CHAPTER I

INTRODUCTION

1.1 Nuclear Magnetic Moment[1,2]

Classically, a system of charge in motion gives rise to a magnetic moment that is proportional to its angular momentum. One could write

$$\vec{\mu} = \gamma \vec{J}, \tag{1.1}$$

where $\vec{\mu}$ is the magnetic moment, $\vec{J}$ is the angular momentum and γ is the proportional constant called the gyromagnetic ratio.

For an electron of mass m and charge $-e$ moving with velocity v in a circular Bohr orbit of radius r. One could derive

$$\vec{\mu} = \frac{g_1 \mu_B}{\hbar} \vec{L}, \tag{1.2}$$

where $L = mvr$, called the orbital angular momentum, $\hbar$ is the modified Planck constant($\hbar = h/2\pi$), g_1 is a constant factor and equal to unity and $\mu_B = \frac{e\hbar}{2mc}$ is called the Bohr magneton.

We have known that many nuclei have a nuclear spin. When eq.(1.2) is applied to a system of nuclei, the nuclear magnetic moment $\vec{\mu}$ due to a nuclear spin $\vec{I}$ is

$$\vec{\mu} = \frac{g_N \mu_N}{\hbar} \vec{I}, \qquad (1.3)$$

where $\mu_N = \frac{e\hbar}{2M_p c}$, called the nuclear magneton, M_p being the mass of proton, μ_N is equal to 5.05×10^{-24} erg/gauss, g_N is a nuclear g-factor, a constant depending on types of nuclei.

The γ in eq.(1.1) then equals $\frac{g_N \mu_N}{\hbar}$. Typical examples of values of γ and g_N for nuclei are shown in table 1.

Table 1. Typical values of γ and g_N

Isotope	Spin I	$\gamma/2\pi$ MHz/ 10kG	g_N
H^1	$\frac{1}{2}$	42.576	2.793
H^2	1	6.536	0.857
F^{19}	$\frac{1}{2}$	40.06	2.63
Na^{23}	$\frac{3}{2}$	11.26	2.216
I^{127}	$\frac{5}{2}$	8.52	2.79

1.2 Nuclear Paramagnetism (3)

Many atomic nuclei have non-zero spin angular momenta $I\hbar$ and magnetic moment $\mu = \gamma I \hbar$ associated with it. It is these moments that give rise to nuclear magnetism. Let us consider an assembly of non-interacting nuclei of spin number I, in thermal equilibrium at a spin temperature T in a steady magnetic field H_o. The nuclei are found in the energy level $-m\mu H_o/I$, where m is the magnetic quantum number, which takes the values, I, I - 1, - - - - - (-I + 1), - I. The population in each level is limited by the Boltzmann factor

$$\exp\left(\frac{m\mu H_o}{IkT}\right) ,$$

where k is the Boltzmann constant.

In practice the magnetic energy μH_o is very small compare with the thermal energy kT, then

$$\exp\left(\frac{m\mu H_o}{IkT}\right) \approx 1 + \frac{m\mu H_o}{IkT} . \qquad (1.4)$$

Hence the population of each level per cm^3 N(m), is given by

$$N(m) = \frac{N}{2I + 1}\left(1 + \frac{m\mu H_o}{IkT}\right) . \qquad (1.5)$$

The proportionality constant N/(2I + 1) is such that it gives correctly the total population in all (2I + 1) levels:

$$\sum_{m=-I}^{I} N(m) = N. \qquad (1.6)$$

The total magnetic moment per cm^3, namely, the magnetization M, is therefore given by

$$M = \sum_{-I}^{I} N(m)m\mu/I$$

$$= \frac{N\mu^2 H_o}{I^2(2I+1)kT} \sum_{-I}^{I} m^2$$

$$= \frac{N\mu^2 H_o(I+1)}{3kTI} . \qquad (1.7)$$

Since $\sum_{-I}^{I} m^2 = \frac{1}{3} I(I+1)(2I+1).$

The static magnetic susceptibility is therefore given by

$$\chi = \frac{M}{H_o}$$

$$= \frac{N\mu^2(I+1)}{3kTI} . \qquad (1.8)$$

The proportionality of χ to $1/T$ is the well-known Curie law for paramagnetism.

1.3 Energy in the Magnetic Field[4]

Since quantum-mechanical arguments show that the value of $\vec{I}.\vec{I}$ is $I(I+1)\hbar^2$, the length of the nuclear angular momentum vector is

$$|\vec{I}| = \left[I(I+1) \right]^{\frac{1}{2}} \hbar \, . \qquad (1.9)$$

The nuclear magnetic moment of a nucleus with spin I is a vector of length

$$|\vec{\mu}| = g_N \mu_N \left[I(I+1) \right]^{\frac{1}{2}} , \qquad (1.10)$$

it has component

$$\mu_z = g_N \mu_N m , \qquad (1.11)$$

where m is the magnetic quantum number and have the values I, $I-1$, $I-2$, - - - - , $-I$, along the direction of an externally applied magnetic field H, that is z-direction.

