Reports

Temperature of an Iron Meteoroid in Space

Abstract. *The solar absorptance and hemispherical emittance of meteoritic iron has been measured from −100° to 300°C for a surface characterized by a 400-grit finish. If it is assumed that 10 percent of the surface is optically black because of holes and cracks, the temperature of an iron meteoroid at the earth's mean distance from the sun would be about 90°C.*

The temperature of a small inert body in space is determined by the irradiance of the sun and the ratio of its solar absorptance to its hemispherical emittance. Small bodies would include all known meteorites, from those weighing a few grams to the largest, the Hoba of Southwest Africa. The Hoba is estimated to weigh 60 tons, and would be about 2.5 meters in diameter if it were spherical.

Many of these bodies are composed of nickel-iron. Prior to encountering the earth's atmosphere, they would probably resemble bright and shiny stainless steel and have the appearance characteristic of a freshly cut iron meteorite. The optical properties of such a surface must be measured before the temperature of the meteorite in space can be calculated.

A technique has been developed (*1*) for directly measuring the solar absorptance and hemispherical emittance from −100° to 800°C. In these experiments the sun is simulated by a cored carbon-arc image furnace, and the space environment is simulated with an evacuated chamber whose walls are optically black and cooled to −196°C with liquid nitrogen. A thin circular specimen of the metal is suspended in the center of the chamber by fine wires and it is irradiated through a large quartz window by the beam of the image furnace. If the beam irradiance, the projected area of the specimen, and its heat capacity are known, and if the rate of rise in temperature is measured, the solar absorptance α for the surface of the specimen may be calculated. After the specimen has reached a high temperature, 300°C for the meteorite specimen, it is allowed to cool by radiation alone. The hemispherical emittance ϵ of the surface of the specimen may be calculated from the area of the specimen, its heat capacity, and its rate of cooling.

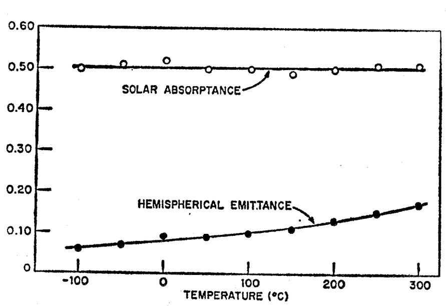

Fig. 1. Solar absorptance and hemispherical emittance of meteoritic iron with a 400-grit finish.

A disk, 2 cm in diameter and 1 mm thick, was machined from a Canyon Diablo octahedrite iron meteorite. It was then sanded with 400-grit carborundum paper to obtain a surface finish which the meteorite might be expected to have while still in outer space. This surface finish is neither specular nor diffuse; it is a compromise between a very rough and polished finish. The disk was then mounted by peening three 5-mil thermocouple wires into 6-mil holes drilled in the edge. A temperature range of −100° to 300°C was selected as representative of the probable range of temperature of an object revolving about the sun between the orbits of Jupiter and Mercury.

The solar absorptance and hemispherical emittance for a surface of meteoritic iron characterized by a 400-grit finish are shown in Fig. 1. Values for the specific heat used in these calculations were taken from data of Butler and Jenkins (*2*).

Since iron meteorites are quite irregular in shape when recovered, it may be assumed that they are irregular in shape before entering the earth's atmosphere. In some cases, there are deep holes in the body of the meteorite; the diameter of the aperture is sometimes less than the diameter of the interior of the holes. These holes may be optically black because of their shape, regardless of the surface of the metal itself. The fracture planes of the Sikhote-Alin meteorite are quite bright, but there are cracks which act like Mendenhall wedges and look black. All holes and cracks will increase both the absorptance and emittance in proportion to their areas, hence it may be assumed that the total area may be divided in two parts, one smooth and one rough. The smooth areas will exhibit the optical properties measured, the rough areas will be black at all temperatures ($\alpha = \varepsilon = 1.0$). That 10 percent of the total surface area is rough is also assumed.

The average absorptance and the average emittance may be calculated from the sum of the ratios of the different areas multiplied by their respective optical properties. Under the assumed conditions, then:

$$\text{Average absorptance} = 0.9\,\alpha + 0.1$$
$$\text{Average emittance} = 0.9\,\varepsilon + 0.1$$

where α and ε were taken from the experimental data given in Fig. 1. When this calculation has been completed an α/ε ratio can then be found for each temperature.

The equilibrium temperature of a spherical body in space is

$$T = \left[\frac{\alpha}{4\varepsilon}\,\frac{H}{\sigma D^2}\right]^{1/4} \qquad (1)$$

where D is the distance from the sun in astronomical units, H the solar con-

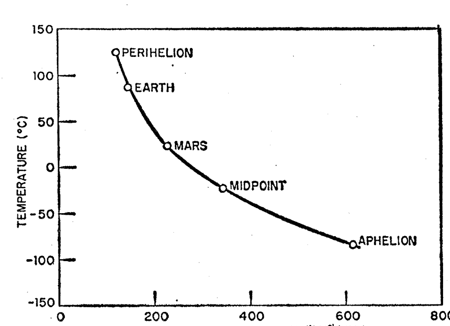

Fig. 2. Temperature of an iron meteoroid in the Pribram (*3*) orbit.

stant, (0.033 cal $cm^{-1}sec^{-1}$), σ the Stefan-Boltzmann constant, and T the temperature in degrees Kelvin. (One astronomical unit is equal to the mean radius of the earth's orbit.)

