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CURRENT PROBLEMS IN RESEARCH

Interior of the Moon

Observations from space vehicles will provide further clues to the history of the earth-moon system.

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Study of the moon's surface has produced a wealth of observational material. Despite the abundance of observations, the origin of many of the surface features remains in doubt. By contrast, very few data relate to the nature of the moon's interior. Because of the inaccessibility of the moon's interior it is unlikely that any detailed picture of its nature will be forthcoming in the near future. The study of the lunar interior offers a wide field for speculation.

Astronomical Data

The mean density of the moon is well established at 3.34. This value is tantalizingly close to the density of a large number of silicate materials found on or near the surface of the earth. The densities of peridotite and eclogite, two rocks that may form portions of the upper mantle of the earth, are about 3.3. Indeed, Bullen (*1*) has reversed the argument and uses the mean density of the moon as evidence for a density of 3.3 in the upper part of the mantle.

While the mean density of the moon is well established, the distribution of density within the moon is as yet not known. It is generally assumed that the moon is a homogeneous body in which density increases only through an increase in pressure. Jeffreys (*2*) assumes that the moon is of one material, with a density ranging from 3.28 near the surface to 3.41 at the center. The justification for this assumption lies in the apparent homogeneity of the earth's mantle over the pressure range attained within the body of the moon. In making this assumption Jeffreys ignores the inhomogeneous nature of the outer part of the earth and the possibility that the crust-mantle boundary may be a phase change.

It is possible to obtain an estimate of the density distribution from an analysis of the moon's motion about the earth and the rotation of the moon. The motion of the moon is complicated by the fact that the moon's three moments of inertia are different. On the average, the moon rotates at such a rate as to keep the same face toward the earth. The largest moment of inertia is about the axis of rotation, and we denote it by C. The least moment of inertia, A, is about the axis pointing towards the earth. The earth's attraction maintains a permanent tide within the moon, and this tide is along the axis of A. The principal moment, B, is along the tangent to the orbit. The differences between the moments of inertia give rise to observable peculiarities in the moon's motion. The study of these peculiarities is difficult because of the smallness in the differences in the moments of inertia. A further difficulty results from the small ellipticity of the visible disk of the moon and the large irregularities of the lunar topography.

The triaxial figure of the moon causes the axis of least moment of inertia to perform small oscillations in both directions about the line of centers connecting the earth and moon. The moon's orbit changes because of the action of the sun, and as a result the actual motion is very complicated. The mean position of the moon's axis of rotation lies almost in the plane containing the pole to the ecliptic and the pole to the moon's orbit. The moon's axis of rotation oscillates about this mean position. The mean position of the axis of rotation is inclined to the pole of the orbit. This inclination depends on the ratio

$$\beta = \frac{C-A}{B} \approx \frac{C-A}{C} \qquad (1)$$

Since the direction of the axis of rotation is well observed, this ratio is accurately determined.

A measure of the homogeneity of the moon is provided by the ratio of the moment of inertia C to MR^2

$$g = \frac{3}{2}\frac{C}{MR^2} \qquad (2)$$

where M is the mass of the moon and R is the mean lunar radius. If the moon were a homogeneous sphere this ratio should be 0.6. For the earth, with its density concentrated towards the center, the value of g is 0.49. For a hollow sphere, g should be unity.

The effects of $C-A$ and $B-A$ on the orbital motion depend on their ratio to Ma^2. The effects on the rotation depend on the ratio of the differences in moments of inertia to the moment C. Combining orbital data and observations of the rotation makes it possible to obtain g, and thus a measure of the density distribution of the moon.

