RADIATION INDUCED ROTATION OF INTERPLANETARY DUST PARTICLES; A FEASIBILITY STUDY FOR A SPACE EXPERIMENT

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ABSTRACT

Irregular interplanetary dust particles may acquire a considerable spin rate due to two non-statistical dynamical mechanisms induced by solar radiation. These arise from variations in surface albedo as discussed by Radzievskii (1954) and from irregularities in surface geometry as discussed by Paddack (1969). We report on an experiment which will lead to an evaluation in space of the effectiveness of these two spin mechanisms. We utilize the technique of optical levitation in an argon laser beam to provide a stable trap for particles (10-60 microns in diameter). The spin rate and direction of the spin axis are measured in a straightforward manner. The objective is to design an optical trap for dielectric particles in vacuum which can be used to study these rotation mechanisms in the gravity-free environment of a Spacelab experiment.

Calculations of the collision and sputtering rates of interplanetary dust particles seem unable to account for the large flux of submicron particles which has been observed. We are exploring whether rotational bursting is an effective mechanism for reducing the size of interplanetary particles. If so, this would generate an important dynamical component of the size distribution of the zodiacal cloud. Specifically, we look for mechanisms by which the solar radiation can impart a non-statistical torque to a particle. By non-statistical we imply that the torque should not arise by a sequence of random events, but should result from the regular response of an irregular particle to the solar radiation direction. Such a non-stochastic torque will spin up the particle until internal cohesion yields to rotational bursting. For any compact solid, bursting will occur when a point on the surface has a rotational speed on the order of 300 m/sec.

I. Halliday and B. A. McIntosh (eds.), Solid Particles in the Solar System, 391–394.

Two such mechanisms have been proposed which seem suited to the solar environment. Purcell (1975) has advanced still other mechanisms suited to the interstellar environment where there is no dominant radiation direction. The first of the spin mechanisms was advanced by Radzievskii (1954) who noted that variations in albedo over the surface of a particle could give rise to a torque perpendicular to the incident radiation direction. The common toy store radiometer would work in this way if in fact it were operated in a sufficiently high vacuum. The second spin mechanism was advanced by Paddack (1969) who noted that reflections from an irregular surface geometry could result in a non-stochastic torque. If that torque were applied along the radiation direction, then the same face would always be aligned with the radiation direction. An analogous example is provided by a windmill whose helically-pitched blades cause the spin axis to follow the wind direction. In both cases, an irregular surface geometry and/or chemical composition is expected to exhibit a preferential sense of rotation with respect to the solar radiation direction.

This idea was tested by Paddack (1969) in a hydrodynamic analogy. Randomly selected, centimeter-sized stones were dropped through a column of water. It was observed that the stones acquired a spin whose axis lay along the direction of fall. Of central importance is that repeated trials with the same stone resulted in the same angular acceleration. This arose because the stones were observed to always expose the same face to the direction of fall, so long as their orientation at release did not deviate too extremely from the preferred orientation. The average over all Paddack's samples could be summarized by saying that the stones exhibited an equivalent moment arm equal to 5×10^{-4} times the maximum linear dimension of the particle.

This dimensionless asymmetry parameter (5×10^{-4}) has repeatedly appeared in the literature as the basis for estimating the lifetime for a particle subject to rotational bursting. For example, the value of this parameter is crucial to Sekanina (1979) in the analysis of fragmentation in comet tails. The goal of the present joint experiment between the Space Astronomy Laboratory (SUNY/Albany) and the Goddard Space Flight Center is to assess the feasibility that a Spacelab experiment can demonstrate these non-statistical spin mechanisms and measure the asymmetry parameter.

Our current series of experiments is an extension of the laser levitation experiments conducted by Ashkin and Dziedzic (1971, 1976) at the Bell Telephone Laboratories. A vertically directed argon laser beam is brought to a focus. Just beyond the focus, there is a vertical position in the diverging beam at which the radiation force on a particle will just balance the gravitational force. We use a laser output of 150mw-2.5w with particles 10μ - 60μ in diameter. Analysis of the light refracted through a transparent sphere shows that a force will be exerted transverse to the beam in a direction that drives the particle to a

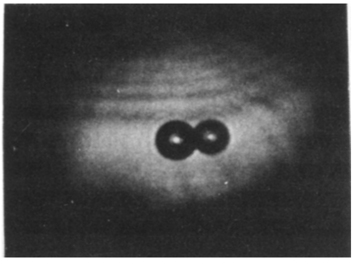

Fig. 1. Near field image of a pair of spheres levitated in an argon laser beam. The spheres are 20μ and 25μ in diameter.

region of maximum intensity. Since the natural beam of a laser has a Gaussian cross-section, it follows that the vertical position referred to above is, in fact, a point of three-dimensional equilibrium for a spherical particle. We have successfully levitated and confined spheres, clusters of spheres, and slightly irregular particles of silica. In Figure 1 we show the forward scattering, near field image of a pair of levitated spheres 20μ and 25μ in diameter. Figure 2 shows the forward scattering, a field image (or Mie scattering pattern) of the same pair of particles.

