in the water column has been described by Jerlov (*1*). We explored the possibility of applying one optical technique, measurements of light scattering, to the study of variations in the water column in the Arctic Ocean.

The absence of significant air-sea interface makes the central Arctic region optically unique. The ice cover both delays the transfer of wind-blown terrigenous particles into the surface layers and prevents the mixing of these layers by wind wave generated turbulence. The general climatic conditions during the period of study (late winter) preclude recent river runoff as an effective source of scatterers, although it may be an important source over longer periods of time. The extent of the spring phytoplankton crop is also unknown. Since the intensity of optical scattering depends on the totality of particles present, its variation as a function of depth should then be related to the light level preferred by the phytoplankton, the type of terrigenous particles, the nature of the detritus, the density structure, and mixing caused by shear flow and nonlinear effects of internal waves.

The measurements of light scattering were made on the Ice Island T-3 (82°N 156°W) between 10 April and 12 April 1968, by the use of samples obtained with a plastic-lined sampling bottle. A small-angle scattering meter with a helium-neon laser as a source was used to obtain relative values with overall precision of about 1 percent, taking into account variations in output of the laser, fluctuations of the detector, and sampling error. Figure 1 shows the light scattered through 0.83° (in relative units) plotted against the depth in meters, with the general structure of the water column indicated schematically (*2*).

Most noticeable is the strong variability near the surface. Each day the curves repeat strong fluctuations near the surface. Less evidence of variability is seen below the thermocline. Neal observed similar fluctuations in temperature profiles, suggesting that the stratification in the nepheloid layers may be caused by density gradients rather than by preferential growth of the phytoplankton at depths associated with optimum levels of light.

A more thorough study of the hydrographic and optical properties of this region should provide useful data on the structure of the water column in the absence of wind waves. The stability of the platform (T-3) makes it ideally suited for the study of mixing caused by internal-wave and shear-generated turbulence.

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Mössbauer Investigation of Shocked and Unshocked Iron Meteorites and Fayalite

Abstract. *Mössbauer spectra of several iron meteorites have been measured by a resonant scattering technique rather than by the conventional transmission method, thereby eliminating the necessity for the preparation of thin samples. No significant differences were observed in the spectra of specimens of mechanically deformed, shocked, and unshocked iron meteorites, nor in the absorption spectra of artificially shocked and unshocked fayalite.*

The 14-kev gamma decay of the excited Fe^{57} nucleus exhibits a strong Mössbauer effect (*1*). The natural abundance of Fe^{57} (2.2 percent) makes many naturally occurring minerals that contain iron possible candidates for Mössbauer study. We here describe a nondestructive method for studying the Mössbauer spectra of iron meteorites or other iron-bearing metallic samples and the results of a Mössbauer investigation of single crystals of shocked and unshocked fayalite.

Meteorites may be divided into two general groups (*2*): (i) stony meteorites, which have about 25 percent elemental abundance of iron in various iron phases, and (ii) iron meteorites, which have about 90 percent iron, chiefly in iron-nickel alloys. Previous Mössbauer studies have been made on stony meteorites (*3, 4*). Sprenkel-Segel and Hanna (*3*) have shown that Mössbauer absorption spectra obtained from samples of powdered stony meteorites can be used to identify the iron-bearing phases present. However, there are no previous studies of the Mössbauer spectra from iron meteorites.

Table 1. Internal magnetic fields in meteorite samples and iron-nickel alloys.

Substance	Major elemental content (%) Fe	Major elemental content (%) Ni	Internal field (ratio to pure Fe)
Bartlett meteorite	90.4	8.9*	1.03
Odessa meteorite	90.7	7.2*	1.03
Fe-Ni alloy	90	10	1.029†
Fe-Ni alloy	95	5	1.017†

* Determined by chemical analysis (*8*). † Determined from graph (*7*).

In the usual Mössbauer experiment, gamma-ray intensity transmitted through an absorber is measured as a function of the velocity of the gamma-ray source (*5*). Use of transmission geometry, however, requires that the absorber sample be rather thin (about 1 mil for metallic iron). Two advantages can be gained if the samples of iron meteorites do not have to be powdered or ground to thin dimensions: (i) there is a minimum consumption of the samples, and (ii) more can be learned about the natural properties of the meteorites, such as inherent magnetization, which may be changed by sample deformation during grinding or polishing.

