energy. Such gamma rays might be thought to occur upon the de-excitation of the excited state in another nucleus, which had been placed in this excited state by radioactive decay or by Coulomb excitation. This effect is well known in optical spectroscopy as resonance fluorescence. Before Mössbauer's discovery, knowledgable physicists were certain that nuclear resonance fluorescence could not take place. They knew that energy and momentum must be conserved. The gamma ray carries off a momentum $p = h\nu/c$, and the recoiling nucleus carries off this same momentum. The energy imparted to the recoiling nucleus is $E = p^2/2m$. Conservation of energy required that the energy of the nuclear transition be divided into two parts: most of the energy is carried away by the gamma ray, and the rest is carried away by the recoiling nucleus. Mössbauer showed, however, that for nuclei in solids, some of the gamma rays carry the full energy of the nuclear transition. In a solid, a nucleus

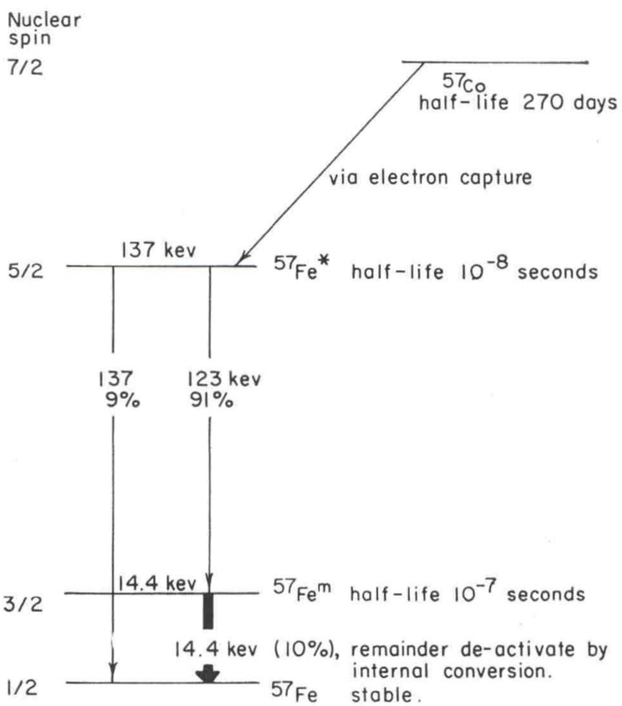

Figure 2. Decay scheme of ^{57}Co. The shaded transition includes the Mössbauer radiation.

is not free to recoil with arbitrary energy. Since the recoil energy is insufficient to break the chemical bonds which hold the nucleus, the question becomes one of creating, or not, a lattice phonon. Radiation of the nominal transition energy is hence composed of two components. One of these is slightly shifted and broadened by having created simultaneously a lattice phonon, and the other (recoilless, or Mössbauer, fraction) carried the full energy of the transition. The spread of energies of this Mössbauer radiation is limited only by the uncertainty principle, which means that the radiation from long-lived (metastable) nuclear levels can be sharp indeed. Mössbauer spectroscopy is concerned only with this recoilless fraction—the remainder represents unwanted background noise.

3. What can be learned?

A Mössbauer spectrum consists of the relative transmission of a sample as the energy of the Mössbauer gamma rays is varied. The variation of energy is not large. Doppler motion of the source up to a few centimeters per second ordinarily suffices to cover the region of interest. The relative energy shift is the ratio of the Doppler velocity to the velocity of light.

The Mössbauer spectrum may consist of one, two, or more lines. Probably the most striking effect on the spectrum is that caused by a large magnetic field.[5] In metallic iron, the magnetic field spontaneously present at the iron nucleus at room temperature is 330 kG. This splits the ground state ($I = \frac{1}{2}$) into two levels and the excited state ($I = \frac{3}{2}$) into four levels. Six of the eight possible transitions are allowed by the magnetic dipole selection rules, $\Delta m = \pm 1, 0$. The $3:2:1:1:2:3$ intensity ratio of the lines is a consequence of the change of sign of the gyromagnetic ratio in the ground and excited states, plus an application of the Clebsch–Gordan coefficients, taken over a random orientation of the magnetic field.

The spacing of these six lines measures the magnetic field (Fig. 3). Mössbauer spectroscopy has been used to follow the decreasing internal magnetic field as the temperature is increased toward the Curie temperature. Internal magnetic fields exist in a number of iron phases and compounds. These differ appreciably at room temperature for alpha iron (also known as ferrite), martensite, and