

From the 90-h run we set an upper limit at a level of 3 standard deviations of about  $2 \times 10^3 \text{ W m}^{-2} \text{ Hz}^{-1}$  for wide-band unpolarised gravitational radiation and an upper limit, again at a level of 3 standard deviations, of about  $1 \times 10^6 \text{ W m}^{-2}$  for a continuous sinusoidal signal in the frequency range of 910–1,070 Hz, assuming the radiation is unpolarised and incident normal to our detectors for the total length of the run in each case.

Our corresponding upper limit for isotropic wideband unpolarised radiation<sup>7</sup> is about  $4 \times 10^3 \text{ W m}^{-2} \text{ Hz}^{-1}$  and for an unpolarised monochromatic source is about  $2 \times 10^6 \text{ W m}^{-2}$ , the exact value depending to some extent on the relative orientation of the source and the detectors.

This work has some relevance to the interpretation of the pulse experiments of J. Weber. Observations from several groups seems to be in conflict with Weber's results but we feel that because of the differing signal processing techniques used it has not been clear that an explanation in terms of a very large flux of small gravitational radiation pulses is completely ruled out. But a flux consisting of 5,000 or more pulses per day depositing an aggregate energy of about 500 times the mean thermal energy per mode in one of our detectors (500 kT), would have been observed at the three standard deviation level in the present experiment, independent of details of pulse duration and waveform. If Weber's coincidences were the result of pulses corresponding to energies of 0.2 kT or less in his detectors our estimate of his experimental sensitivity, as well as the more detailed analysis of Levine and Garwin<sup>8</sup>, suggests that the total energy flux required would be greater than the limit above.

Our negative result thus provides evidence against the hypothesis that the signals reported by Weber are caused by a large flux of very small pulses.

We acknowledge the financial support of the University of Glasgow and of the Science Research Council and thank Professor J. C. Gunn for his interest and encouragement.

J. HOUGH  
J. R. PUGH  
R. BLAND  
R. W. P. DREVER

Department of Natural Philosophy,  
University of Glasgow, UK

Received December 31, 1974; revised February 24, 1975.

- Drever, R. W. P., Hough, J., Bland, R., and Lessnoff, G. W., *Nature*, **246**, 340–344 (1973).
- Mast, T. S., Nelson, J. E., and Saarloos, J. A., *Astrophys. J. Lett.*, **187**, L49–L51 (1974).
- Forward, R. L. (see Burke, W. L.), *Phys. Rev.*, **8D**, 1030–1035 (1973).
- Weinreb, S., *Tech. Rep.*, 412 (MIT, 1963).
- Davies, R. D., Ponsonby, J. E. B., Pointon, L., and Jager, G. de., *Nature*, **222**, 933–937 (1969).
- Press, W. H., and Thorne, K. S., *A. Rev. Astr. Astrophys.*, **10**, 335–374 (1972).
- Misner, C. W., Thorne, K. S., and Wheeler, J. A., *Gravitation*, equation 37.21 (Freeman, San Francisco, 1973).
- Levine, J. L., and Garwin, R. L., *Phys. Rev. Lett.*, **33**, 794–797 (1974).

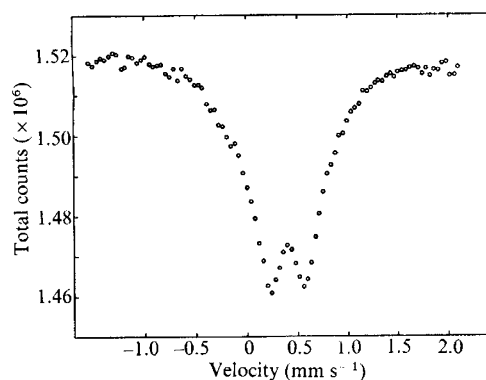


Fig. 1 Mössbauer absorption spectrum of  $^{57}\text{Fe}$  in thoro-steenstrupine. Other spectra, spanning velocities up to  $4.0 \text{ mm s}^{-1}$  showed no evidence of any  $\text{Fe}^{2+}$  ions.

