MOTION OF SMALL PARTICLES IN THE SOLAR SYSTEM

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Unlike planets and satellites, smaller bodies in the solar system, like asteroids, comets, and meteoroids, are affected by nongravitational forces due to collisions, viscosity, and in some cases electromagnetic forces. The way such forces change the orbits of the bodies seems not to have been analyzed until recently. For example, it is generally believed that collisions between asteroids will make their orbits spread over an increasing volume of space and that collisions inside meteor streams will make their cross sections increase. At least under certain conditions the reverse is true, as shown by the papers of Baxter[1] and Trulsen[2] at this symposium. Furthermore, besides the usual picture of meteoroids being emitted by comets, we should also discuss the reverse process; viz, comet formation by bunching in a meteor stream.

We shall discuss a very simple model to illustrate the manner in which celestial mechanics works in a special case.

Suppose a number of particles ("apples") are enclosed in a spacecraft that is orbiting in a circle of radius r_o around a central body with mass M_c. We assume that both the spacecraft and the particles have a mass so small that their mutual gravitation is negligible. Hence, the particles orbit around the central body in Kepler ellipses (neglecting the case in which particles are stuck to the wall of the spacecraft). Seen from the spacecraft they will perform oscillations, which sooner or later will be damped by collisions with the walls or with each other. We may also assume that the spacecraft contains some gas so that eventually all relative motions are damped.

When this state is reached, all particles must move in circles located in the plane of the spacecraft's orbit for the same reasons that cause the Saturnian rings to be flat. However, unlike the rings, all of the particles must move with the same period because of their location inside the spacecraft. This means that their orbital radii all must equal the orbital radius r_o of the center of gravity of the spacecraft. Hence, all of the particles will be located on a straight line (or, more accurately, on a small part of a circular arc) through the center of gravity,

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[1]See p. 319.
[2]See p. 327.

pointing in the direction of motion. Let this line be the y axis of an orthogonal coordinate system. Let the x axis point in the radial direction and the z axis in the axial direction. Suppose that we displace one of the particles a distance z in the axial direction. The gravitation $\kappa M_c r^{-2}$ from the central body will then have a z component $f_z = -\kappa M_c r^{-3} z$ not compensated for by the centrifugal force. Hence, the particle will describe harmonic oscillations in the z direction with a period equal to the orbital period. This is just another way of saying that the orbital plane of the particle has an inclination $\neq 0$.

Further, a displacement in the x direction will produce a similar oscillation with the same period. (This oscillation, however, is coupled with an oscillation that has a double amplitude in the y direction. In the x, y plane, the particle describes an "epicycle" that is an ellipse with the y axis twice the x axis.) This means that the eccentricity is $\neq 0$.

Hence, seen from the spacecraft, the particles move parallel to the x, z plane as if they were subject to an *apparent attraction* that is transverse to the motion

$$\mathbf{f}_a = -\frac{\kappa M_c}{r_o^{\,3}} \cdot \boldsymbol{\rho}$$

with $\rho = (x^2 + z^2)^{1/2}$. This force acts perpendicular to the velocity of the spacecraft and tends to bring all particles to the y axis, a result that is achieved when the oscillations are damped.

The phenomena described here are strongly related to the jetstream producing effects that are analyzed by Baxter and by Trulsen.

Suppose that the motion we have considered is perturbed by the gravitation of a small body passing not very far from the spacecraft. Under certain conditions, which have been discussed elsewhere (H. Alfvén, 1971), the perturbation is such as to make all of the alined particles move toward the center of gravity of the spacecraft. In certain special cases, the result is that all of the particles will reach this point at the same moment. This means that besides the apparent transverse attraction there may also be, under certain conditions, an apparent *longitudinal* attraction (although this term is not very accurate).

It is possible that similar phenomena may bunch a large number of grains in a meteor stream in such a way as to produce a comet.

REFERENCE

Alfvén, H. 1971, Apples in a Spacecraft. Science **173**, 522-525.

DISCUSSION

DOHNANYI: What do you feel is the basic difference between a jetstream and a meteor stream?

ALFVÉN: The terminology here is always difficult. You can use the word "jetstream" for the theoretical conception of streams formed by viscosity effects acting on particles moving in Kepler orbit. Then the question arises whether meteor streams and asteroid streams really are caused in this way. I think that there are strong arguments for this, but it is not proved yet and cannot be proved until we know the densities of the small particles in these streams. For the formation of such a stream, there must be enough interaction among the particles, or between them and a gas, or some kind of similar effect must be present.

WHIPPLE: Dr. Schatzman (1953) worked out this problem several years ago using a large number of particles for a loose comet nucleus. Generally, the particles eventually come together. However, the time constant is the vital weakness in a jetstream theory applied either to the asteroid belt or to a meteor stream in the solar system today. Other minor forces, such as the Poynting-Robertson effect, planetary perturbations, and collisions with extraneous fast moving bodies with loss of fine particles and gases, have time to act and destroy the possibility of coagulation in such a jetstream.

ALFVÉN: The time constant is of interest for the application, but there is not enough information to support Dr. Whipple's general statement.

DISCUSSION REFERENCE

Schatzman. 1953, La Physique des Comètes. Liège Symp., pp. 313-323. Louvain.