant magnetic moments, due to the electrons being grouped in pairs causing the magnetic moment to be cancelled by its neighbour.

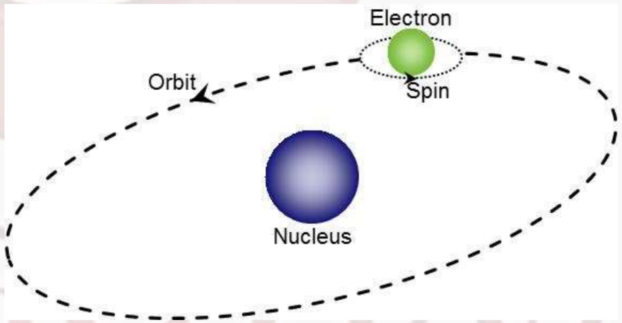


Figure-The orbit of a spinning electron about the nucleus of an atom.

Magnetic Dipole moment

In certain magnetic materials the magnetic moments of a large proportion of the electrons align, producing a unified magnetic field.

The field produced in the material (or by an electromagnet) has a direction of flow and any magnet will experience a force trying to align it with an externally applied field, just like a compass needle.

These forces are used to drive electric motors, produce sounds in a speaker system, control the voice coil in a CD player, etc...

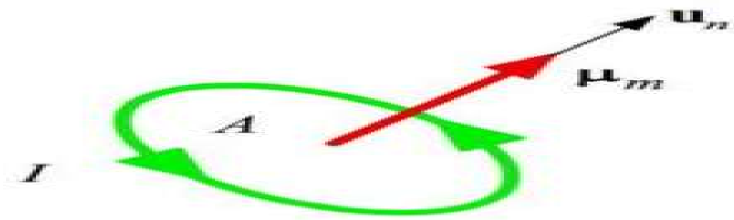
The interactions between magnetism and electricity are therefore an essential aspect of many devices we use every day.

Magnetic Dipole Moment

If the circulating current is I and area enclosed by the current is A then the magnetic moment μ_m is defined by,

- Magnetic dipole moment: $\mu_m = IA\mu_n$

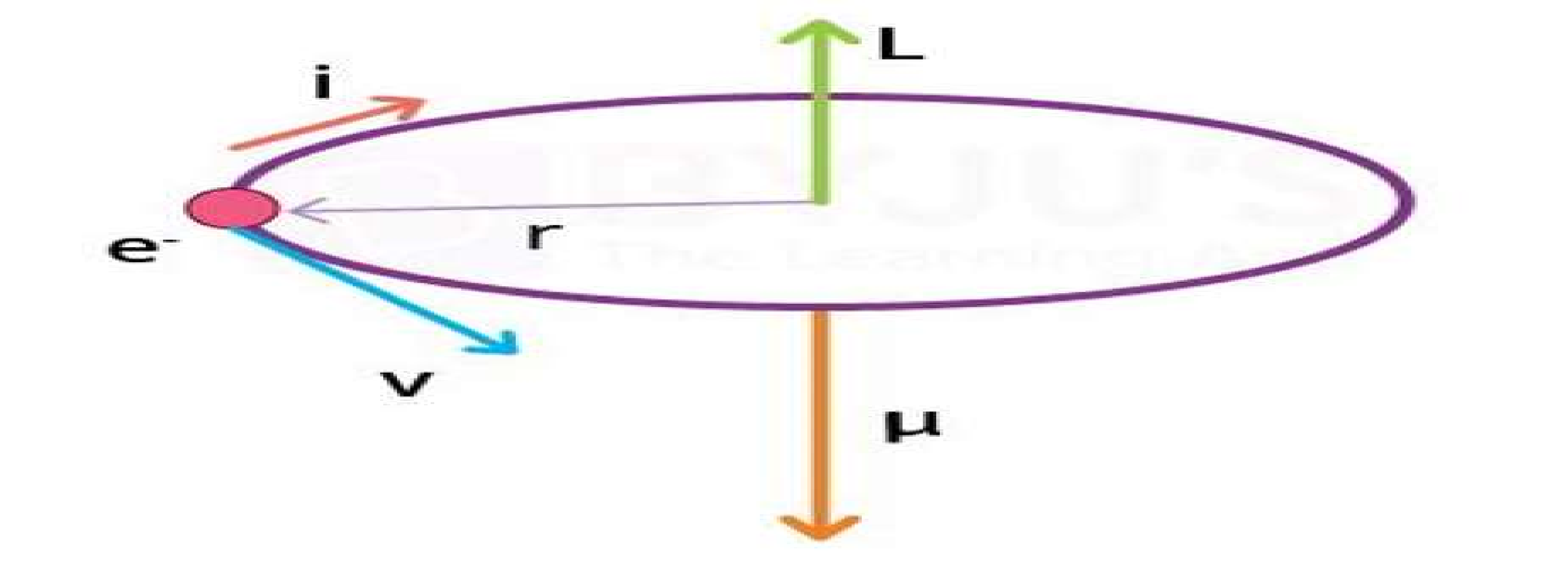
Definition of a magnetic dipole moment.



