THERMAL GRADIENTS IN INTERPLANETARY DUST PARTICLES: THE EFFECT OF AN ENDOTHERMIC PHASE TRANSITION; G. J. Flynn, Dept. of Physics, SUNY-Plattsburgh, Plattsburgh NY 12901

The interior temperature distribution as a function of time was modeled for particles ranging from 10 to 60 microns in radius experiencing rapid heating. The incorporation of a phase which undergoes an endothermic transition, for example the dehydration of a hydrated silicate, is shown to produce a transient thermal gradient which can persist for several seconds in the largest of these particles. This is comparable to the time spent within 100 K of the peak temperature for some micrometeorites entering the Earth's atmosphere. In these particles temperature indications derived from bulk or interior properties, such as the presence of low-temperature minerals, tracks, and volatile elements, may not reflect the surface temperatures reached on atmospheric entry. Thus, temperature indicators measured in the interior may not be used to infer entry velocities for these particles.

Models of the heating experienced by micrometeorites on atmospheric entry assume the temperature of the particle is the same throughout. Szydlik and Flynn (1) have confirmed that, for reasonable values of thermal conductivity, particles whose heat transfer is dominated by thermal conductivity reach thermal equilibrium on time scales short compared to the entry heating pulse. However Bonny et al. (2) proposed that the phase transition of an organic material might slow this thermal equilibration, and Rietmeijer (3) suggested decomposition of FeS might play a similar role. The dehydration and decomposition of the hydrated silicates is strongly endothermic, thus hydrated IDPs contain a phase with the required properties. Indications of thermal gradients in polar micrometeorites (4) and interplanetary dust (5) demonstrate that a thorough investigation of the effects of endothermic phase transitions in micrometeorites is required.

Simulation Procedure

In this simulation each particle is modeled as a sphere of radius $0.05xR_p$ (where R_p is the radius of the particle) surrounded by 19 concentric shells each of thickness $0.05xR_p$. Initially the entire particle is at 300 K (the approximate temperature of a dust particle in space at 1AU). The exterior surface of the outermost shell is suddenly heated to $T_{surface}$. The heat flow through each shell in a time interval dt = 0.0025 sec is calculated using the heat transfer equation:

$$dQ = kA(T2-T1)dt/h \quad \text{(Equation 1)}$$

where k = thermal conductivity, (T2-T1) = temperature difference across the shell, A is the cross-sectional area, and h is the shell thickness. The temperature of each shell is then calculated by allowing the heat transferred from the adjacent shell to warm the interior shell, that is:

$$T = T_{initial} + dQ/mc \quad \text{(Equation 2)}$$

where m is the mass of the shell and c is the specific heat of the material. If this heating would cause the temperature of the shell to rise through the phase transition temperature the temperature remains at the phase transition temperature until a sufficient amount of heat has been transferred to accomplish the phase transition in this shell. Then the temperature of the shell is allowed to rise again following Equation 2. The simulation continues in 0.0025 sec increments until the interior reaches the surface temperature.

Results of the Simulations

Figure 1 shows the temperature as a function of depth below the surface and time for simulations of particles having radii of 50 microns, 30 microns, and 10 microns. In all cases shown a thermal conductivity of 0.000002 cal/g.cm.K, the value measured at 300^{o} C for lunar soil in a vacuum (6), and a heat capacity of 0.2 cal/gm, a value typical for ordinary chondrites (7), were used. The phase transition temperature was 900 K, and the phase transition was assumed to require 600 cal/gm. This value is similar to literature values for the dehydration and decomposition of hydrated silicates. For example, the dehydration and decomposition of kaolinite [$Al_2Si_2O_5(OH)_4$] requires the input of about 300 cal/gm.

For the 50 micron diameter particle, 3.8 seconds elapsed after the surface was raised to 1000 K before a point 25 microns below the surface exceeded the phase transition temperature of 900 K. In the absence of this endothermic phase transition the point 25 microns below the surface exceeds 900 K in less than 0.8 seconds. Thus, endothermic phase transitions can significantly extend the duration of thermal gradients in micrometeorites. For steep entry angles some large IDPs spend only a few seconds within 100 K of their peak temperature (8), thus the thermal gradient produced by this endothermic phase transition can result in the interior never approaching the surface temperature.