Our initial work with irregular particles has involved spheres of silica on which submicron structures are electrostatically attached to the surface or, in some instances, are crystals growing right through the otherwise spherical surface. An example of a particle with sub-micron structures is shown in Figure 3. Upon levitation these particles are usually found to rotate with a frequency of a few Hertz. The axis of rotation always lies along the beam axis. The frequency of rotation can be somewhat altered by changing the incident intensity so that the particle finds a new equilibrium position within the diverging beam. The particles have never been observed to tumble in a way as to expose different faces to the incident radiation.

It is important to point out that we have not directly observed the windmill spin mechanism. The observations described here were made at atmospheric pressure. Due to the surface irregularities, the transmitted beam experienced localized variations in intensity which gave rise to uneven thermal gradients. The air responding to these thermal gradients is responsible for the spin of the particle. However, it should be realized that this spin is a thermal analogy to the windmill mechanism in the same sense that Paddack exhibited a hydrodynamic analogy. That is, the irregular particle is observed to choose a unique orientation with respect to the incident beam and to rotate in a way such that the same face is always exposed to that beam. Unfortunately, the particle reaches its terminal rotational speed so rapidly that we have not been able to derive an

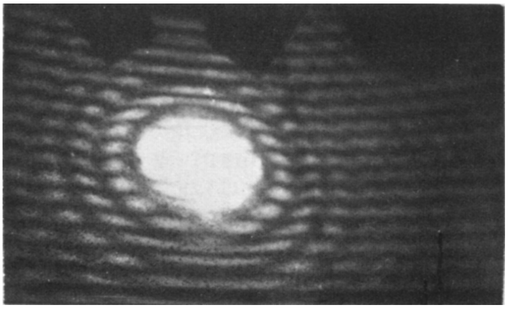

Fig. 2. The far field or Mie scattering pattern in the forward direction for the pair of particles in Figure 1.

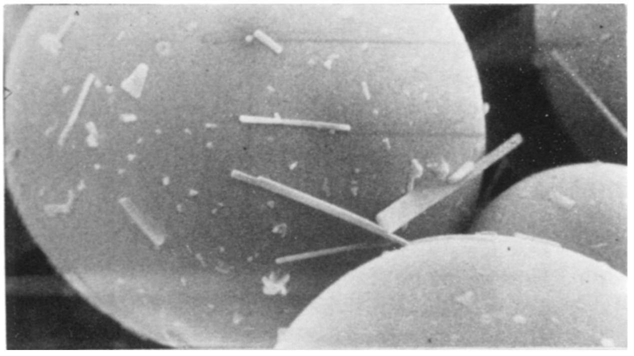

Fig. 3. A 27μ sphere with surface irregularities that induce a rotational spin (magnification 2600x).

asymmetry parameter to compare with that derived by Paddack.

The future of our study will be aimed at the creation of optical traps in vacuum capable of confining particles with the structure of interplanetary dust in the gravity-free environment of Spacelab. A pair of focused, intersecting, anti-parallel laser beams provides three-dimensional confinement in the region of space between the foci while also providing a beam axis with which to reference the spin axis of the particle. A gravity-free environment is mandated by such an experiment employing particles with realistic dielectric properties. Levitation in vacuum in a terrestrial environment requires a laser power that will melt all but the most highly transparent particles.

The authors wish to express their appreciation to H. Safren and J. Bufton for their invaluable experimental assistance. This work is supported under a NASA Research Grant NSG-7501.

REFERENCES

Ashkin, A. and Dziedzic, J.M.: 1971, *Applied Physics Letters*, 19, 283.
Ashkin, A. and Dziedzic, J.M.: 1976, *Applied Physics Letters*, 28, 333.
Paddack, S.J.: 1969, *J. Geophys. Res.*, 74, 4379.
Purcell, E.M.: 1975, "Interstellar Grains as Pinwheels," in The Dusty Universe, ed. G.B. Field and A.G.W. Cameron, Neale Watson Academic Publications, Inc., N.Y., 155.
Radzievskii, V.V.: 1954, *Dokl. Akad. Nauk, SSSR*, 97, 49.
Sekanina, Z.: 1979, "Dynamical and Photometric Investigation of Cometary Type II Tails," Semiannual Progress Report, no. 15, Smithsonian Institution Astrophysical Observatory, Cambridge, Mass.

DISCUSSION (Edited to replies by Ratcliff)

Reply to Hawkes: The rate of sputtering is too low to change the particle surface geometry sufficiently to interfere with the windmill mechanism and make it necessary to go to a random-walk approach.
Reply to Brownlee: I am not optimistic about the potential of super-fluid helium for levitation. We discarded electrostatic levitation because there are too many sources of torque that can mask the rotation mechanism.