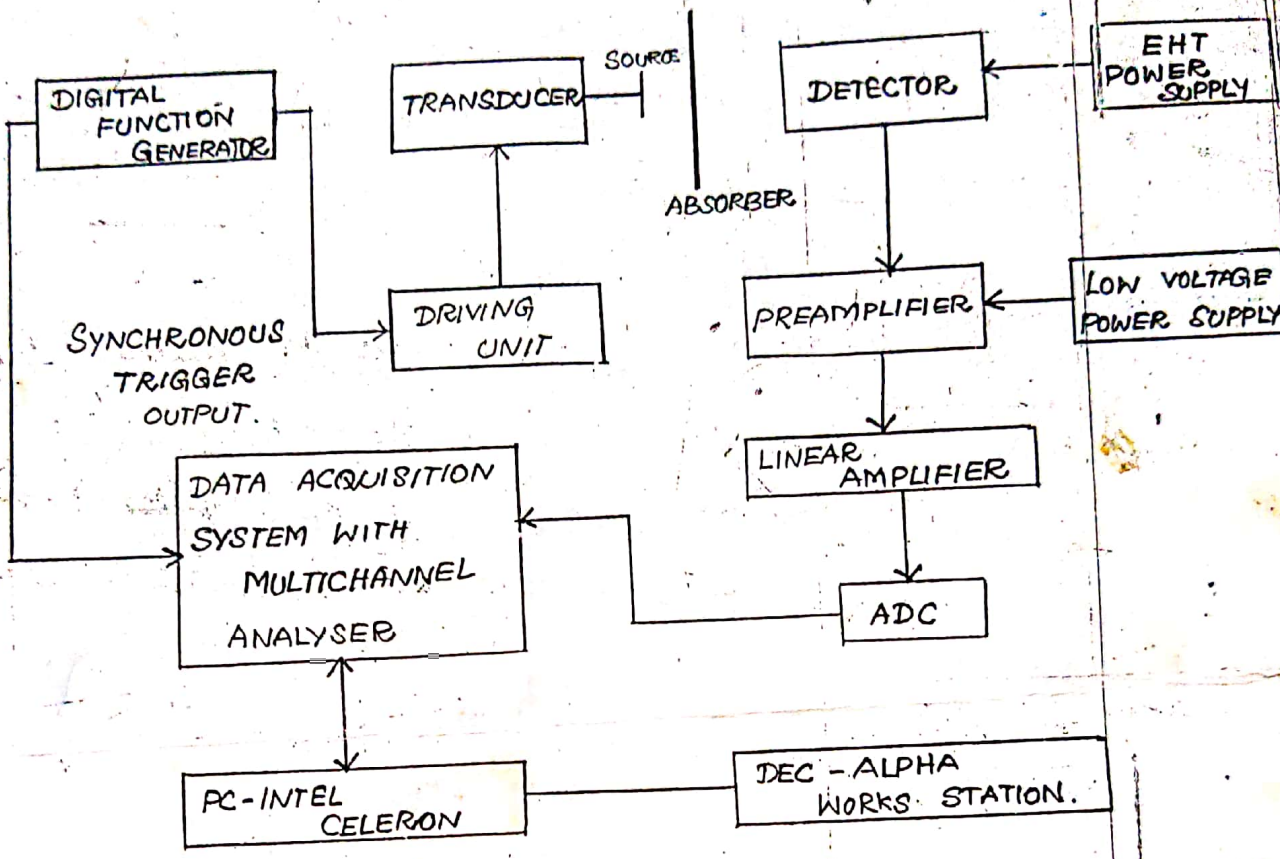
MÖSSBAUER SPECTROMETER:

Block diagram of a Constant acceleration Mössbauer Spectrometer:



The purpose of any Mössbauer spectrometer is to produce a known and precise energy shift between the source and the absorber. Generally, there are two ways followed in recording their Mossbauer spectrum.

