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Phases and Stresses in Ferrous Metals by Mössbauer Spectroscopy†

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Abstract—Mössbauer spectroscopy is based on resonant absorption of gamma rays by nuclei. Of the several dozen isotopes for which the Mössbauer effect has been measured, iron is by far the easiest. A spectrometer consists of a gamma-ray source, the substance under study, a detector and electronics for sorting and storing the received pulses, and a Doppler shift mechanism for sweeping the energy of the gamma rays. An extra, resonant absorption occurs for discrete energies of the gamma rays. The major phases of iron yield distinct spectra: ferrite has six widely spaced lines, iron carbide has six lines less widely spaced, and austenite yields a single line. Corrosion products, too, can be identified. The effect of stress in the magnitudes normally encountered is subtle—the center of the pattern and the magnitude of the splitting change slightly. There is reason to believe that the experimental techniques are now becoming adequate to this measurement, and that surface stress can be determined to a precision of 10,000 psi in about 30 min.

1. Introduction

The Mössbauer effect is now 10 years old.[1] Conceived by nuclear physicists, and utilized brilliantly in sophisticated experiments involving relativity[2] and solid state theory,[3] the chemical and analytical consequences are now being widely appreciated. Useful applications are being, and have been, found in chemistry, biochemistry, metallurgy, and geology.

Superficially, a Mössbauer spectrometer bears little resemblance to an optical spectrometer. The major components consist of a radioactive source, selective detector of gamma rays, a Doppler scanning device, and pulse-handling electronics (Fig. 1). Radioactive processes are ordinarily insensitive to the state of chemical combination. The extraordinary purity of the Mössbauer gamma rays reveals something of the chemical environment of the nuclide under study, even though the actual "chemical effect" changes the nuclear energy levels by only a few parts in 10^{11}.

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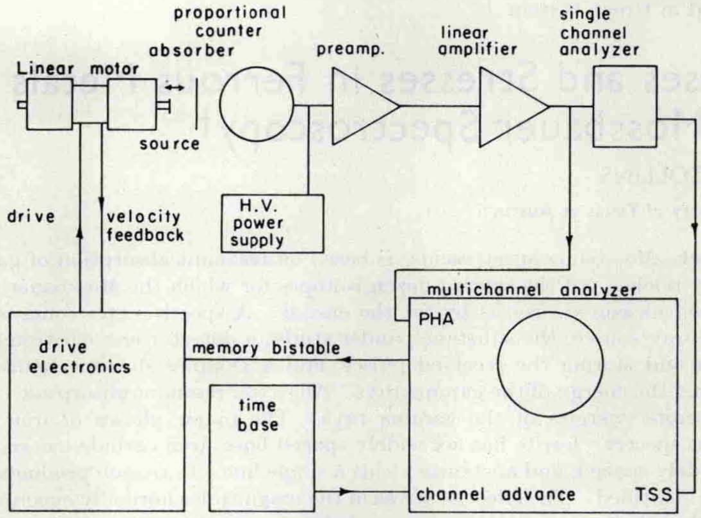

Figure 1. Block diagram of a Mössbauer spectrometer. The multichannel analyzer is operated in the PHA (pulse height analysis) mode for set-up of the single channel analyzer, then switched to TSS (time sequence scaling) for data aquisition.

Many of the heavier elements exhibit the Mössbauer effect.(4) Most of the chemical applications have involved ^{57}Fe and ^{119}Sn, as these combine ease of experiment with chemical interest. These are stable isotopes. Only the source is radioactive, in general. This paper will concentrate on ^{57}Fe, and metallurgical aspects in particular.

2. Theory

Mössbauer spectroscopy is based on the discovery of Rudolph Mössbauer that certain gamma rays emitted in the course of radioactive decay are extremely pure. Nuclei, like atoms or molecules, can often exist in energy states other than the ground state. Transitions between these states typically occur with emission or absorption of gamma rays with energies of 10–100 kev or more. An excited nuclear state will chemically resemble the ground nuclear state, since the atomic number is unchanged. The excited state differs in spin, size, and of course energy (Fig. 2).

The excitation of a ground state nucleus into an excited state occurs readily when stimulated by a gamma ray having the correct