The time in seconds for a nonrotating sphere to reach temperature equilibrium is somewhat less than $2.4L^2/Z$, where L is the radius in cm and Z the thermal diffusivity. The exact temperature distribution over the surface is difficult to determine, but the most extreme difference would occur in a nonrotating sphere. In this case, the maximum temperature gradient would fall between the point on the surface of sphere closest to the sun and the point diametrically opposite. The amount of energy emitted from a unit area of the cold side is $\varepsilon\sigma T^4$. If all this energy were conducted from a unit area of the hot side, the difference in temperature between the two points would be $2\,L\varepsilon\sigma T^4/k$ where k is the thermal conductivity. For a sphere 3 m in diameter at perihelion where the temperature is 400°K, if the values of k and Z of Butler and Jenkins (*2*) are used, the maximum possible temperature difference would be 7°C with an equilibrium time of less than 5 days. The values for temperature and time would be smaller for a rotating body.

To demonstrate how the temperature of a small body varies with distance from the sun, we have assumed that the body is following the Pribram orbit (*3*), corresponding to one of the few well-observed falls. The value of H is found by calculating the distance from the sun at various positions and then by applying the inverse-square law to the solar constant. The temperature of the body is a function of H and the ratio α/ε as is shown in Eq. 1. Since the value of α/ϵ is a function of the temperature, it was necessary to use a series of approximations to obtain the desired temperature. At each position, a temperature was arbitrarily assumed, the values of α and ε corresponding to this temperature were taken from Fig. 1, and were entered, with the appropriate value of H, in Eq. 1. The temperature so calculated was usually different from that assumed therefore, new values of α and ε were selected and the process repeated until the calculated temperature agreed with that used to select α and ε. The results of these calculations are plotted in Fig. 2.

The maximum temperature of the meteoroid is 125°C at perihelion; it is 90°C at one astronomical unit and the lowest temperature is −80°C at aphelion.

That meteoroids are quite cold before entering the earth's atmosphere (*3*) is contrary to our measurements and calculations. Had we assumed that the entire surface of the meteoroid exhibited the surface characteristics of the measured sample its temperature would be 137°C, at 1 astronomical unit, and if it were all optically black, it would be 13°C at 1 astronomical unit.

We conclude that the equilibrium temperature of an iron meteoroid just before entering the earth's atmosphere will be close to 90°C.

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References

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Tellurium Content of Marine Manganese Oxides and Other Manganese Oxides

Abstract. *Tellurium in amounts ranging from 5 to 125 parts per million was present in all of 12 samples of manganese oxide nodules from the floor of the Pacific and Indian oceans. These samples represent the first recognized points of high tellurium concentration in a sedimentary cycle. The analyses may lend support to the theory that the minor-element content of sea-floor manganese nodules is derived from volcanic emanations.*

As a part of a continuing study of the distribution and abundance of tellurium in various materials of the earth's crust, analyses were made of 100 samples of manganese oxide by the analytical method of Lakin and Thompson (*1*) for determining tellurium.

Samples supplied by D. F. Hewett and H. A. Tourtelot of the U.S. Geological Survey consisted of 12 samples of sea-floor nodules and 88 others (22 oxides from hot-spring aprons, 14 supergene oxides, 18 hypogene vein oxides, 9 stratified oxides, and 25 unclassified continental oxides). Of the 88 samples only 9 contained tellurium in concentrations exceeding the sensitivity of the tellurium test (0.1 part per million when a 50-mg sample is used). Seven of the nine, representing all types of continental oxides, contained 0.1 to 0.5 ppm tellurium; the remaining two, both supergene vein oxides, contained 6 and 15 ppm.

All the sea-floor nodules, however, contained appreciable amounts of tellurium. They were collected by the Scripps Institution of Oceanography at widespread localities in the Pacific and Indian Oceans, and contained 5 to 125 ppm tellurium with a median content of 30 ppm and an average content of 40 ppm. Sample locations and analyses are listed in Table 1. Semiquantitative spectrographic analyses of 10 of these samples (280491 to 280500) have been published (*2*).

The last two samples in Table 1 were analyzed at a later date than the other ten samples and there seems to be no chance of anomalously higher tellurium contents resulting from contamination of any kind.

The high tellurium content of the nodules is of particular interest because, so far as the authors are aware, it represents the first place in the sedimentary cycle of tellurium where appreciable concentration of tellurium has been found. Tellurium apparently is concentrated in oxides, and is unlike selenium, which is known to be concentrated in sulfides.

Neither enough information is now available to the authors regarding the samples whose analyses are reported here, nor were a sufficient number of manganese nodules analyzed, to per-

Table 1. Tellurium analyses of samples (*5*) of manganese oxide nodules from the Pacific and Indian Oceans.

Location		Depth	Source	Te (ppm)
Latitude	Longitude			
19°07′N	169°44′W	1750	HoG*	125
17°48′N	174°22′W	1810–2290	HG	125
9°57′N	137°47′W	4930	PO	8
18°55′S	146°32′W	4460	PO	50
11°14′S	88°35′W	4460	PO	5
21°27′N	126°43′W	4300	PO	25
41°59′S	102°01′W	4200	PO	13
29°44′S	37°15′E	4840	IO	40
23°17′N	141°13′W	5400	PO	30
40°23′N	127°59′W	1260	MR, PO	30
16°29′S	145°33′W	1140–1300	PO	10
19°30′N	122°00′W	4400	PO	125

* HoG, Horizon Guyot, Pacific Ocean; HG, Hess Guyot, Pacific Ocean; PO, Pacific Ocean; IO, Indian Ocean; MR, Mendocino Ridge.