Micrometeorites up to several hundred microns in diameter are known to survive atmospheric entry without melting (1, 2). A method to calculate the surface temperature of a micrometeorite during atmospheric entry was developed by Whipple (3). However, the internal temperature profiles of these micrometeorites are not known.

Flynn (4) has shown that the temperature versus time profile can be sharply peaked, especially for particles entering nearly normal to the Earth's surface. For normal entry a 20 μm particle having a density of 1 gm/cc spending only 1 second within 100K of the peak temperature. The effect of reducing the entry angle is to reduce the peak temperature and increase the duration of the pulse, thus normal entry represents the most extreme case of a thermal spike. The interior temperature distribution of a micrometeorite experiencing such a rapid thermal pulse will be determined by the time required to reach thermal equilibrium for these micrometeorites.

The peak temperature reached by a micrometeorite on atmospheric entry has been used as a criterion to distinguish main-belt asteroidal from cometary micrometeorites (5). These results suggest that a significant fraction of the micrometeorites recovered from the Earth's stratosphere are derived from main-belt asteroidal sources (5, 6). However this conclusion is based on observations of bulk properties of the micrometeorites, including the concentrationss of volatile elements and the presence of solar flare tracks or low-temperature mineral phases, while only the surface temperatures are calculated using the Whipple model (3). While simple thermal conductivity arguments suggest the temperature gradients in these particles are small, detailed thermal modeling has not previously been performed.

The interior temperature profiles of micrometeorites experiencing the thermal pulse on atmospheric entry have been calculated by solving the thermal diffusion equation in spherical coordinates. The series solution given by Carslaw and Jaeger (7) was used. A constant surface temperature and an initially uniform interior temperature were assumed. The evolution of the interior temperature as a function distance from the center and of time was then calculated. A thermal diffusivity of 1 x 10^-9 m^2/sec, the value reported by Cremers and Hsia (8) for lunar soil in a vacuum, was assumed since the porous lunar soil seemed to be the best literature analog to the porous chondritic cosmic dust particles.

The temperature profile as a function of radial position from the center for a 60 μm diameter spherical particle are shown in Figure 1. The "relative temperature," plotted on the vertical axis, is the fractional increase in temperature from the original temperature difference between the interior and the surface. Temperature profiles are shown for four timesteps,
0.05 sec, 0.1 sec, 0.2 sec, and 0.5 sec after application of the thermal pulse at the surface. As seen in Figure 1, 0.2 sec after application of a thermal pulse at the surface the center of the particle will have heated to about 80% of the difference between the starting interior temperature and the surface temperature. Within 0.5 sec the entire particle will be at the same temperature as its surface.

These results indicate that so long as the thermal diffusivity of the cosmic dust particles is not significantly lower than the value for the lunar soil, the interior temperature of a micrometeorite during atmospheric entry will closely track the surface temperature even during the sharp thermal pulse experienced under normal entry conditions.

The time scales directly with thermal diffusivity in this model. Thus if the thermal diffusivity of a cosmic dust particle was one-fifth the assumed value, then the equilibration time would increase by a factor of five. Even in this case the central temperature would rise by 80% of the difference between its original temperature and the applied surface temperature with 1 second. This would allow the central temperature to track the surface temperature to within about 100K for most entry angles. However in the extreme case of normal entry (where the surface may remain within 100K of the peak temperature for only a second or two) this difference could be a few hundred degrees.


Figure 1:
Relative temperature (see text) versus distance from the center at 0.05, 0.1, 0.2, and 0.5 seconds after a 60 µm diameter micrometeorite is heated at its surface.