

LUNAR BREAKUP AND CAPTURE CLOSE TO THE EARTH, W. Roger Buck,
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Several mechanisms for the capture of the moon by the earth have been suggested which involve passage of the moon or a larger proto-moon within the Roche limit of the earth-moon system(1,2,3,4,5). This situation could arise for a hyperbolic orbit before capture or an elliptical one of high eccentricity. Models of accretion have shown that such a large body would be likely to accrete near earth orbit(6). Some workers have suggested that a body would not be broken up by such a passage(2,3), while others have held that it would(4,5). Aggarwal and Oberbeck(7) have investigated the stresses in spherical bodies at different distances from the earth. They find that such a body would break into smaller bodies on coming close to the earth. The distance from earth would depend on the size and density of the body, but it is within about two earth radii. This is not the classical Roche limit, since a body passing close to earth for only a short time cannot deform to fill an gravitational equipotential surface. Thus the self gravitation of the more nearly spherical body will be greater than for the body filling a Roche equipotential.

Calculations are presented on the dynamics of the passage of a moon-sized or larger body passing within the limit of breakup as estimated by(7). The fragments of this body are not gravitationally bound together when close to earth. The trajectories of these fragments are followed to determine if they separate into different orbits or if their mutual gravitational attraction pulls them together when they move away from earth. Next the case of an approach so close to the earth that fragments of the body would collide with the earth is considered. Here only the trajectories of the fragments which do not collide with earth are followed.

The method used here is to consider the body to have fragmented, on close approach to the earth, into an assemblage of particles held together only by gravity. The trajectories of the particles are followed by numerical integration of the equation of motion for each particle. The particles are taken to be spherical for simplicity (see figure). The acceleration of each particle is due only to the gravitational attraction of the other particles and the earth. At each time step the positions of the particles are calculated and from the relative positions the gravitational accelerations are computed. The changes in position and velocity are calculated under the assumption that the acceleration is constant during the time step. The time step for the runs is reduced until further reduction has no appreciable effect on the trajectories. The initial conditions for the runs are with the body at closest approach to the earth and all the particles moving at the escape velocity of the center of mass of the body relative to the earth. In the case of fragments of the body colliding with the earth the calculation is similar except for the initial condition. The runs start at closest approach to the earth, but all the particles which collide are taken to have zero velocity.

In all the cases without collision it is found that the body of particles moves apart when close to the earth, but is bound together when it is several earth radii away. This is consistent with the suggestion(2,3) that the moon could have come well within the Roche limit without permanent breakup. The suggestion that partial capture of material from a larger proto-moon coming within the Roche limit(4,5) does not seem possible. The collisional case has some interesting consequences. The particles which do not collide with earth are initially moving at greater than their escape velocity relative to the

LUNAR BREAKUP AND CAPTURE

Buck, W. R.

earth. Because they have to escape the potential field of the part of the body which collides as well as that of the earth, their orbit becomes bounded around the earth. As with the other cases the particles are gravitationally held together in one body orbiting the earth. The difference between this mechanism and the one suggested by Cameron and Ward(1) is that the fragments of the body which do not collide with the earth are not affected by the shock effect of the fragments which do collide. The evolution of the orbit of this body of material, which did not collide with earth, should be from a highly eccentric orbit to a more circular one. Tidal interactions should also lead to an increase of the orbital radius with time, given that the capture was prograde.

The most interesting consequence of the collisional case is that it may offer a mechanism explaining the low iron content of the moon. This is because for some trajectories of collision only crust and mantle material of a differentiated proto-moon would not collide with the earth. Another interesting consequence of this capture mechanism is that it implies a large increase in the angular momentum density of the earth-moon system over that of the pre-collisional earth. The angular momentum density of the system has been noted as an anomalous feature of the system(7).

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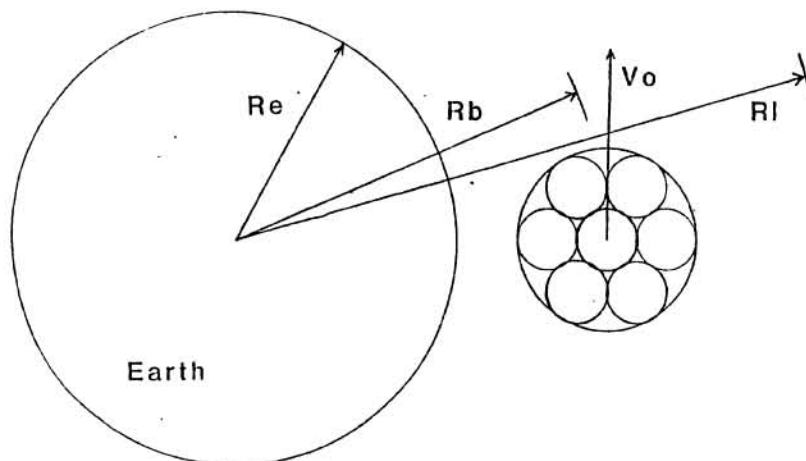


Figure. Idealization of a large body passing close to the earth as spherical particles used for calculation of trajectories. R_e is the radius of the earth, R_b is the distance for breakup for a body of density 4 g/cm^3 , R_l is the Roche limit for the same density and V_o is the velocity at closest approach.