In scattering geometry, the intensity of the radiation scattered by the sample is measured as a function of source velocity. At resonance, the Fe^{57} nuclei in the scatterer absorb the incident photons and are excited. They then decay, emitting radiation isotropically. Thus, at resonance, the detector shows a maximum intensity, in contrast to the transmission method, where resonance is indicated by a minimum. Scattering geometry does not place limitations on the thickness of the sample to be studied.

Spectra were obtained using a Mössbauer spectrometer with constant acceleration (Austin Science Associates, model K3 transducer, model S3 drive electronics) (*5*). The source was mounted on the armature of the velocity transducer, and its radiation was collimated by a graded shield. The radiation, scattered through an angle of about 90° by the sample, was detected by a proportional counter filled with krypton-methane gas. The source used for all spectra was a 2.5-mc (30 January 1968) source of Co^{57} diffused into a palladium foil. This source emitted Mössbauer radiation at a single resonant energy.

In the 14-kev decay of Fe^{57}, internal conversion occurs about nine times more often than gamma-ray emission. Internal conversion is followed by the emission of x-rays from iron, which include a 6-kev line. Resonant absorption in the scatterer is more easily detected if the 6-kev x-ray intensity is measured as a function of source velocity rather than the reemitted 14-kev radiation.

Samples from the Sikhote-Alin, Wabar, Bartlett, Odessa (Texas), and Canyon Diablo meteorites were studied. The Sikhote-Alin specimen was selected because it showed pronounced mechanical deformation; the Wabar specimen showed petrographic evidence of shock and thermal effects. The Bartlett specimen showed no petrographic evidence of a history of shock and was a small single find. The Odessa sample showed no petrographic evidence of shock, even though the morphology of the Odessa craters indicates that the impact of this mass was a highly energetic event. Spectra were obtained from two samples of the Canyon Diablo meteorite. One of these samples showed previous petrographic evidence (*6*) of extreme shock, approximately 600 kb; the other sample showed no petrographic evidence of a history of shock.

The flat saw-cut face of each sample was lightly etched with either HCl or HNO_3 to remove surface distortions caused by sawing. No other sample preparation was required.

The spectra were obtained by measuring the intensity of the radiation scattered from the flat, lightly etched face of each sample as a function of source velocity. A scattering spectrum from natural iron foil (1 mil thick) was also taken for comparison.

In a further attempt to determine whether mechanical shock produces any change in Mössbauer spectra, absorption spectra of two samples of fayalite (Fe_2SiO_4) were measured. Fayalite was chosen because it has a high iron content and because of the abundance of other minerals of the olivine solid-solution series in meteorites which show varying histories of shock. One of these samples had previously been artificially shocked to approximately 450 kb (*7*), whereas the other sample was an unshocked control specimen. These samples were crushed into a coarse grain-sized powder and used as an absorber in Mössbauer transmission geometry. The velocity scales on all spectra were calibrated against the known positions of absorption lines of an enriched Fe^{57} foil.

Table 2. Parameters of absorption spectra of shocked and unshocked fayalite.

Sample	Line width (mm/sec)	Quadrupole splitting (mm/sec)
Shocked	0.36, 0.44	2.82
Unshocked	0.35, 0.41	2.80

The scattering spectra for the six meteorite samples and the natural iron foil are shown in Fig. 1. The typical six-line hyperfine pattern of Fe^{57} is observed (*5*). The ratio of the heights of the outer lines to the base-line intensity for the spectrum of iron foil is 0.084, as compared to a typical value of about 0.24 in transmission geometry. Outer line widths (full width at half maximum) in the scattering spectrum of iron foil were 0.32 mm/sec as compared to a typical value of 0.39 mm/sec in transmission spectra.

The relative internal hyperfine magnetic fields in the iron foil and the Bartlett and Odessa samples were calculated from the splitting of the spectral lines (Table 1). The results of Mössbauer studies of Fe-Ni alloys having compositions similar to the meteorites used here (*8*) are also shown in Table 1.