Direction of magnetic dipole moment:

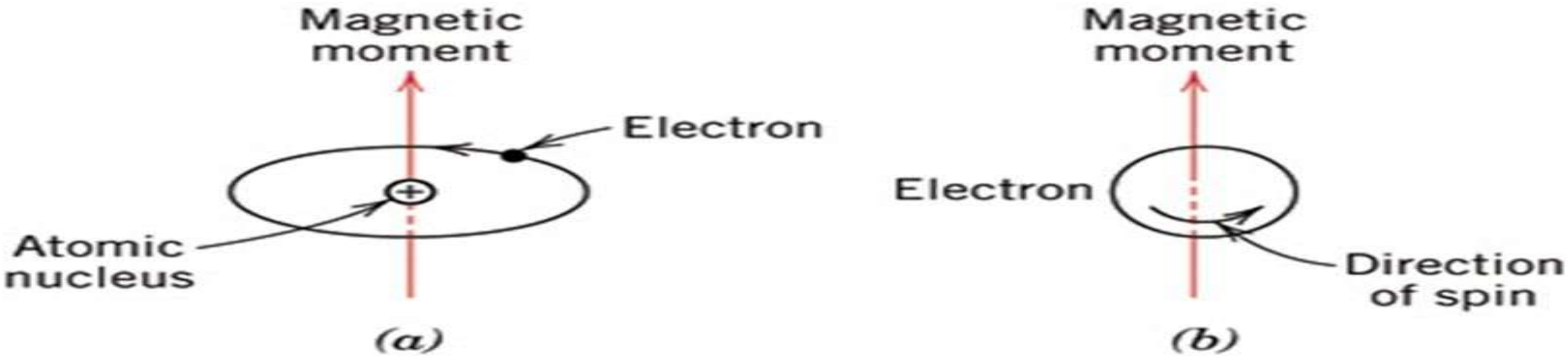
if electron revolve round the nucleus in counter clockwise angular moment (L) directed upward and magnetic moment (μ) downwards