The potential energy U of a magnetic moment $\vec{\mu}$ in a magnetic field $\vec{H}$ is,

$$U = - \vec{\mu} . \vec{H}$$

$$= - \mu_z H . \qquad (1.12)$$

The energy of nuclear dipole in a state characterized by m

is

$$U(m) = -g_N \mu_N mH , \qquad (1.13)$$

and a nucleus of spin I has $(2I+1)$ energy levels one for each value of m.

1.4 Nuclear Magnetic Resonance[4,5]

We have seen that the nucleus possesses two important properties associated with its angular momentum. These properties are spin and magnetic moment. When such nucleus is placed in a static magnetic field H_o, it may take up one of the $2I+1$ orientations and $2I+1$ energy levels. Transitions among these levels are possible. The energy difference between any two such levels is

$$U(m'') - U(m') = g_N \mu_N H_o(m' - m''). \qquad (1.14)$$

Bohr's explanation of the hydrogen spectrum involved the postulate that a system characterized by two discrete energy states separated by energy ΔU may make a transition from one state to the other accompanied by either emission or absorption of a quantum of electromagnetic radiation of energy

$$h\nu = \Delta U . \qquad (1.15)$$

The transitions are permitted by the selection rule, for example, when m changes by $+1$ or -1, electric dipole transitions occur between adjacent states of an energy level scheme such as that of Fig. 1, which applied to a nucleus of of spin I = 5/2 .

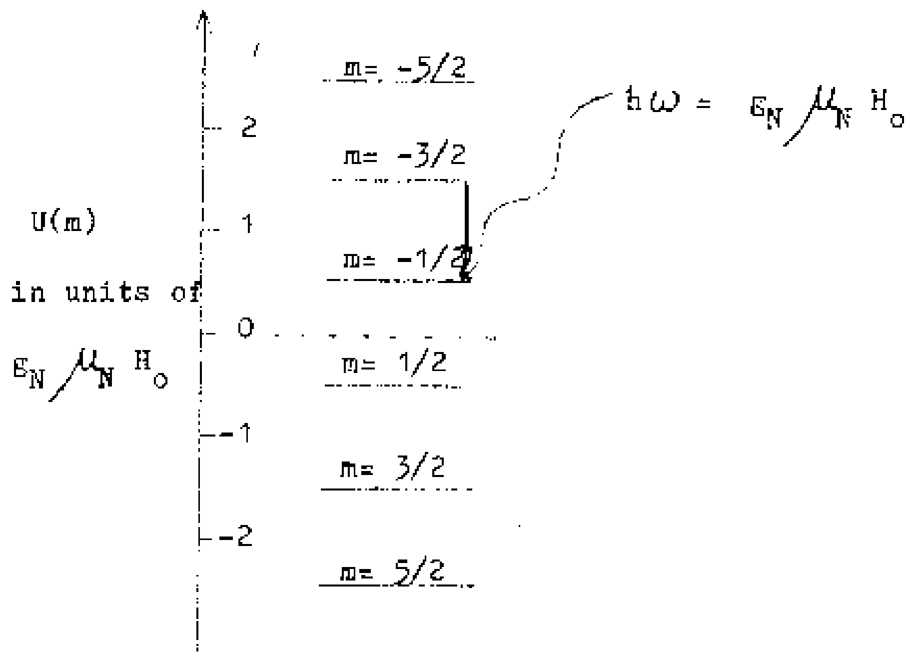

Fig. 1. Energy level diagram for a nuclear moment of spin 5/2 showing the absorption of a quantum of radiation which induces a transition between a pair of adjacent Zeeman levels.

The selection rule applied to eq.(1.14) and eq.(1.15) determines the frequency of the radiation emitted or absorbed by the nuclear magnetic moment:

$$\hbar\omega_o = g_N \mu_N H_o ,$$

$$\text{or} \qquad \omega_o = \gamma H_o . \qquad (1.16)$$

which is the Larmor frequency that will be described in chapter 2.

To summarize, if one subjects a sample containing nuclear magnetic moment to radiation at the Larmor frequency, a nucleus in a lower energy state may absorb a quantum of energy from the radiation field and make a transition to the next higher energy state. The absorption is called a resonance phenomenon.

1.5 Measurement of Magnetic Field [7]

A measurement of the earth magnetic field is based on the effect a magnetic field exerts on protons in nuclei of atoms of water. According to theory, most elementary particles including proton in water, spin on their axes like tops. They are also magnetized. In the presence of a magnetic field, such as the earth magnetic field, the spinning proton precess around the direction of the field. The rate of precession is proportional to the strength of the magnetic field. By measuring the frequency of precession, one can calculate the earth magnetic field. Detailed discussions on principle of measurement will be given in chapter 2 and details of experimental set up in chapter 3. The results of measurement will be presented in chapter 4 of this thesis.