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Meteorite physical properties, meteor models, and the structure of minor solar system bodies

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Abstract

Meteorites provide our primary laboratory samples of materials from the solar system. Their properties are our best representatives of the materials that make up asteroids, the rocky material of ice rich bodies from comets to trans-Neptunian objects, and the interplanetary dust whose entry into the Earth's atmosphere we observe as meteors. Thus measurements of the relevant physical properties of meteorites put important constraints on our models of the nature and evolution of these objects.

1. Introduction

The physical properties of meteorites are interesting in and of their own right for meteoriticists interested in characterizing and understanding the origin and evolution of different meteorite classes [1]. But they are also essential data for our ability to model the origin and evolution of material in space where these meteorites originated [3].

In the past ten years, significant advances have been made in the measurement of meteorite density and porosity [1, and references therein]. From this, a new understanding of the structure and evolution of asteroids has been developed. Meteorites are denser, sometimes significantly denser, than the asteroids from which we believe they were derived. From this, we infer that S-type asteroids (presumably similar in material to ordinary chondrites) are roughly 20% underdense; C-type asteroids (thought to be similar to various carbonaceous meteorite types) are roughly 50% underdense; and icy material, inferred by the study of comet tails to be half dust and half ice, must be by density nearly 80% empty space.

These values have given strong credence to the rubble-pile model of asteroid structure, which in turn implies their formation as the result of perhaps multiple episodes of catastrophic disruption and reaccretion.

The magnetic susceptibility of meteorites has been measured for more than a thousand meteorites [cf. 6], and can be used to indicate the metallic iron content of the material. This is a useful tool for the rapid and non-destructive classification of meteoritic material, and one that holds great promise for use in future spacecraft missions to asteroids.

Recently, the present authors [5] have begun measurements of meteorite thermal properties, including thermal conductivity and heat capacity. These data, while still in a preliminary form, suggest that the thermal inertia of meteoritic material is surprisingly low [4, 5, 7]: two to ten times less than what might be expected simply based on the thermal properties of the constituent minerals of a meteorite. This result holds the promise of significantly changing our understanding of the thermal evolution of asteroids, comets, and even meteors themselves.

In addition, we plan to begin soon the measurement of meteorite tensile strengths. This value, which has rarely been measured directly for meteoritic material, is an important factor in the modeling of bolide break-up and cratering on asteroidal surfaces [2].

2. A wish list

At a session of an international workshop on bolides held in Prague in May 2009, participants were asked, "what data do you wish you had?" from the meteorite community in order to better understand and model the nature of bolides and meteors. Their wish list included (in no particular order):

1. Tensile strength as a function of sample size
2. The shape of fragments (including cross-sectional areas)
3. Some measure of internal shock structure
4. Thermal expansion coefficient
5. Heat of ablation
6. Temperature dependence of viscosity (to explain fusion crust structure)

7. The diffusion rate of sodium and magnesium in this material (to explain emission lines in meteor spectra)
8. Stress-strain curve close to failure
9. The albedo of meteorites
10. Temperature and pressure for sublimation, and how it evolves with time and temperature (to understand differential ablation)
11. Size distribution of meteorite components (not only chondrules, but also of mineral grains and metal grains in meteorites)
12. Electrical conductivity (one theory explains breakup of meteors as the result of electrostatic buildup)

It was noted that many of these data already exist but perhaps not in a form useful to the meteor/bolide community. This list could and should be supplemented by participants at this EPSC workshop.

3. Future work

To measure these and other physical quantities in meteorites, three important requirements must be met.

First, there must be a source of meteoritic material made available for these measurements, some of which require cutting or destroying the material (which most meteorite curators are understandably reluctant to allow).

Second, there must be a laboratory that is capable of making these measurements in ways that are reliable and, if at all possible, non-destructive. This may mean devising novel ways of making these measurements.

Finally, there needs to be an understanding of both the nature of the meteorites and the nature of the bodies that can be modeled by these meteorites, to insure that the measurements are done in a way that is relevant to the actual physical processes. For example, if the meteorite is altered by the measurement process then the resulting measurements may yield values that are in fact inappropriate for use in modeling planetary processes.

For this reason, reliable physical property measurements will generally require close collaboration between meteoriticists, planetary scientists, and solid state experimentalists. Where this combination of talents is possible, however, there is no shortage of useful data that can be obtained. And indeed, collaboration among teams interested in these measurements (as has happily occurred already among different groups measuring meteorite densities) can only result in more reliable data and ultimately a better understanding of the physical processes from parent body evolution to bolides in planetary atmospheres.

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