A least-squares fit of the shocked and unshocked spectra of the Canyon Diablo sample (Fig. 1, E and F) was made with a mathematical model of six Lorentzian lines. The best fit showed that the positions of the corresponding lines in the two spectra are identical to within the resolution of the data. Thus the hyperfine magnetic fields at the Fe^{57} nuclei in the two samples are the same, to within about 1 percent. Under constant hydrostatic pressure, the hyperfine field in metallic iron, as measured by the Mössbauer effect, is significantly decreased (*10*). For example, a pressure of 150 kb results in a decrease in the field of about 2 percent. Heymann *et al.* (*6*) estimate shock pressures in some Canyon Diablo samples to be as high as 600 kb. No residual evidence of this history of pressure appears in the Mössbauer spectra of the samples studied.

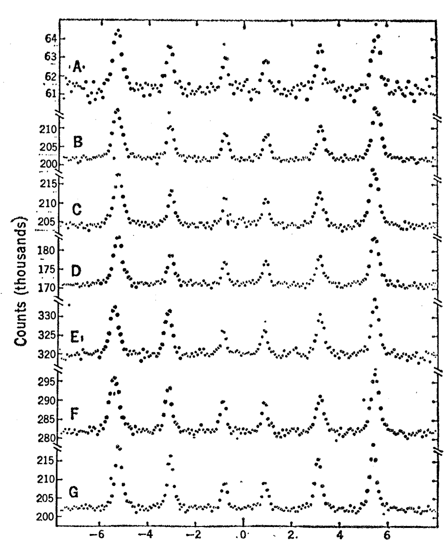

Fig. 1. Scattering Mössbauer spectra of (A) Sikhote-Alin, (B) Wabar, (C) Bartlett, (D) Odessa (Texas), (E) Canyon Diablo (shocked), (F) Canyon Diablo (unshocked) meteorites, and (G) metallic iron foil. Positive source velocity indicates source approaching scatterer.

The absorption spectra of samples of shocked and unshocked fayalite compare well with the room-temperature spectra of fayalite (*11*). Spectral parameters are summarized in Table 2. The two-line spectrum obtained for each sample is characteristic of the quadrupole splitting caused by the interaction of the Fe^{57} nucleus with an electric field gradient at its crystal site (*5*). In several materials (cobalt and cobalt chloride) the magnitude of quadrupole splitting varies with hydrostatic pressure (*10*). However, no statistically valid differences are seen in the spectra; differences in the quadrupole splittings in the two cases are within experimental uncertainty. On the other hand, marked asterism and line-broadening were observed in unrotated x-ray diffraction patterns of the shocked fayalite; these characteristics are not present in diffraction patterns of the unshocked sample.

The Mössbauer effect is essentially a probe of short-range interactions. The spectra observed are chiefly a result of the interaction of a significant fraction the Fe^{57} nuclei with their nearest neighbors. Thus, constant hydrostatic pressure, which distorts the crystalline structure down to the scale of the unit cell, has a strong effect on the Mössbauer spectrum of a sample. Once the pressure is released, however, the long-range effects that remain (for example, changes in petrographic structure) do not alter the spectrum from that observed before the pressure was applied.

The lack of apparent differences between the Mössbauer spectra of shocked and unshocked specimens may in part be the result of the annealing effect of the thermal profile accompanying shock-loading events. The identical Mössbauer spectra with a large amount of asterism and line-broadening, which was observed in the x-ray diffraction patterns of the shocked fayalite, could possibly be explained by slightly disoriented poligonization of the previous structure of the single crystal at a scale below the limit of optical resolution (~0.5 μ) and above that (~100 Å) which should be observable in the Mössbauer spectrum.

Scattering is considerably less efficient than transmission, if a thin absorber is available. The counting rates for scattering are only about 5 percent of the counting rates for transmission for the same source and for the most favorable geometries. Furthermore, a large percentage of the 6-kev radiation is caused by x-ray fluorescence after photoelectric absorption of some of the radiation from the source. This fluorescence is independent of the source velocity and merely adds to the background of the Mössbauer spectrum, decreasing the ratio of signal to noise. These problems could be considerably reduced if a stronger source were used, for example, one of the order of 100 mc. In spite of these difficulties, scattering is a sensitive method for obtaining Mössbauer spectra of thick iron-bearing samples, such as iron meteorites, for which nondestructive analysis is preferable.