One way is to mount the source on a mechanical constant-velocity drive and register the total number of counts in a fixed time. The same procedure is followed for different velocities. Here a single channel analyser is sufficient to detect and record the spectrum. But this

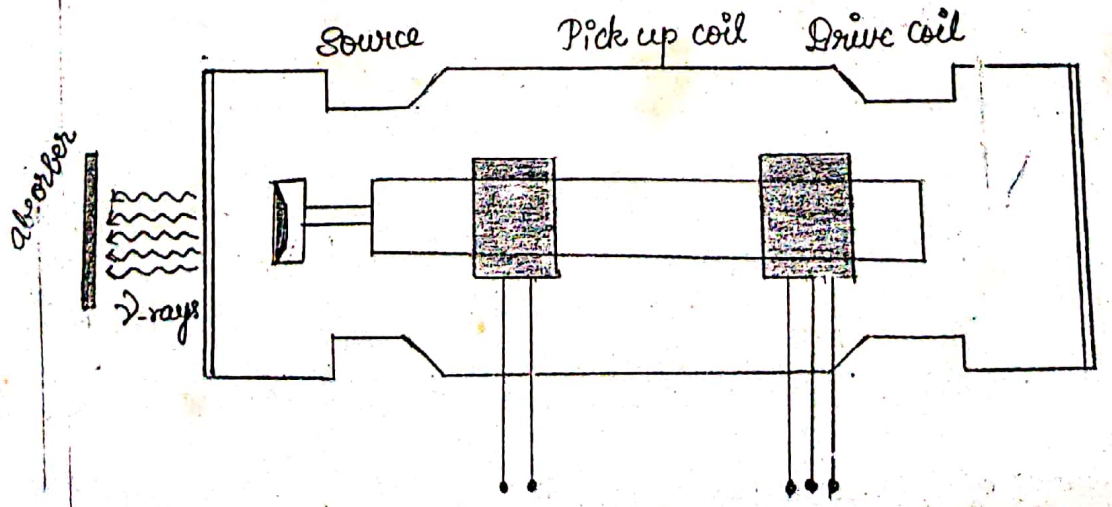
In this a range of velocities is scanned linearly and repetitively with the count being recorded in a multichannel analyzer such that the velocity increment per channel is constant.

→ method has many disadvantages.

Another way is to mount the source on Oscillatory Velocity drive or constant acceleration drive (constant acceleration spectrometer) which varies the velocity of the source relative to the absorber. Here, a multichannel analyzer (MCA) is used to collect and accumulate the signals corresponding to different velocities of the source. This method is widely used since it gives a continuous visual display of the spectrum which can be inspected at any time during the course of the run.

The block diagram of a constant acceleration Mössbauer spectrometer is shown in fig (1) consists of a driving system (electromagnetic transducer and driving unit), digital function generator, detector, pre-amplifier, linear amplifier, ADC and data acquisition system with multichannel analyser.

Schematic diagram of the Mössbauer transducer:



The Mössbauer velocity transducer is shown in
It provides a precise motion to the gamma-ray source dur
the Mössbauer experiments.

The velocity transducer is based on the principle of two mechanically coupled loud speakers, whose voice coil generates the motion. The driving coil causes the motion of transducing element as per impressed signal from function generator. Another coil called pick up coil measures the instantaneous velocity. The difference between the impressed signal and that from the pick-up coil is proportional to the deviation of the actual velocity from its correct value. This difference is amplified by the feedback amplifier and fed back to the driving coil. Before operation, the error signal is minimised by adjusting the gain and frequency response of the feedback response of the feedback amplifier loop. Both driving coil and pick up coil ~~and~~ are rigidly mounted to a common tube and the source in turn is rigidly mounted to this tube. The frequency of the transducer is approximately 23 Hz at normal operation.

The digital function generator provides the Mössbauer driving system with reference signal that determines the waveform of the source motion. It also provides start pulse

tiate the multichannel scaling cycle and channel advance pulse. The digital f.g. generator can provide either a square pulse for constant velocity mode or a triangular wave for constant acceleration mode. The perfection of the above signal controls the linearity and its frequency fixes the zero-velocity channel. The accuracy of the spectrometer depends on the stability of the wave used.