If the surface temperature is increased the rate of heat transfer increases, and the duration of the thermal gradient decreases. For a surface temperature of 1200 K the point 25 microns below the surface of this 50 micron particle reaches 900 K in only 1.6 seconds (see Figure 1). As particle size decreases, the duration of the thermal gradient also decreases. For a surface temperature of 1000 K, Figure 1 shows that it takes 1.3 seconds for the 30 micron radius particle to reach the condition that only the inner half is below the phase transition temperature, and the 10 micron particle takes only 0.14 seconds to reach this condition.

Implications for Atmospheric Entry Heating

For the 50 micron radius particle whose surface is rapidly heated to 1000 K, 3.8 seconds after the application of the heat at the surface 25% of the interior volume remained at or below the phase transition temperature. If the heating were stopped at this time, then the outer 25 microns of the particle would contain the thermally altered phase while the inner 25 microns would contain the unaltered phase. In addition, solar flare tracks, which are annealed at about 900 K, would be preserved in the inner half of the particle but erased in the outer region, and volatile elements with loss temperatures lower than the phase transition temperature would be retained in the interior.

Internal thermometers, including the presence of tracks, mineral phases stable only at low temperatures, and volatile elements, are used to infer the sources of IDPs (9, 10). The effect of an endothermic phase transition is to establish a significant transient thermal gradient which allows the interior of the particle to remain at a lower temperature than the surface. If bulk particle properties are used to infer surface temperature, and place limits on the entry velocity of the particle, an endothermic phase transition will result in the underestimation of the particle heating, thus underestimating the velocity limit. This does not cause a serious complication for the identification of cometary particles using the method described by Flynn (9) and Love and Brownlee (10) since the cometary particles are those heated above a certain minimum temperature. However, identification of cometary particles would be compromised in particles containing phases which undergo exothermic phase transitions.

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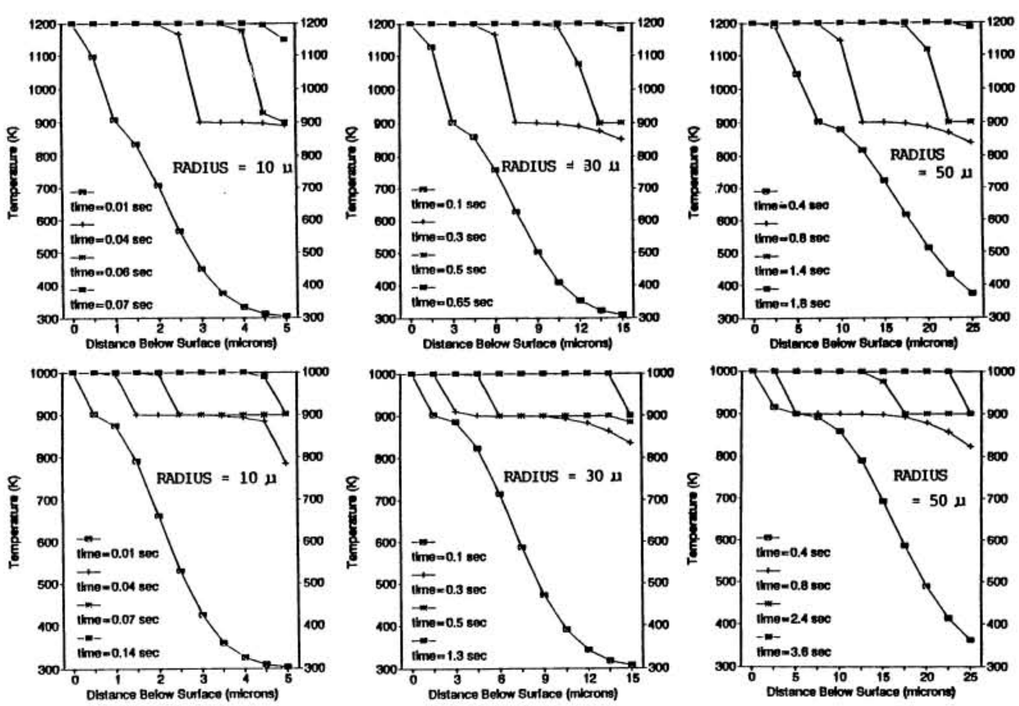

Figure 1: Temperature versus distance below the surface for 10, 30, and 50 um particles heated suddenly to 1200 K (top row) or 1000 K (bottom row) containing a phase having an endothermic phase transition at 900 K. Figures show only the outer half of the particle. See text for thermal parameters.