Origin of the Moon

Recalculation of early earth-moon distances suggests dramatic events a billion years ago.

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The moon is now the target of the biggest scientific projects of the two superpowers of the world. Billions of dollars and rubles are spent on the exploration of the properties of our closest neighbor in space. Thus it is surprising that important new results concerning the history of the moon can be obtained by a high school teacher having no other assets than his interest and his free time.

It is still more surprising that, in a time when many scientists spend a considerable part of their year attending conferences and when so much effort is spent on scientific information and documentation, the results of his investigation can remain almost unknown for about a decade.

In a recent article in *Science*, G. J. F. MacDonald treats the problem of the origin of the moon, giving an account of the classical work of George Darwin. About a century ago Darwin showed that the tides made the moon's distance from the earth increase and that, consequently, the moon earlier must have been much closer to the earth. He calculated the orbit of the moon back to a period when it was only a few times the earth's radius away. Darwin had developed a theory according to which the moon was formed by tidal fission from an elongated, rapidly rotating earth. However, the coordination of this theory with his calculations, just mentioned, led to difficulties concerning the inclination of the lunar orbit relative to the plane of rotation, at least in the case of low viscosity. In the popular literature Darwin's hypothesis has been "developed," and it is often claimed that when the moon was thrown out it left a hole which is now the Pacific Ocean. This idea, of course, does not stand a serious scientific criticism.

Gerstenkorn's Calculations

H. Gerstenkorn, a high school teacher in Hannover, Germany, has taken up the problem again and has repeted Darwin's calculations, using modern values for some of the parameters. Especially important is the fact that he continued the calculation beyond the point where Darwin interrupted it. He thus found that, when the moon was close to the earth, the inclination of the moon's orbit was much greater than it is now, indeed so great that the moon passed over the poles of the earth. Still earlier the moon moved in a retrograde orbit. Gerstenkorn has traced the moon's orbit back still farther and has found that once the orbit was so eccentric that it was a parabola. In this way he has demonstrated that the moon may have been an independent planet which was captured by the earth in a parabolic retrograde orbit. The tidal action explains the development of the earth-moon system to the present state.

Gerstenkorn published his results in 1954 in *Zeitschrift für Astrophysik* under the title "Ueber die Gezeitenreibung beim Zweikörperproblem." It is not very easy to understand at once that this title hides some very important results about the origin of the moon. For my own part I must confess that I was not aware of the paper until 1961, when a reference in a survey article by Öpik attracted my interest.

Although this experience could be the starting point for a discussion about the present state of science and documentation, I believe it is still more interesting to discuss the dramatic events which, according to Gerstenkorn, took place some billion years ago.

His calculation of the minimum distance of the moon gives 2.89 times the radius of the earth, which happens to be exactly the Roche limit. This limit determines how close to a planet a satellite can come and remain stable. In the same way that the moon produces tides on the earth, the earth produces tides on the moon, and any mother planet does the same to her satellites. The height of the tides depends on the distance: the closer a satellite is to the planet, the higher the tides are. At a distance R_R given by

$$R_R = 2.44\, R_P\, (\rho_P/\rho_S)^{\frac{1}{3}}$$

(R_P is the radius of the planet, and ρ_S and ρ_P are the mean densities of the satellite and the planet) the tides become infinitely high, so that the satellite, if liquid, is disrupted. This means that the tide-producing force of the planet exceeds the gravitation of the satellite, so that matter can be thrown out from the satellite. If a liquid satellite is placed inside the Roche limit it will be completely disrupted. A solid satellite is split into pieces if the tidal force exceeds the cohesion of the body. Introducing the mean densities of the earth and the moon into the formula, we find that the moon may break up if brought to a distance less than 2.89 times the earth's radius.

Since Gerstenkorn's work the problem has been recalculated by Rouskol at the Schmidt Institute in Moscow, and by MacDonald, who, for the minimum distance, finds 2.35 and 2.72 times the earth's radius. It is not quite clear why the three results differ.

Implications

If we accept Gerstenkorn's calculations, the moon seems once to have been so close to the earth that it may have been disrupted and some of its matter may have been thrown out into space. If we try to visualize what happened at this time we are facing the most dramatic event in the history of the earth.

The moon was originally an inde-

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pendent planet moving around the sun in an orbit very close to the earth's orbit. Once it happened to come so close to the earth that it was captured and began to move around the earth. The orbit was retrograde—that is, the moon went round the earth in a sense contrary to the earth's rotation. Therefore the effect of the tides worked in a direction contrary to the present direction, so that the orbit of the moon shrank continuously. At the same time the inclination of the orbit became steeper and steeper relative to the equatorial plane of the earth, and finally it moved over the poles. The distance of the moon was only four earth radii, and the moon was still approaching the earth.

If there had been somebody on the earth who was able to see the moon, he would first have seen it as an ordinary planet, which sometimes looked bright and sometimes faint. Once, when it was unusually bright, it did not fade away in the usual way but stayed close to the earth, and very slowly became brighter and brighter. Gradually the moon came to look almost as it does now. However, as hundreds of millions of years passed, the moon approached slowly and seemed to grow larger and larger, so that finally its apparent diameter was more than 20 times the present one (its apparent surface being 400 times larger than it is now). At the same time the tides increased, and when the moon was closest to the earth the height of the tidal waves was several kilometers. But, if the moon produced such an enormous tide on the earth, the tidal effect which the earth produced on the moon was still larger. As a matter of fact, the strength of the earth's gravitational pull on the surface of the moon finally became greater than the moon's own gravitation; in other words, the moon came inside the Roche limit.

When this happened there was a partial disintegration of the moon. Large and small rocks, stones, and sand were thrown out from the moon because of the attraction of the earth and spread throughout the whole space around the earth and the moon, filling the sky and obscuring the sun. But now the moon had reached its minimum distance from the earth and the action of the tides changed, so that the moon began to retire.

Some of the fragments of the moon, which were thrown out into space, rapidly fell on the earth. Other fragments circled around in complicated orbits under the action of the gravitation of the earth and the moon. Many of these finally fell on the earth, and others fell on the moon. Hence, when the moon was receding from the earth it must have been subject to an intense bombardment of fragments of "itself," in the form of large meteors. It is possible that many if not all of the craters of the moon were produced in this way. This means that the moon may have got its present scarred face during a relatively short period after its closest approach. After its brutal rendezvous with the earth, the moon increased its distance more and more until it reached its present orbit.

But let us now return to the earth and see how it was affected. The tidal waves reached a maximum of between 5 and 10 kilometers, and, as the rotational period of the earth was 4.8 hours, they swept around with great speed. Moreover, the moon had a period of only 6.9 hours, and as it went over the poles of the earth there was no part of the earth which was not violently "polished." When the moon broke up at the Roche limit, much of the debris fell on the earth. How much is difficult to compute. It is possible that it was only a small amount of matter, which we now are looking for in vain. But it is also possible that so much of lunar matter fell down that the upper layer of the earth—the crust—originally derives from the moon.

It will be an interesting task to try to reconcile this picture with the results of geology. There is no doubt that an event of this kind must have changed the surface of the earth so drastically that it could not have escaped the notice of the geologists, unless it happened at a very early period in the geological development.

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