A proportional Counter filled with a mixture of 90% Ar and 10% CH_4 gas is used as detector behind the absorber. Beryllium windows at the middle of the cathode on one side allows high energy γ-rays. The output of the detector is fed to the preamplifier. It accepts the signal directly from the detector and amplifies with minimum shaping in such a way that the maximum signal to noise ratio is preserved. The output of the preamplifier is fed to the linear amplifier inorder to amplify and shape the detector output. In this way, the Mössbauer spectrum is recorded.

10.5 RELAXATION PROCESSES

Consider absorption of electromagnetic radiation by a macroscopic sample in which we observe resonance. For simplicity we shall consider a system whose nuclei possess spin ½. Let n_1 and n_2 be the number of spins occupying the lower and upper states respectively. When the sample absorbs energy, n_1 and n_2 should change and the population difference must decrease with time. Consequently, the electromagnetic energy absorbed by the sample should also decrease and ultimately become zero. But the intensity of NMR spectrum is usually independent of time indicating a constant population difference. In other words, there must be some mechanism in the system which allows the spins occupying the upper state to lose energy by non-radiative transitions and return to the lower state. The transfer of energy from the spin system to other degrees of freedom is referred to as **relaxation.**

Two different relaxation processes are common for nuclei. In the first, the spins in the upper state transfer the excess energy to the surroundings (lattice). This phenomenon is called **spin-lattice relaxation** and the time required for the population difference to become $1/e$ times the population difference at $t = 0$ is referred to as the **spin-lattice relaxation time** or longitudinal relaxation time T_1. T_1 varies over a large range, being $10^{-2} - 10^4$ s for solids and $10^{-4} - 10$ s for liquids. In addition to spin-lattice relaxation, relaxation of spin can also occur by a direct interaction of two spin states. Consequently, if initially the spins have a common phase, the phases will become random in the course of time. The dephasing time is known as **spin-spin relaxation time** or transverse relaxation time T_2. For solids, T_2 is of the order of 10^{-4} seconds, while for liquids $T_2 \simeq T_1$. The shape of the spectral lines depends significantly on the relaxation time. When the relaxation time is very long, the lower state is being repopulated at a slow rate resulting in saturation.

For the spin 1/2 system, let N be the total number of spins, $n(0)$ and $n(t)$ be the population difference at time $t = 0$ and $t = t$ respectively. Then

$$\frac{dn_1}{dt} = \omega n_2 - \omega n_1 = \omega(n_2 - n_1) = -\omega n \tag{10.8}$$

where ω is the transition probability per unit time for induced absorption/emission. Since $n_1 + n_2 = N$ and $n_1 - n_2 = n$,

$$n_1 = \frac{1}{2}(N + n), \qquad \frac{dn_1}{dt} = \frac{1}{2}\frac{dn}{dt} \tag{10.9}$$

From Eqs. (10.8) and (10.9)

$$\frac{dn}{dt} = -2\omega n, \qquad n(t) = n(0)\, e^{-2\omega t} \tag{10.10}$$

The time required for the value $n(t)$ to become $n(0)/e$ is defined as the spin-lattice relaxation time T_1. Therefore,

$$T_1 = \frac{1}{2\omega} \tag{10.11}$$

That is, the spin-lattice relaxation time is inversely proportional to the transition probat per unit time for induced absorption.

10.6 BLOCH EQUATIONS

Spin Spin relaxation

The spin spin relaxation is the mechanism by which M_{xy}, the transverse component of the magnetization vector, exponentially decays towards its equilibrium value in nuclear magnetic resonance and magnetic resonance imaging

Spin lattice relaxation is the mechanism by which the component of the magnetization vector along the static magnetic field reaches thermodynamic equilibrium with its surroundings in nuclear magnetic resonance and magnetic resonance imaging.