Angular momentum and Magnetic moment both are antiparallel always i.e. L= - μ

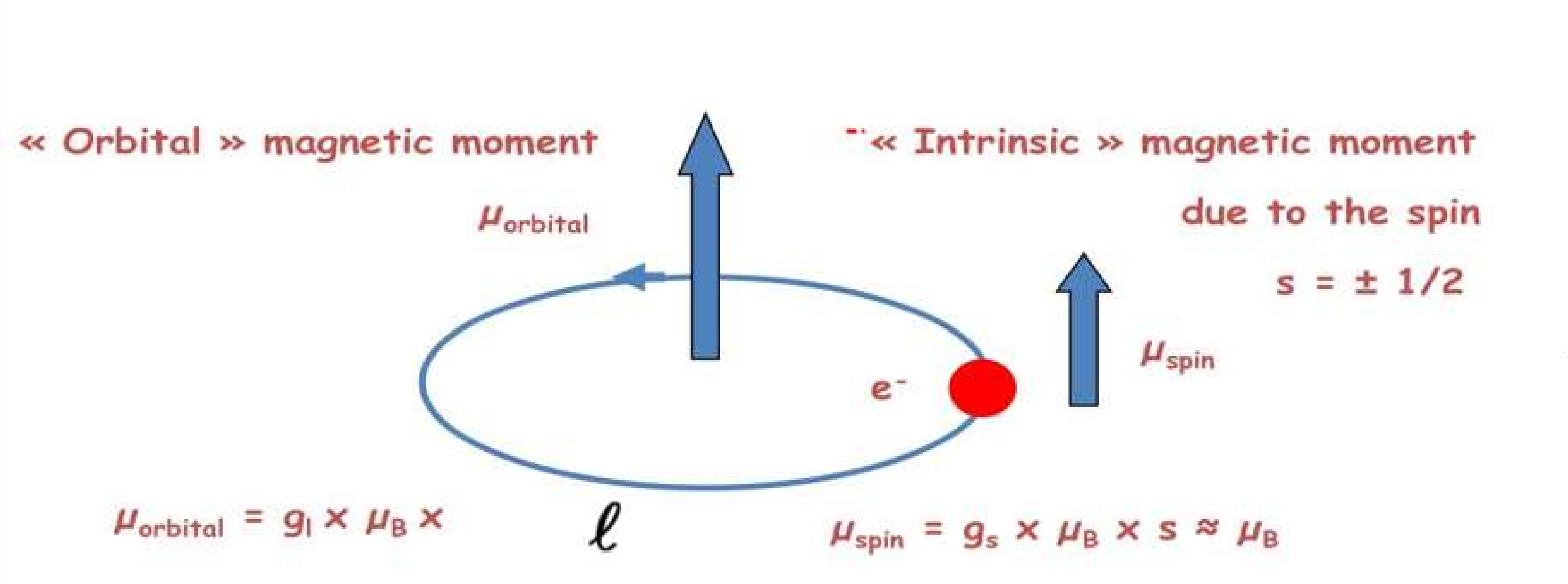


Magnetic Dipole moment

- Origin of magnetic moments – key idea is that each electron has magnetic moments that originate from two sources
  - Orbital motion around the nucleus: electron can be thought of as a small current loop, generating a very small magnetic field
  - Spin: electron spins around an axis (remember spin up and spin down?), generating a magnetic moment



Magnetic Dipole moment



Total magnetic moment= Orbital magnetic moment+ spin magnetic moment

$$\mu_{total} = \mu_{orbital} + \mu_{Spin}$$

Magnetic Dipole moment

Magnetic moment of an atom:

There are two contributions to the magnetic moment of an electron: (a) Orbital motion of electrons and (b) Spin.

Orbital magnetic moment: Consider an electron revolving around a nucleus. The current constituted by this electron is

$$i = \frac{charge}{\text{time period}} = \frac{e}{\mathrm{T}}$$

If v is the speed of electron in the circular orbit of radius r, then

$$\mathrm{T}= \frac{2\,\pi\,r}{v}$$

Therefore,

$$i = \frac{e}{\mathrm{T}} = \frac{ev}{2\,\pi\,r}$$

Magnetic moment due to orbital motion of the electron is

$$M = iA = \frac{ev}{2\,\pi\,r}\pi r^2 = \frac{evr}{2} \quad \text{.................................(1)}$$

Dipole moment

From Bohr's condition of quantized orbits, the angular momentum of the electron is given by

$$L = m_e v r = \frac{lh}{2\pi}, l = 0,1,2,3 \ldots \ldots$$

Where m_e is the mass of the electron? This gives

$$vr = \frac{lh}{2\pi m_e}$$

Substituting this in (1)

$$M = \frac{e}{2} \times \frac{lh}{2\pi m_e}$$

$$M = l\frac{eh}{4\pi m_e}, \; l = 0,1,2,3 \ldots \ldots$$

The quantity $\frac{eh}{4\pi m_e}$ forms a natural unit for magnetic moment and is known as the Bohr magneton (μ_B) and has a value of 9.28×10^{-24}ampere m^2. Thus,

$$M = l\mu_B, \; l = 0,1,2,3 \ldots \ldots \; \ldots$$

Magnetic Dipole moment

Note: *According to quantum theory, angular momentum L is given by*

$$L = \sqrt{l(l+1)}\,\frac{h}{2\pi}$$

and the z component is given by

$$L_z = m_l\,\frac{h}{2\pi}, \text{ where } m_l = 0, \pm 1, \pm 2, \ldots$$

Thus, quantum mechanically, orbital magnetic moment is given by

$$M = m_l \mu_B,\ \ m_l = 0, \pm 1, \pm 2 \ldots \ldots\ \ldots$$

Gyromagnetic ratio: The ratio of the magnetic moment to angular momentum is called gyromagnetic ratio (γ). The orbital Gyromagnetic ratio is given by

$$\gamma = \frac{M}{L} = {l\frac{eh}{4\,\pi m_e}}\Big/{-\frac{lh}{2\,\pi}} = \frac{-e}{2m_e}$$

The negative sign shows that the angular momentum and magnetic moment are in opposite directions. Thus,