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Milankovitch Radiation Variations: A Quantitative Evaluation

Abstract. *A quantitative determination of changes in the surface temperature caused by variations in insolation calculated by Milankovitch has been made through the use of the thermodynamic model of Adem. Under extreme conditions, mean coolings of 3.1° and 2.7°C, respectively, at latitudes 25° and 65°N are obtained for Milankovitch radiation cycles. At the sensitive latitude 65°N, a mean cooling below the present temperature for each of the times of radiation minimum is only 1.4°C. This result indicates that the Milankovitch effect is rather small to have triggered glacial climates.*

In recent years there have been a number of attempts (*1*) to correlate Pleistocene climate cycles with variations in insolation predicted by Milankovitch (*2*) in his astronomical theory of glaciation; but few quantitative temperature evaluations of the Milankovitch effect have been made, particularly on a global basis. Current knowledge and techniques now permit an approach to the solution of this problem.

We have applied Adem's thermodynamic model (*3*) to the determination of Pleistocene paleotemperatures on the basis of the insolation changes calculated by Milankovitch. Input data at 512 grid points over the Northern Hemisphere in Adem's model consist of de-

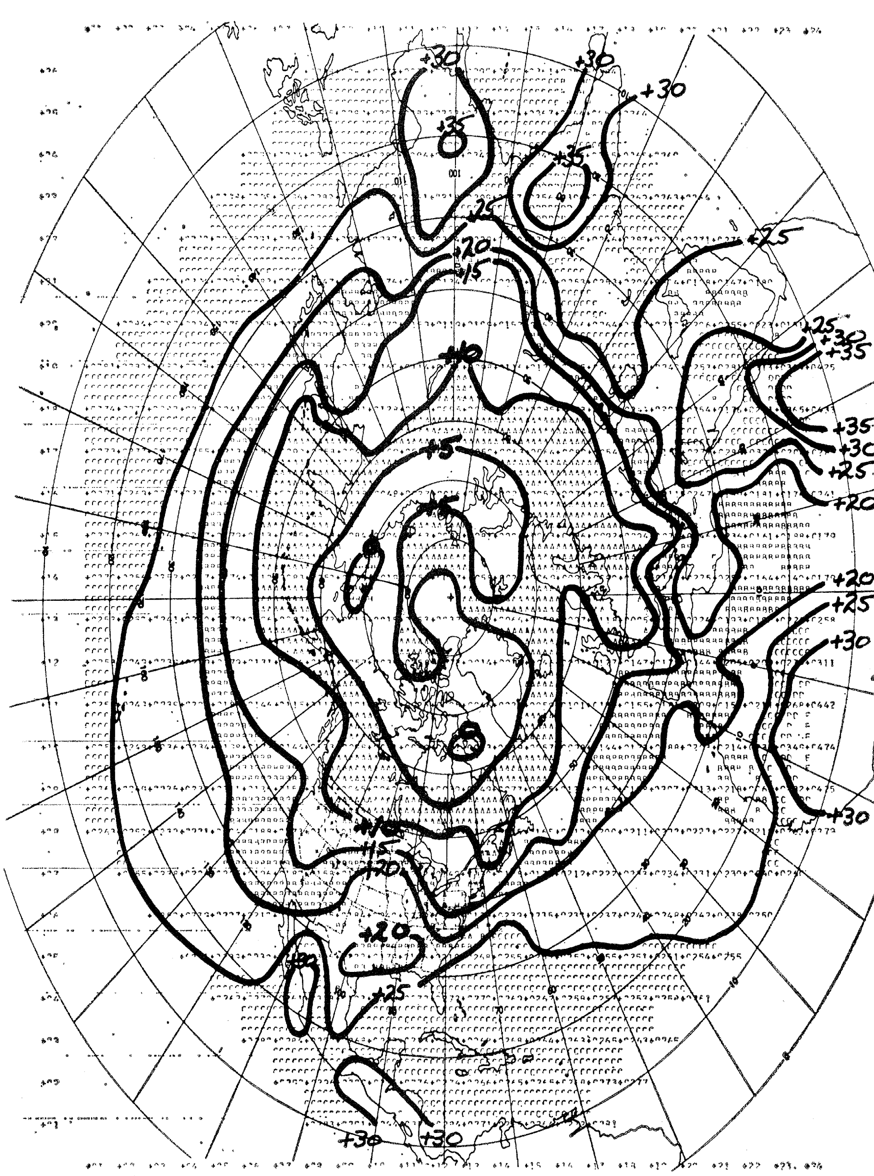

Fig. 1. Present June surface temperatures for the Northern Hemisphere computed with the use of Adem's thermodynamic model.