Bernhard went to public school for four years. After that he had to go to supplementary school on Saturdays for two years. He read anything technical that he could get hold of, and the old schoolteacher taught him all he knew.

When he lost his arm, at the age of fifteen, he was through with the school.

Next year, in 1895, he went to Reval to confirmation and stayed there. He was employed by a ship salvage company, and had to be at the office at night, to receive telegrams and telephone messages.

Then he worked for some time retouching photographs, and went in 1898 to work as designer in the "Volta" factory of electrical supplies. There he discovered that he had to do the work of a diploma engineer for little pay, and wanted therefore to pass an engineer's examination.

The Director of the salvage company, Baron Francken, who had much to do with the islanders in salvage work and piloting, and who maintained a very sympathetic attitude towards them, tried to help Bernhard Schmidt along and gave him a loan, which enabled him to go to Sweden and study at the Chalmers Technical University in Gothenburg, and later at Mittweida in Germany (1901). But he never became a diploma engineer . . .

His interest in astronomy and optics had become too great . . .

THE ORIGIN OF THE MOON

E. J. Öpik

The problem of tidal evolution of the system earth-moon, first investigated by Sir George Darwin (son of Charles Darwin, the naturalist) in 1879, and later reconsidered by Sir Harold Jeffreys, has been recently subject to mathematical study by H. Gerstenkorn (*Zeits. f. Astroph.*, 36, p. 245, 1955). Although generally following Darwin, Gerstenkorn investigates numerically the purely two-body problem, neglecting the influence of the sun. The simplification is justified for the past history of the system; at present the oceanic tides caused by the moon are twice as high and four times as efficient in slowing down the earth's rotation, as solar tides are, and in the past, when the moon was nearer, its influence must have been very much greater than that of the sun. Therefore, over the entire period of past tidal evolution the share of solar tides is estimated at about 2 per cent of lunar tides, and can be neglected in a first approximation. Other simplifications of the problem, such as the neglect of atmospheric tides, would cause errors much greater than this. On the other hand, there is an improvement over Darwin's treatment, in that a smaller value of the earth's moment of inertia is assumed (0.834 that used by Darwin), in agreement with our present knowledge of the concentration of mass towards the centre of the earth (Darwin considered a homogeneous model of the earth).

Gerstenkorn's numerical results, obtained by calculating backwards from the present state, are given in Table 1; the individual time values have been recalculated.

Table 1

The Two-Body Evolution of the Earth-Moon System

Time, years	Period of rotation of earth, hours	The Moon's Orbit: Inclination (mean) to earth's equator	Perigee distance, earth's radii	Eccentricity	Period of revolution	Stage
-1.7×10^8	2.62	148°.6	26.1	1.00	∞	Capture
-5.3×10^7	2.76	145 .7	25.6	0.66	37.2 days	
—320,000	3.29	132 .4	17.1	0.08	4.61 „	
—10,000	3.69	118 .7	10.0	0.02	1.86 „	
—170	4.20	92 .3	4.80	0	14.7 hours	
—26	4.55	68 .1	3.34	0	8.50 „	
0	4.79	45 .7	2.89	0	6.86 „	Closest approach
5	4.86	40 .4	2.92	0	6.99 „	
13	4.96	33 .8	3.20	0	8.00 „	
38	5.12	28 .8	3.90	0	10.8 „	
200	5.39	24 .8	5.34	0	17.2 „	
1,900	5.80	21 .9	7.87	0	1.28 days	
29,000	6.50	20 .1	12.2	0	2.46 „	
420,000	7.49	19 .0	18.1	0	4.47 „	
4.3×10^6	8.85	18 .4	25.5	0	7.45 „	
3.5×10^7	11.0	18 .8	34.8	0	11.9 „	
2.2×10^8	14.2	19 .9	44.7	0	17.3 „	
9.1×10^8	18.6	21 .5	53.2	0	22.7 „	
2.5×10^9	23.9	23 .8	60.3	(0)	27.3 „	Present state

The time, given in the first column of the table, is reckoned from a certain "zero hour", or the moment of closest approach; before this moment the distance of moon from earth decreases, afterwards it increases. The time before "zero hour" (first six lines of the table) is negative.

In discussing the results, one must keep in mind that it is a purely mathematical scheme; it represents things as they *could* have happened, and not necessarily as they *did* happen. This refers especially to the more remote epochs. Also, not all phases of the table need have been actually passed through; the moon may have "jumped into the picture" at any stage near, or before "zero hour".

With these reservations, we may note the following points of import. The distance of closest approach is found to be 2.89 earth's radii, or almost exactly Roche's limit (*cf. Irish Astron. J.*, 1, p. 25, 1950), which means either that the moon had a narrow escape from being broken up into thousands of fragments by tidal forces, or that fragments already existing gathered into one body as soon as they got out of the dangerous proximity of the earth.