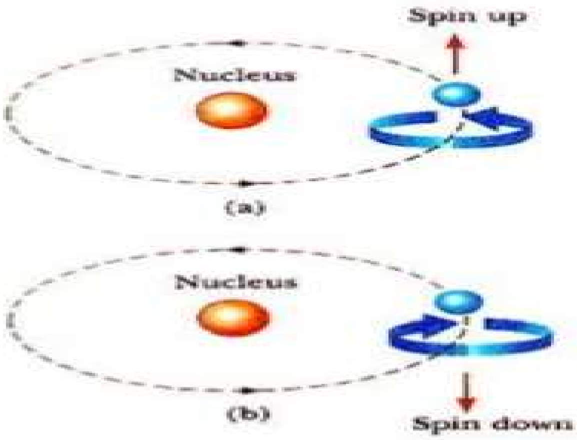
$$\boldsymbol{M} = \boldsymbol{\gamma L}$$

Spin magnetic Moment

Atomic Magnetic Moment

Atomic magnetic moment can be classified into two types:

- orbital magnetic moment.
- spin magnetic moment.



- An orbital magnetic moment due to orbital angular momentum.
- A spin magnetic moment due to electron spin.

Spin magnetic Dipole moment

Spin magnetic moment: The magnetic moment associated with the spin of the electron is called spin magnetic moment. Although it has a quantum mechanical origin, spin can be thought of as the rotation of electronic charge about its own axis. The magnetic moment due to spin comes out to be

$$M_S = g\,\gamma \boldsymbol{S}$$

where **S** is the spin angular momentum. Its z-component is quantized and is given by

$$S_Z = \frac{m_s h}{2\,\pi}$$

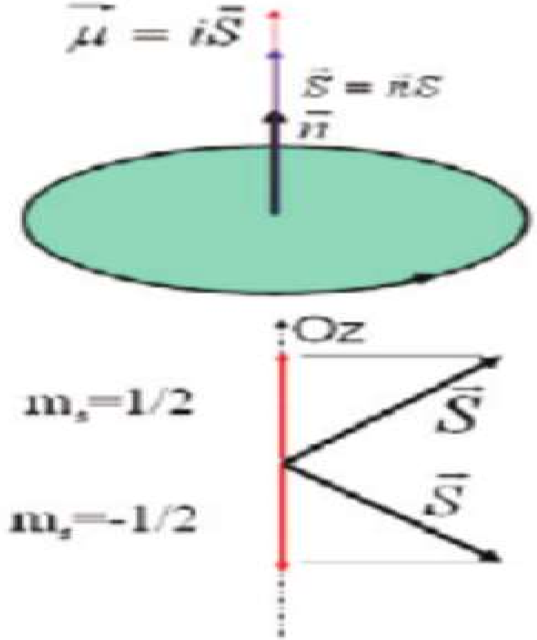
Where $m_s$is the spin magnetic quantum number which can take values of +1/2 and -1/2. g is called Lande's g-factor and has a value 2 for electron spin. Thus

$$M_S = g\,\gamma \frac{m_s h}{2\,\pi} = \frac{eh}{2\,\pi m_e} m_s = 2\mu_B m_s \,, m_s = \pm\frac{1}{2}$$

Thus the magnitude of the magnetic moment of an electron due to its spin is one Bohr magneton.

Magnetic Dipole moment

The origin of the magnetic moments



$\vec{L} \Longrightarrow \vec{\mu}_L = -\gamma\vec{L}$

By analogy :

$\vec{S} \Longrightarrow \vec{\mu}_S = -2\gamma\vec{S}$

$\vec{\mu}_{at} = \vec{\mu}_L + \vec{\mu}_S$

$\boxed{\vec{\mu}_{at} = \vec{\mu}_S}$ e.g. if $\vec{\mu}_L = 0$

$S_z = m_s\hbar$

$\mu_{s_z} = -2\mu_B m_s$

Summary:

- Motion of electron produces current
- Orbital and spinning motion of electron in an atom behave as magnetic dipoles i.e. it produces magnetic moment.
- There are two types of magnetic moment (i) orbital and (ii) spin
- Total magnetic moment is the sum of orbital and spin magnetic moments
- Unit of magnetic moment is Bohr magneton (μ_B) and has a value of $\mu_B = 9.28 \times 10^{-24}$ ampere m^2.
- The angular momentum and magnetic moment are in opposite directions.

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