CHAPTER I

INTRODUCTION

1.1 <u>Survey of Nuclear Magnetic Resonance</u>. [1,2,3]

In addition to acting as point electrostatic charges, some atomic nuclei possess magnetic moments. If an external magnetic field is applied to a system of nuclei with magnetic moments, these nuclear magnets will experience torques and will tend to be lined up parallel to the field. Although direct observation of such a lining up is difficult, it is possible, under appropriate conditions, for these magnets to absorb energy from a magnetic field oscillating with a frequency in radio-frequency region. Such absorption gives rise to what is called nuclear magnetic resonance (often abbreviated as NMR). If the nucleus has no magnetic moment, no magnetic resonance spectrum can be observed. Nuclear resonance effects were first detected in bulk matter in 1945 by Purcell, Torrey, and Pound at Harvard University and by Bloch, Hansen, and Packard at Standford University, using such simple materials as solid paraffin and water. The technique of nuclear magnetic resonance has been widely applied to the studies of physics of solids, liquids and gases, because it is directly observed in bulk matter in its normal physical states.

By measuring NMR spectra, we are using a nucleus as an extremely small magnetic probe to investigate local magnetic effects inside a molecular system.

1.2 An Outline of the Investigation in this Thesis.

In the present investigation, the experiments were performed to observe the homogeneity of an electromagnet, in the Physics Department, by measuring the magnetic field intensities at various positions in the magnetic pole gap, with a nuclear magnetic resonance detector. Glycerol was selected to use as the sample in the r.f. probe, because of its very low dielectric loss.

In the experiment, the magnetic field strength was determined by measuring the resonant frequency with the FM/AM Signal Generator, which is used as a frequency meter. In addition, the oscilloscope was also used to measure the resonant frequency, by observing the zero-beat on the oscilloscope.

1.3 Basic Theory of Nuclear Magnetic Resonance [4,5].

When a system of N non-interacting identical nuclei of spin I is placed in a uniform magnetic field H_o, the $2I + 1$ energy levels for each nucleus are equally spaced and given by

$$ E_m = - m \gamma \hbar H_o \quad , \quad \gamma = \frac{2\pi\mu}{I.h} \quad , \quad (1.1) $$

where m, the magnetic quantum number, is the component of I along the Z - direction, ranging from I to - I, and γ is the nuclear gyromagnetic ratio. In equilibrium at temperature T, the nuclei distribute themselves among these various levels according to Boltzmann distribution. The number of nuclei N_m occupying the mth energy level is

$$ N_m = \text{constant } e^{-E_m/kT} \quad , \quad (1.2) $$

where k is the Boltzmann constant.

In the presence of an oscillating r.f. magnetic field in the plane perpendicular to static field H_o and of frequency $\nu = \dfrac{\gamma H_o}{2\pi}$., transitions, corresponding to $\Delta m = \pm 1$ will occur. A net absorption of the r.f. energy results if the spin system is in thermal equilibrium because the lower energy levels will be more populated than the upper levels.

According to the interactions among nuclear spins, the absorption line will have a finite width which can be described by a shape function $g(\nu)$, so normalized that

$$\int_{-\infty}^{+\infty} g(\nu)\, d\nu = 1. \qquad (1.3)$$

From the theory of radiation, the magnetic dipole transition probability is given by,

$$P_{m \rightleftharpoons m-1} = \frac{\pi}{3}\gamma^2 (I + m)(I - m + 1)\rho_\nu \quad , (1.4)$$

where ρ_ν is the isotropic unpolarized radiation density, i.e., the energy density per unit frequency range in an isotropic, unpolarized radiation field.

In this case, the effective relationship between the actual applied r.f. field and the isotropic, unpolarized radiation field of Eq. (1.4) can be expressed as

$$\rho_\nu = \frac{3}{4\pi} H_1^2\, g(\nu) \quad , \qquad (1.5)$$

where H_1 is the amplitude of the circularly polarized component of the appropriate sense. Its value is one-half the amplitude of the oscillatory field.

In equilibrium at temperature T, since at ordinary values of T and H_o the energy difference are so small compared to kT, the difference between the population of level m and the next higher level, m-1, is to a good approximation

$$N_m - N_{m-1} = \frac{N}{2I + 1} \cdot \frac{h\nu}{kT} \qquad , \qquad (1.6)$$

Each upward transition of this surplus results in an absorption of energy $h\nu = \gamma \hbar H_o$, with the upward and downward transitions of the remaining bulk of the spins giving no net effect. The power absorbed in the sample per unit volume is

$$P_a = \frac{\gamma^2 \ H_1^2 \ N(h\nu)^2 \ I \ (I+1) \ g(\nu)}{6 \ kT} \qquad , \qquad (1.7)$$

where the transitions have been summed over m = I to m = -I+1 .

The presence of this absorption causes a reduction in the Q-factor of a circuit supplying the oscillatory magnetic field. A resonance is detectable by observation of the decrease in the Q of the tank circuit, or in the shunt resistance of a shunt resonant frequency, or of the static field H_o, to the correct value. Because the Q-factor is the ratio of energy stored to energy dissipated per radian, contributing elements of dissipation may be treated separately as inverse Q's. These give additively a net inverse of the Q of the circuit.

In the sense then, the inverse Q for the nuclear absorption is

$$\frac{1}{Q} = \frac{\mathcal{P}_o}{\nu\, H_1^2} = \frac{\gamma^2\, h^2}{6\, kT}\, NI(I+1)\, \nu\, g(\nu).\qquad (1.6)$$

In computing the absorption power, it has been assumed that the thermal distribution and the corresponding lower level surpluses exist in the steady state in the presence of the signal r.f. field. It is conventional to describe the heat contact between the spin system and its surroundings in terms of a spin-lattice relaxation time T_1. For the spin I of 1/2, it is found that the approach to equilibrium can be describe by an exponential law.

It is convenient to define a second time, $T_2 = \frac{1}{2}\, g\, (\nu)_{max}$ making the saturation factor $\left[1 + \gamma^2 H_1^2\, T_1 T_2\right]^{-1}$ at maximum absorption. The T_2 is a measure of the inverse of the line-breadth in the absence of broadening resulting from inhomogeneity of H_o .