Classical description of NMR

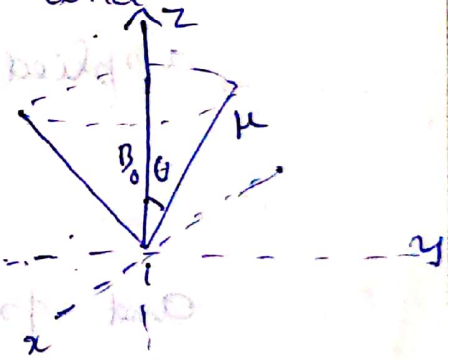
If the spinning nucleus is regarded as being equivalent to a current circulating in a closed loop, it behaves like a magnetic dipole whose magnetic moment vector μ is given by

$$\mu = I \pi r^2 \quad \text{——} \quad (1)$$

where I is the equivalent current and r is the radius of the loop. A charge of q coulombs rotating at $\frac{v}{2\pi r}$ revolutions per second is equivalent to a current

$$I = \frac{5qv}{\pi r c} \text{ amperes} \quad \text{——} \quad (2)$$

where c is the velocity of light and v is the velocity of the rotating charge



Substituting eqn (2) in eqn (1)

$$\mu = \frac{5qv}{\pi r c} \pi r^2$$

$$= \frac{5qvr}{c} \quad \text{——} \quad (3)$$

If the mass of the nucleus is M, the spin imparts an angular momentum vector P given by

$$P = MVr \quad \text{——} \quad (4)$$

The magnetic moment and angular momentum vector are collinear and substituting (4) in (3)

$$\mu = \frac{5qP}{Mc} \quad \text{——} \quad (5)$$

Fig: The precession of the magnetic moment vector μ about the direction of the magnetic induction B_0

The ratio μ/p $(= 5q/Mc)$ is the gyromagnetic ratio γ which is a characteristic nuclear property.

If a spinning charged particle is placed in a magnetic field of strength B_0, with its magnetic moment vector μ inclined at an angle θ to the direction of this field (defined as the z direction) it will experience a torque L which tends to align it parallel to the field. The magnetic field causes the angular momentum to change, and the rate of change with time is equal to the torque exerted on the magnetic moment by the applied field

$$\frac{dP}{dt} = L \quad \text{——— (6)}$$

and from simple electromagnetic theory

$$L = \mu \times B_0 \quad \text{——— (7)}$$

Substituting eqn (5) and (7) in (6) gives

$$\frac{dp}{dt} = \frac{5q}{Mc} p \times B_0 \quad \text{——— (8)}$$

The torque causes p to precess about B_0 with an angular frequency ω_0 rad/sec defined by $\frac{dP}{dt} = d\psi\phi$ ~~——— (9)~~

$$\frac{dP}{dt} = p\omega_0 \quad \text{——— (9)}$$

Substituting eqn (9) into eqn (8) gives
The angular frequency of an NMR transition due to ~~eq~~ $P \times B_0$ is

$$\omega_0 = \gamma B_0 \qquad \text{——— (10)}$$

This is the Larmor equation,

$$\omega_0 = 2\pi\nu_L$$

$$\nu_L = \frac{\gamma B_0}{2\pi} \qquad \text{——— (11).}$$

The precessional frequency is independent of θ the angle of inclination of P to B_0.

If a small secondary magnetic field B_1 is applied at right angles to the main field B_0, i.e., in the xy plane, then at a particular point on the precessional path the nuclear dipole experiences a combination of B_0 and B_1 which tends to change the angle (but not the precession rate) by an amount $+\delta\theta$; at a point π radians further along the precessional path, however the combination of B_0 and B_1 will tend to change θ by $-\delta\theta$. Integrating this over the whole precessional path indicates that B_1 is fixed in the xy plane it cannot bring about any net change in the orientation (and thereby magnetic energy) of the particle; no absorption of energy from B_1 can occur

In order for B_1, to change the magnetic energy, it (B1) has to rotate in the xy plane at the Larmor frequency, i.e it must be resonance with the precession about B_0.
A rotating magnetic induction of this type arise from circularly polarized electromagnetic radiation of frequency ν_L; for most purposes, however linear polarization is satisfactory.
Energy may now be absorbed from B_1 since it is in resonance with the precession and the effect is to tip M towards the xy plane (i.e to increase θ) by an amount depending on the strength of B_1

When the rf pulse is turned off the net magnetization begins to swing back towards the Z axis (direction of B_0), inducing an NMR signal in the receiver coil.