The ratio of $C-A$ to Ma^2 is determined by the mean motion of the perigee and node. In order to obtain

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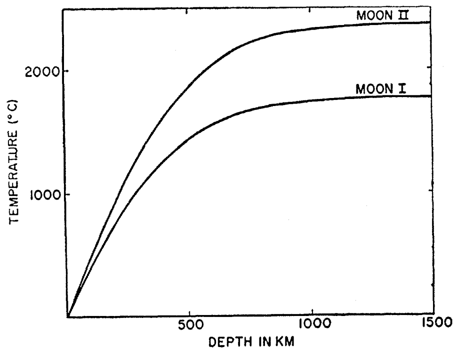

Fig. 1. Temperature distribution in the moon, after 4.5×10^9 years, for a cold moon (I) and a hot moon (II).

the effect of the figure of the moon, it is necessary to calculate the mean motion; in the calculations the moon is assumed to be spherical. In these calculations it is also assumed that the earth is a spherical body. The difference between the observed and the theoretical values then must be due to the effects of the figures of the earth and moon on the moon's motion. In a year the perigee moves by about 1.46×10^5 seconds of arc. Of this total motion, the figure of the earth contributes 6 seconds, while that of the moon contributes only 1 second. Recent satellite data establish a definitive value for the figure of the earth. In order that the effect of the figure of the moon can be abstracted from the observations, it is necessary to know the principal terms to at least one part in 10^6. The principal term in the motion of the perigee is due to the sun.

The principal solar terms are calculated from a theory of the moon's motion developed by Brown (*3*). It now appears that calculations based on Brown's theory are not sufficiently accurate to determine the principal solar terms to the accuracy needed for the separation of the effect of the moon's figure. If Brown's theory is taken at face value and new data are used for the figure of the earth, the data on the motion of the moon, together with the inclination of the axis of rotation, give

$$g = 0.87 \qquad (3)$$

This implies that the interior of the moon is considerably less dense than the outer parts. Indeed, it would seem that the moon is more like a hollow sphere than like a homogeneous sphere. This suggests very strongly that there are inconsistencies either in the reduction of observations of the moon's motion or in the numerical development of Brown's theory.

The physical librations of the moon provide an estimate of the ratios of the difference in moments of inertia to the mean moment of inertia. The physical librations are distinct from the geometrical librations. The physical librations result from the nodding of the axis of least moment of inertia about the line of centers. They are measured by obtaining the angular distance from a crater to a point on the limb. Since the limb is indistinct, due to the topography, these measurements have in the past led to inconsistent results. In recent years, photographic methods have been applied to the determination of the physical librations. A reduction of the values given by the Russian astronomer Habibulin gives results as follows:

$$\alpha_O/\alpha_T = 40$$
$$\beta_O/\beta_T = 16.8$$
$$\gamma_O/\gamma_T = 9.0$$

The outstanding feature of these results is that the observed ratios α_O, β_O, and γ_O, where

$$\alpha = \frac{C-B}{A},\ \beta = \frac{C-A}{B},\ \gamma = \frac{D-A}{C}$$

are much larger than the ratios (α_T, β_T, and γ_T) that would be predicted for a homogeneous moon in hydrostatic equilibrium. The deviations between the observed and the theoretical values would be even greater if the moon were heterogeneous, with density concentrated towards the interior.

The observed values of α, β and γ indicate that the moon is far from being an equilibrium figure. This, in turn, implies that the interior of the moon must be able to support stresses of considerable magnitude. Rough estimates of those stress differences created by the inequalities of the figure are of the order of 10 to 100 bars (*2*). Thus, the astronomical data on the rotation of the moon suggest that the moon is a relatively strong body capable of supporting strength differences comparable in magnitude to those supported within the earth (*4*).

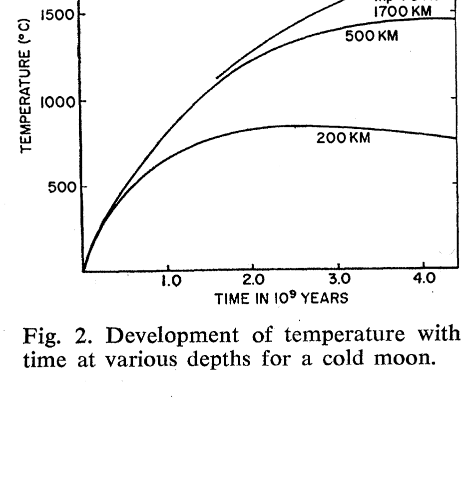

Fig. 2. Development of temperature with time at various depths for a cold moon.

