CHAPTER I

INTRODUCTION

1. The Theory of Relativity and the Search for a Preferred Frame of Reference.

Considering the amount of new information obtained in the physical sciences in recent years, it does not appear that we are near exhausting the wealth of nature; in fact, the more accurate and extensive experiments one has conducted, the more one has become aware of the underlying complexities of physical phenomena. The recent discoveries of Quasars and Pulsars have played their part in opening our eyes to the mystery of the world around us.

The special theory of relativity stands in interesting contrast. Its basic postulates have stood unchallenged ever since they were first conceived by Einstein in 1905, and even though they have frequently been questioned, there has been no evidence to suggest a possible limitation of the theory in its given framework.

The theory maintains that all inertial frames of reference are equivalent and that in such frames the velocity of light is a universal constant independent of the velocity of the source or the observer. That such should be the case is a remarkable finding if one considers the theory in its full implication. As Bondi (1962) has pointed out, there is, cosmologically speaking, in contrast to the theory, a preferred frame of reference determined by the "fixed" stars. Travel relative to that frame would be readily detectable by observing the colour of the sky. The stars in the direction of motion would be blue shifted while those behind would be red shifted, giving a direct indication of the state of motion. It has been pointed out (Isaak, 1965) that it is even possible in principle to detect such motion by measuring the angular dependent energy distribution of the neutrino flux.

It would not be possible, in the spirit of an Einstein Gedanken-experiment, to build a completely self-enclosed laboratory by shielding against the neutrino flux, as the mass needed to do so would give rise to spontaneous gravitational collapse.

Hence, when discussing a laboratory experiment, one cannot ignore the influence of the rest of the universe. This is further brought out by considering the nature of gravitational and inertial forces. Newton would have considered inertial forces strictly in terms of an acceleration of the laboratory relative to absolute space. Today, through the efforts of Mach (1904) (Sciama, 1953; Dicke, 1960) one considers such forces in terms of a retarded gravitational interaction with distant matter; i.e., the 'accelerated' distant matter is thought of as generating a gravitational wave which interacts with the laboratory.

From this point of view one could expect the results of experiments carried out in the local frame to be affected by the matter distribution of the universe and to be varying with time and the relative velocity of the earth frame.

Considering then the aether drift experiments, as first conducted by Michelson and Morley, one detects a change in emphasis. Whereas the first experiments tried to resolve the question of the existence of a classical aether, the recent ones have attempted to discover an anisotropic interaction between local and distant matter observable in the local frame. As these experiments are direct tests of the fundamental postulates of the special theory, they are also the most accurate test of Lorentz invariance.

The aether drift experiments can be divided into two categories, those only sensitive to second order terms in v/c and those to first order terms. The most accurate one of the second order type conducted by Jaseja, et al. (1964) put a limit of 1km/sec on the aether drift compared to the classically expected effect of 30 km/sec. The first order experiment by Cedarholm and Townes (1958, 1959) using two ammonia beam masers established a limit of 30 m/sec.

It was at this time that Mössbauer discovered the effect of recoilless emission and absorption of gamma rays, and in 1960 Ruderfer suggested using this effect with a potential sensitivity four orders of magnitude higher than the ammonia maser in an aether drift experiment. As the effect does involve nuclear and electromagnetic interactions as well as the propagation of electromagnetic radiation, it is potentially a very powerful test for the invariance of these mechanisms, all of which could be affected by a nonuniformity in the distribution of distant matter.

The aim of the aether drift experiment reported in this thesis is to fully exploit the inherent sensitivity of the Mössbauer effect and to try to achieve an experimental accuracy limited mainly by present day technology.

2. Resonance Fluorescence.

Resonance fluorescence was first observed in atomic systems by R. W. Wood. As this phenomenon depended on the quantization of the energy levels, a similar effect was expected for nuclear transitions involving gamma rays. Early experiments by Kuhn (1929) and others, however, were not successful in detecting such effects.

The difficulty of observing a gamma ray resonance can be appreciated if one considers the recoil imparted to the radiating system of mass M during the emission of one quantum of energy E_o. By conservation of momentum this recoil energy will be

$$R = E_{\circ}^{2} / 2Mc^{2}$$

During the absorption of a similar quantum of energy, another recoil will be imparted to the absorbing system, such that the emission and absorption line will be separated by an energy 2R. Whereas this recoil energy is negligible for atomic transitions, it is large enough for nuclear transitions to prevent an effective overlap of the emission and absorption lines.

In a gas or a weakly bound lattice, the lines will also be Doppler broadened because of the thermal motion of the radiators. Assuming a Maxwellian velocity distribution for the unbound atoms, the lines will have a Gaussian shape of width $D = \frac{E_{\circ}}{c}\left(\frac{3kT}{M}\right)^{1/2}$. The full width of the emission and absorption lines will be the sum of the Gaussian component and the Lorentzian width Γ, the latter being determined by the mean life τ of the state $\Gamma = \hbar / \tau$.

A number of techniques have been employed to either compensate for the recoil loss or to broaden the lines to increase the effective overlap. Moon (1951) used high speed rotors to Doppler shift the 411 kev gamma ray from ^{198}Au ($\beta^- \rightarrow {}^{198}$Hg) toward the absorption line, and was thus able to demonstrate an increase in the resonant scattering cross-section from which the mean life of the excited state could then be deduced.

Other methods include the heating of the source to broaden the emission line (Malmfors (1952)) and the utilization of the recoil from a previous nuclear decay or reaction (Ilakovac and Moon (1954), Metzger (1956)).

A breakthrough in the study of nuclear resonant fluorescence occurred when Mössbauer (1958) showed that under certain conditions gamma rays were emitted with a negligible recoil and the line unbroadened by the thermal motion of the atoms in a crystal. This effect became a useful research tool when it was found in 1959 that at room temperature 70% of the 14.4 kev gamma radiation from ^{57}Fe occurred without recoil.