Experiment Nr. 17

Mössbauer Effect

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Mössbauer spectroscopy makes use of the resonance absorption of γ radiation by atomic nuclei to study properties of solids. This is a process in which an atomic nucleus absorbs a γ quantum, undergoing a transition from its groundstate to an excited state. It is called resonance absorption since for this process to take place the incident γ quantum needs to have exactly the right energy to fit the transition energy. To obtain such γ rays one uses radioactive sources in which the same kind of nuclei that are to absorb the radiation is also emitting it after radioactive decays.

A difficulty in this is that the γ quanta possess momentum. Momentum conservation requires that momentum is transferred to the emitting and absorbing nuclei, and together with it kinetic energy. This energy is missing in the energy balance, and it is usually large enough to prevent resonance absorption of γ rays in free nuclei, for instance in gases. In solids, however, the nuclei can no longer freely recoil and the momentum is transferred to the whole crystal, which is so massive that the concomitant recoil energy becomes negligibly small. It may happen that phonons are excited in the process of emission or absorption, but there is always a finite probability that this is not the case. Then one observes the extremely sharp nuclear resonance. This mechanism was discovered in 1958 by Rudolf Mössbauer and is now called the Mössbauer effect. Mössbauer got the physics Nobel prize for this discovery in 1961.

Owing to the sharpness of many Mössbauer resonances, they are well suited to measure hyperfine interactions, i.e., the splittings and shifts of nuclear levels due to interactions between the nuclei their environment. The hyperfine interactions give valuable information on solid state properties like chemical bonding or magnetism. There are three types of hyperfine interactions, namely the magnetic or Zeeman splitting, the electric quadrupole splitting, and the isomer shift, which allow one to measure the magnetic field, the electric field gradient and the the s electron density at the nuclei. To scan hyperfine spectra one varies the energy of the γ rays emitted by the source via the Doppler effect, i.e., by moving the source with velocities that usually need not exceed a few mm/s.

In our lab course experiment, we use the 14.4 keV gamma rays of the iron isotope ^{57}Fe, which is the best and most widely used of all Mössbauer isotopes because of its excellent energy resolution and because iron is a ubiquitous element present not only in many materials of technological importance, but also in many natural materials like soils and minerals. Because of the merits of iron Mössbauer spectroscopy to study minerals, all three of the probes that are presently under way to the planet Mars carry Mössbauer spectrometers to study the Martian soil.

The first task in the lab course is to calibrate the velocity of the spectrometer with a Michelson interferometer. Then we shall study iron compounds. The participants can choose between different tasks, and if they wish they can also make suggestions of their own what materials they wish to study, or even bring iron bearing their own materials, of which we will then measure Mössbauer spectra and try to interpret them. A standard task is the investigation of the so called Morin transition in hematite (Fe_2O_3), the most common oxide of iron. Hematite is basically an antiferromagnet, but it undergoes a reorientation of the spin direction within the crystal lattice at about –20 ^{o}C, from perpendicular to the crystallographic c axis at high temperatures to parallel at low temperatures. The sensitivity of Mössbauer spectroscopy to this change of the magnetic structure nicely shows the power of the method in solid state physics.