The Thermal State of the Moon

The thermal state of the moon's interior is determined by the distribution of radioactivity, the distribution of thermal conductivity, and the temperature distribution at the time the moon was formed. Of these parameters, the two for which uncertainty is greatest are the initial temperature of formation and the radioactivity. The factor of uncertainty for thermal conductivity is probably about 2. In addition, the mechanism by which energy is transferred is not certain. Both convection and radiation may contribute to the transport of energy.

In 1959 and 1960 I carried out calculations on the thermal state of the moon's interior, assuming that energy is transported by ordinary thermal conduction and by radiation (*5*). In these calculations I assumed that the moon has the bulk composition of chondritic meteorites. My principal reasons for assuming a chondritic composition are reviewed in (*6*). The findings in support of a chondritic composition include the general agreement between abundances of the elements in chondrites and in the sun. Furthermore, the density of chondritic meteorites does not greatly differ from the mean density of the moon. The principal heat-producing elements in chondritic meteorites are potassium, uranium, and thorium, and the contents are 8.0×10^{-4}, 1.1×10^{-8}, and 4.4×10^{-8} g/g, respectively.

Figure 1 illustrates the temperature distribution that might be expected in a moon composed of chondritic material. In this model it is assumed that the radioactivity is uniformly distributed. Moon model I represents a cold moon. The initial temperature is taken as 0°C. The opacity is taken at the relatively low value of 100 cm^{-1}, and, therefore, radiation makes a noticeable contribution to the transfer of energy. Moon model II (Fig. 1) represents the present-day distribution of temperature that would be expected for a moon that had formed 4.5×10^9 years ago with initial temperature of 600°C and with

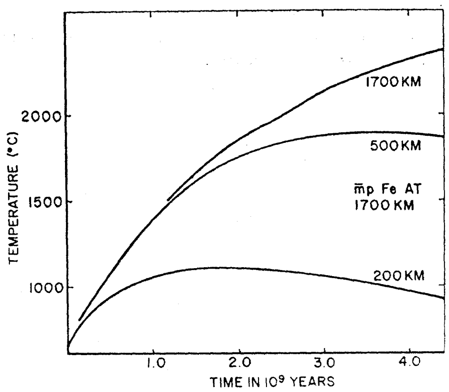

Fig. 3. Development of temperature with time at various depths for a hot moon.

an opacity of 1000 cm^{-1}. The central temperatures reached in the cold and warm moons are 1800°C and 2400°C, respectively.

Figure 2 illustrates the development of the temperature distribution within a cold moon as a function of time. It may be seen that after 3 billion years any iron present would begin to melt at a depth of 1700 kilometers. At this time there would be a tendency towards differentiation if a metallic phase were present within the moon. Figure 3 gives the development in time of the temperature distribution in a warm moon. The principal difference in models I and II is that the melting point of iron is exceeded at a depth of 1700 kilometers after 1.6×10^9 years, and at 500 kilometers shortly thereafter, in model II. At present, the outer 500 kilometers of a warm moon are cooling off while the inner 1200 kilometers of the moon continue to warm up.

A number of other models of homogeneous moons have been investigated. The results are summarized in Table 1. The surface heat flow for a moon of chondritic composition ranges from 10.3 to 16.4 ergs per square centimeter per second. The higher heat flows are associated with the higher temperatures and lower opacities. If the moon is initially at 1200°C and there is no radioactivity, then the surface heat flow is 4.2 ergs per square centimeter per second at the present time. Thus, the initial temperature of around 1200°C would contribute about 25 percent of the present surface heat flow.

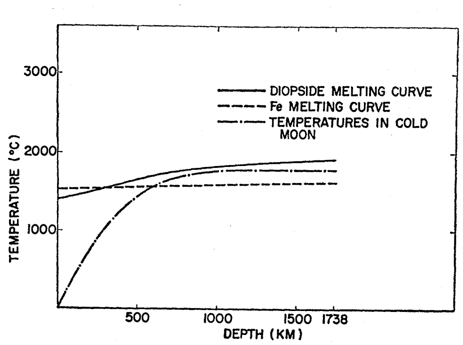

Fig. 4. Melting point of diopside (*10*) and iron (*11*) as a function of depth within the moon.