If the moon existed before "zero hour", it may have started on a retrograde (inclination over 90°), highly eccentric orbit which was transformed into a direct orbit by tidal action. As an extreme case (first line of the table), the moon may have arrived "from infinity" as an originally independent planet (but circled the sun in an orbit almost identical with that of the earth), happening to pass the earth at a distance of 26.1 earth's radii or 0.43 its present distance. There it was captured by tidal forces and within the relatively short interval of 170 million years, at " zero hour ", its orbit relative to the earth was converted into a nearly circular one on the threshold of Roche's limit, of direct motion but with the relatively high inclination of 45.7 degrees. The evolution around " zero hour " was extremely rapid. The distance of the moon then began increasing, but the inclination continued decreasing, attaining a minimum of 18°.4 within 4.3 million years, when the distance had again increased to 0.42 its present value. After that both the inclination and the distance were slowly increasing, arriving at their present-day values 2,500 million years from " zero hour ".

The absolute time-scale, of course, cannot be guaranteed; it is based on the present-day rate of tidal friction in the earth's shallow seas, and this rate must have greatly varied during geological ages. Jeffreys arrived at 4,000 million years for the total time of tidal evolution. It is very likely that at present solar atmospheric tides exactly balance the friction of oceanic luni-solar tides (E. R. R. Holmberg, *Monthly Not. Roy. Astr. Soc., Geoph. Suppl.*, 6, p. 325, 1952; *cf. Irish Astron. J.*, 2, p. 176, 1953); this depends upon the coincidence of the present rate of rotation of the earth with a period of free oscillation of the atmosphere. For how long this state of things lasted, we do not know; it may have been so for hundreds, even thousands of millions of years; for all this period the period of rotation of the earth must have remained essentially constant, which means that the earth must have started with slower rotation than is shown in the table. However, the evolution of the lunar orbit would not have been basically different, and qualitatively the course of events would have been essentially the same as described. With the lower initial rate of rotation of the earth, the rotational fission model of the formation of the moon becomes still less plausible.

The closeness of the moon's minimum distance to Roche's limit is a curious, quite improbable coincidence in the capture process of an originally independent planet. The minimum distance could not have been less, but it could have been any value greater than this limit. If the coincidence is considered significant, it would favour the origin of the moon from matter inside Roche's limit. An aggregate of mass, something like the rings of Saturn, may have existed there near " zero hour ". If the primeval earth was more massive than the present one, and decreased in mass through loss of light gases to space, the orbits of the particles in the ring would have increased (radius of orbit inversely proportional to mass of earth), until Roche's limit was reached. At this stage the particles would coagulate under mutual gravitation, the moon being thus formed, precisely in Roche's limit at " zero hour ". In this case the coincidence is no longer fortuitous.

One way in which the material of which the moon was formed could have been ejected from the earth has been indicated by K. E. Bullen (*Nature*, 167, p. 29, 1951). Developing Ramsey's idea of discontinuous changes of density with pressure (*cf. Irish Astron. J.*, 1, p. 185, 1951), he suggests that, at pressures in excess of 4 million atmospheres, the material of the earth's core (whatever it is) may have undergone sudden transitions which led to an explosion ejecting matter into nearby space. Of course, tidal action should come at once into play, to provide the ejected matter with angular momentum and to prevent it from falling back to earth. A liquid state of the earth would be required for a successful working of this mechanism, and fast rotation would greatly help. Although the hypothesis is hinged on unknown properties of matter and cannot yet be proved or disproved, considerations put forward in a preceding article (Irish Astr. J., September, 1955) make it look rather unpromising. However, the energy involved in the process of lifting a ring with the mass of the moon to a height of only a fraction of the earth's radius would be much smaller than in certain estimates (" On the Energy Required to Form The Moon ", A. N. Datta, *Monthly Not. Roy. Astr. Soc., Geoph. Suppl.,* 6, p. 535, 1954). The loss of mass from the earth (through escape of gases) would first relieve the earth's core of extra pressure and induce the expansion, or explosion of the core, leading to the formation of the ring ; continuing loss of mass (in a ratio of up to 3 to 1; for that purpose the proto-earth must have been at least three times as massive as now) would then help the ring to recede gradually, until Roche's limit is reached.

Of course, once the mass is assumed to be variable, almost anything could be made to happen. We must admit that, if " zero hour " coincided with the epoch of formation of the solar system—and only at this stage rapid variations in the mass of the earth could have occurred—other events, such as accretion and collisions with other bodies, may have changed the picture so much that the simple two-body tidal problem was not applicable.

If, however, the moon was originally an independent planet, captured by the earth, the time of capture (2,670 million years ago according to Gerstenkorn) may have been well after the formation of the solar system. At that epoch the space around the earth may have been relatively free from other bodies, and the two-body approximation to this case would appear quite dependable. In the present solar system Pluto with respect to Neptune is in a similar position of prospective capture, although, owing to Pluto's hyperbolic velocity relative to Neptune (should their orbits meet), the probability of capture is very small.

The capture theory of the moon is thus mathematically simpler than the theory of terrestrial origin, and can be more completely traced back in time. Unfortunately, we cannot be sure that nature actually chose the simpler method in attaching the moon to our planet.