bauer absorption spectrum of a  $100 \text{ mg cm}^{-2}$  sample of thoro-steenstrupine powder. The spectrum is consistent with the iron appearing as  $\text{Fe}^{3+}$  in two different sites, both with octahedral symmetry<sup>2</sup>. Most of the  $\text{Fe}^{3+}$  ions occupy a  $M_2$  site with an isomer shift (relative to metallic iron) of  $+0.40 \pm 0.03 \text{ mm s}^{-1}$  and a quadrupole splitting of  $0.34 \pm 0.03 \text{ mm s}^{-1}$ ; a very small amount (less than 5%) of iron atoms occupying a more distorted  $M_1$  site with an isomer shift of  $+0.37 \pm 0.06 \text{ mm s}^{-1}$  and a quadrupole splitting of  $0.95 \pm 0.07 \text{ mm s}^{-1}$ . The consistency of these parameters with the systematics for other minerals<sup>2</sup>—which allowed the site assignments—and the relatively large intensity of the absorption lines show that the Mössbauer pattern is not affected by the radiation damage that precluded a X-ray diffraction study of the same sample, although thorium-free thoro-steenstrupine is known to crystallise with the apatite structure (J. Metcalf, personal communication). This would be expected, since quadrupole splitting and isomer shift depend primarily on the immediate surroundings of the iron atom. Moreover, if the crystalline environment around the metal ion were damaged appreciably, a more complex pattern with strong interactions could be expected<sup>4</sup>.

I thank J. Metcalf for the loan of the sample and informal teachings of mineralogy, and the Institute of Physics, University of Aarhus, Denmark, for the use of the Mössbauer equipment.

E. J. ANSALDO\*

PO Box 708, Princeton, New Jersey 8340

Received January 22, 1975.

\*Present address: Physics Department, University of Saskatchewan, Saskatoon, S7N7/OWO, Canada.

- de Coster, M., Pollack, H., and Amelinckx, S., *Phys. Stat. Solids*, **3**, 283 (1963).
- Bancroft, G. M., Burns, R. G., and Stone, A. J., *Geochim. cosmochim. Acta*, **32**, 547 (1968).
- Greenwood, N. N., and Gibb, T. C., *Mössbauer Spectroscopy* (Chapman and Hall, London, 1971).
- Matsui, K., Haseguti, R. R., and Onodera, H., *Rad. Effects*, **8**, 195 (1971).

## Mössbauer absorption in a metamict mineral

THE technique and application of  $^{57}\text{Fe}$  Mössbauer spectroscopy to minerals have been discussed fully<sup>1–3</sup> in the context of the determination of oxidation states, coordination numbers, and site symmetry and population. This report shows, with the particular example of metamict thoro-steenstrupine  $\{\text{Na}_2\text{Ce}(\text{Mn,Fe,Ta})(\text{La,Th},\dots)(\text{Si,P})\text{O}_4\}_3\text{H}_2\}$ , that the Mössbauer technique can yield structural information even when X-ray diffractometry is not possible because of the destruction of the lattice ordering by the damage produced by radioactive decays.

The Mössbauer spectrometer used was of conventional design, using a  $^{57}\text{Co}$  in copper source and metallic iron calibration foils, as described previously<sup>3</sup>. Figure 1 shows the Möss-

## Mössbauer spectroscopy of Chinese glazed ceramics

FOR over 1,000 yr the Chinese have manufactured glazed ceramic objects renowned for their aesthetic qualities. The colour of a glaze is generally achieved by the incorporation of transition metal ions<sup>1</sup> of which iron is the most important, being used in at least nine recognised glaze types, ranging in colour from pale blue, through green, to yellow, brown and red. Although reflectance spectra of the glazes allow a simple division into types expected to contain  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  ions, a study of the environment of the iron in each type is of interest. Such data may throw light on the technology of production