The outstanding feature of the temperature-depth curves for the moon is the shallow depth at which melting points of various materials are reached or exceeded. Since the moon is a relatively small body, the central pressure is low, of the order of 46,000 atmospheres. The low central pressure would not markedly raise the melting points of possible constituents. The thermal conductivity is sufficiently low so that only the outer portions of the moon are cooling to any extent. A combination of these two circumstances results in a close approach of the melting-point curve and the calculated temperature distribution, as is illustrated in Fig. 4. The temperatures of the cold moon are plotted, as are the melting points of the silicate, diopside, and metallic iron. The melting point of iron is exceeded at all depths greater than 500 kilometers. The melting point of diopside is not exceeded, though the temperature closely approaches the melting point at depths of the order of 800 kilometers. Thus, in a homogeneous moon having a chondritic composition, the melting point of silicate materials is very nearly reached, even though the initial temperature may have been as low as 0°C.

It would thus appear that in a homogeneous moon the melting temperature of silicates is approached or exceeded, provided that the moon has the composition of chondritic meteorites. If the radioactivity is reduced by a factor of 2, then the temperautre of melting is approached or exceeded if the initial temperature is greater than about 1000°C.

The astronomical evidence suggests that the moon is a relatively strong, rigid body. A strength of 100 bars implies that no major portion of the moon is molten. The discrepancy between the suggestions derived from the astronomical data and from the thermal models can be partially resolved if it is assumed that the radioactivity of the moon is appreciably less than that of chondritic meteorites, or that the radioactivity is concentrated towards the surface. A concentration of radioactivity towards the surface in turn implies a differentiated character for the moon.

Table 1. Results of investigations of various models of homogeneous moons.

Opacity (cm^{-1})	Initial temp. (°C)	Present central temp. (°C)	Surface heat flow (erg/cm^2 sec)
100	0	1780	10.3
1000	600	2380	12.4
1000	1200	2980	14.6
10	1200	2700	16.4
10	1200	1160	4.2 (No radioactivity)

It appears likely that even if the moon were chemically homogeneous the density distribution would undergo discontinuities. At the pressures and temperatures reached within the moon, several of the common silicate phases undergo transitions from low-density to high-density forms. Figure 5 illustrates the depth at which these transitions might be expected if the moon were initially cold (0°C) and homogeneous. Albite plus nepheline would transform to jadeite at a depth of some 750 kilometers, while enstatite would break down to pyrope, sapphirine, and sillimanite at a depth of around 500 kilometers. If the initial temperature were higher, the depth to the discontinuity would be greater. In a cold moon containing material of basaltic composition, the silicate phases would undergo transitions from the low-density to the high-density forms at depths between 500 and 1000 kilometers. If the moon were made up of chondritic materials the same transitions would take place. The density discontinuity in a material of chondritic composition would be a few percent because of the low alkali and alumina content of chondrites.

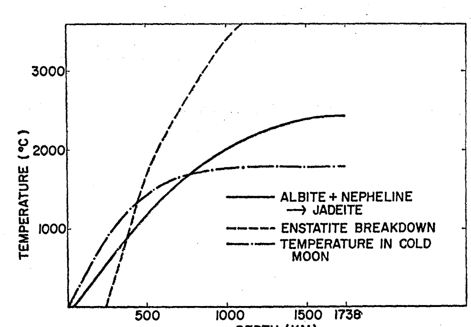

Fig. 5. Possible phase transitions within the moon. The solid curve is derived from data of Robertson *et al.* (*12*). The enstatite breakdown curve is taken from Boyd and England (*13*).

Stress History of the Moon

The thermal histories of the homogeneous models of the moon show that at present the outer parts of the moon are cooling while the inner regions are heating up. Because of the finite thermal expansion of the material making up the moon, this differential cooling and heating will generate thermal stresses within the moon. The build-up and release of these stresses provide a source of seismic activity. An important question for the exploration of the moon is the extent of such seismic activity.

As the temperature distribution within the moon changes, the dimensions of the moon must also change. During periods in which the moon as a whole is heating, the radius increases. If at present the moon is cooling, then the radius should be decreasing.

A study of the surface features of the moon may give some indication as to the thermal history of the moon, by limiting possible changes in the lunar radius. If the volume of the moon has undergone marked changes since the time of formation of the surface features, then the surface features should have undergone visible displacements. Large-scale strike-slip faults on the lunar surface are far more easily recognized than terrestrial strike-slip faults. The lunar surface is free of masking sediments and oceans. Furthermore, the complicated character of the lunar surface provides an abundance of land marks for the detection of relative horizontal movement. The veritable lacework of craters that forms the lunar surface provides an ideal reference against which horizontal movements can be detected. A close examination of the surface of the moon reveals that none of the craters have undergone displacements in which one side of a crater has moved relative to the other side. In a few cases it appears that one side of the crater may have undergone a vertical displacement relative to the other side. A horizontal displacement of half a mile could be detected on a lunar photograph; no displacements of this magnitude have been noted.

The lack of features associated with faults implies that the volume, and thus the surface dimensions, of the moon have remained more or less constant. If the circumference of the moon has been increasing, then we should expect normal faulting and the formation of grabens or rifts. If the circumference of the moon's surface is decreasing, then strike-slip faults and thrust faults would be expected from the resulting compression. A decrease of 1 kilometer in the radius of the moon would result in a decrease in the lunar surface area of about one-tenth percent. The accompanying distortion of the surface features should be noticeable, particularly since it would be expected that the inhomogeneous nature of the lunar surface would lead to local concentration of stresses.

For a spherically symmetric body in which heat is produced at a rate A per unit volume, the equations of conservation of mass and energy combine to give the rate of change of the outer radius as

$$\frac{dR}{dt} = \frac{\alpha}{\rho_s C_p} [K \frac{\partial T}{\partial r}\Big|_R + \frac{1}{R^2}\int_0^R \rho A r^2 dr] \tag{4}$$

where α is the mean thermal expansion, ρ_s is the mean surface density, C_p is mean heat capacity, and K is the thermal conductivity of the surface. The rate of change of radius is proportional to the difference at which heat is flowing from the surface

$$-K \frac{\partial T}{\partial r}\Big|_R$$

(K is the thermal conductivity), and the rate at which heat is being produced within the body. If the heat flowing through the outer surface is equal to the rate at which heat is produced within the body, then the radius of the body remains constant. A change in radius can come about only through an excess of heat production or an excess of heat loss.

A number of factors are important in determining the difference between the rate of heat production and the rate of heat loss. If the radioactivity is concentrated near the surface, then the heat produced near the surface will reach equilibrium with the surface temperature in a shorter time than if the heat were distributed uniformly throughout the body. Of considerable importance is any initial heat that the body may have. This initial heat does not appear explicitly in Eq. 4 but does contribute to the surface heat flow. If a body had no radioactivity, then the initial heat would lead to a decrease in radius with time, since there would be a surface heat flow determined by the initial heat of the body.

Thermal calculations described in the previous section can be used to determine the rate of change of radius. In these calculations the thermal expansion of the lunar matter has been arbitrarily set at 1×10^{-5} deg/°C. This value is likely to be low for silicates by as much as a factor of 2 to 3. Since the rate of change of radius depends linearly on thermal expansion, a doubling of the mean thermal expansion doubles the rate of change of the radius and the total change of the radius.

Figure 6 shows the radius and change of the radius of the moon with time, provided that the moon was initially at 0°C throughout. During the first 2×10^9 years the radius increased by about 5 kilometers in response to the high initial rate of radioactive disintegration. After that period of time the rate of increase of the radius decreases, but the radius reaches a maximum at about 4×10^9 years after initial formation. At present the radius would be decreasing, but at a low rate. The striking feature of the curve is the near constancy of the radius over the past 1.5×10^9 years. The size of the moon determines its thermal time constant, and it appears that the time constant for the change in radius of a homogeneous moon is about 2 to 3×10^9 years.

The case of an initially warm moon is shown in Fig. 7. The general features of the curve are similar to those in the cases discussed above and indicate that the rate of change of radius over the past few hundred million years has been very small.

Further models have been studied. The general features of the models are the same. The amplitude of the variation in radius depends on the initial temperature (lower initial temperatures give rise to the higher increase in

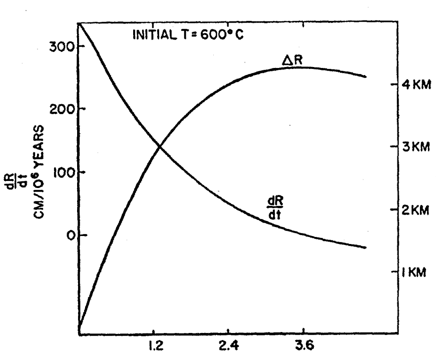

Fig. 6. Change of radius of a moon initially at 0°C, 4.5×10^9 years ago. Opacity, 100 cm^{-1}; ordinary lattice conductivity, 0.025 joule per gram per second per degree centigrade. Final central temperature and surface heat flow, 1780°C and 10.3 ergs per square centimeter per second, respectively.

radius) and on the mechanism of heat transport. If the heat is transported by radiation or by any other mechanism in which heat is more efficiently transferred than by ordinary conduction, then the rate of change of radius is less over any interval in time and the total change in radius over a period of time is proportionately less.

The present surface features indicate that the radius of the moon has remained constant since their formation. On the assumption that the lunar surface formed at an early stage of the moon's history, such an observation could be explained by a number of hypotheses.

1) The radioactivity of the moon is less than that of chondritic materials. A lower radioactivity is also suggested by the close approach of the melting point and of the actual temperature gradient. If the initial rate of heat production is sufficiently small and the moon formed at a low initial temperature, then both terms on the right-hand side of Eq. 4 would be small and the corresponding change in radius would be small.

2) The radioactivity of the moon could be that of chondritic meteorites buried at a sufficient depth. The moon could have a low initial temperature of the order of 1500°C. The history of the radius in time would then be given by Figs. 6 and 7. Such a model for the moon would imply an age for the surface features of at least 2×10^9 years.

3) The moon is a chemically differentiated body with the radioactivity concentrated near the surface. In this case the temperature at depth might again be well below the melting temperature at all points. Furthermore, the rate of heat flux would be equal to the rate of heat production, and the surface heat flow would be due primarily to the initial heat possessed by the moon. Such a model of the thermal structure of the moon explains the lack of large-scale faults and the absence of abundant volcanic activity on the moon. The principal difficulty in such a model is the difficulty of providing a history for the differentiation of the lunar material.

In the models studied the outer portions of the moon are cooling while the inner portions are heating. There is a build-up of stress differences within the moon. If these stress differences exceed some critical value the stresses are relieved either by fracture or by flow. The rate at which the strain energy due to thermal stresses is released can be calculated if a critical stress is assumed. For a strength of 100 bars the maximum strain energy per unit volume is 1.4×10^3 ergs per cubic centimeter. The models give a rate of build-up of maximum stress differences of the order of 10 bars per 10^6 years. The corresponding rate of release of strain energy by failure at 100 bars maximum stress difference will be 4×10^{24} ergs per year. This rate of release of strain energy is of the same magnitude as the present rate of release of strain energy on the earth, as measured by the intensity of earthquakes. If the moon has a chondritic composition, then the moon should have a high degree of seismic activity.

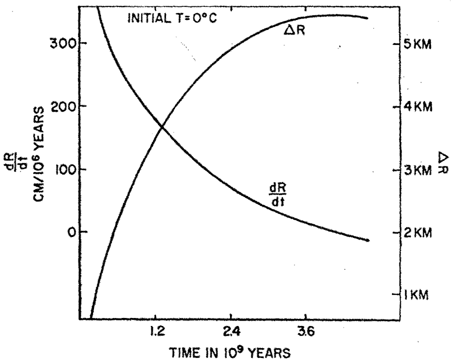

Fig. 7. Change of radius of a moon initially at 600°C. Opacity, 1000 cm^{-1}. Final central temperature and surface heat flow, 2380°C and 12.4 ergs per square centimeter per second, respectively.

In the model studied, the greatest release of strain energy is at a depth of 100 to 700 kilometers. The assumption of deeply buried radioactivity implies deep foci for lunar seismic activity.

Dynamical History of the Moon

In a recent study (*7*), Munk and I reopen the question of the dynamical history of the earth-moon system and of the age of the earth-moon system. We have examined the astronomical data relating to the rate of change of kinetic energy of the earth-moon system. We find that dissipative processes remove energy from the mechanical motion at a rate of 3.2×10^{19} ergs per second. This figure is about three times greater than the figure obtained by Jeffreys (*2*). The discrepancy in the two estimates lies not in the data but in the method of reduction. It should also be noted that the rate of energy dissipated is somewhat greater than the present estimates of the rate of release of seismic energy in the earth.

The mechanism by which the energy is dissipated is still somewhat uncertain. Jeffreys argued that the energy was dissipated within the shallow seas. Munk and I, on reviewing the oceanographic evidence, demonstrated that the energy dissipated in the shallow seas is insufficient, by at least a factor of three, to account for the observed change in kinetic energy of the earth-moon system. A substantial portion of the energy may be dissipated within the body of the earth. This suggestion is strengthened by studies of the damping of seismic waves. Furthermore, recent analysis of bodily tide records in isolated continental stations suggests that the observed phase lag of these bodily tides is consistent with the interpretation that energy is dissipated within the body of the earth.

Extrapolation back in time of the present rate of dissipation is warranted only if the rate of energy dissipation has remained constant. The dissipative character of the earth's mantle depends only on the prevailing conditions of the temperature and pressure. The time constant for the change in temperature and pressure within the earth is very long, and it may be safely assumed that the earth now has much the same dissipative properties that it possessed a few billion years ago. The time needed for the moon to recede from a distance of 10^5 kilometers to its present distance from the earth is 1.3×10^9 years, provided our estimate (*7*) of energy dissipation is correct. This calculation does not take into account the nonlinear interactions as the moon moves closer to the earth. If the nonlinear terms are considered, the time needed for the moon to recede from a distance of 10^5 kilometers to its present distance would be a few hundred million years. The age of the earth is at least 4.5×10^9 years. The data on the secular acceleration of the moon therefore suggest that the earth-moon system is younger than the earth.

The arguments reviewed in the preceding paragraph reopen the possibility that the moon was captured by the earth at a late stage in its history. The problem of an orbital capture of the moon has been considered closed for a number of years, and a capture has been generally assumed to be extremely improbable. Recent work by Russian astronomers, stimulated largely by a remark of Schmidt's (*8*), reopens the question. Schmidt showed that the problem of capture is identical to the problem of breakup of double-star systems, provided that the direction of time in the equations is reversed. Since Schmidt made this suggestion, active work by a number of Russian astronomers (*9*) has done much to clarify the problem of capture. Direct numerical integration shows a possibility of capture, and general inequalities on initial conditions have been formulated indicating the conditions under which capture can take place. There has not been an application of these general results to the problem of the earth-moon system.

Observational Determination of the Nature of the Moon's Interior

A number of straightforward observations would do much to reduce the present uncertainty as to the nature of the moon's interior and the past history of the moon. The placing in orbit of a lunar orbiting satellite and the detailed trackings of the satellite would provide critical information on the ratio $C-A/Ma^2$, and this, combined with data on the inclination of the axis of rotation of the moon, would determine the mean moment of inertia. A knowledge of the mean moment of inertia fixes the degree of differentiation of the moon and provides data of a fundamental character for the investigation of specific lunar models. This observation is perhaps the most critical of all, since it gives an immediate measure of the bulk properties of the lunar interior.

Seismic observations of various kinds will also yield valuable information. Measurement of the level of natural seismic disturbances will provide a means for estimating the current release of thermal strain energy. A network of seismic stations can be used to obtain a detailed description of the variation of elastic-wave velocity with depth.

The measurement of the surface heat flow involves the concurrent measurement of the near-surface temperature gradient and the thermal conductivity of the surface material. The surface heat flow can lead to estimates of the present thermal state of the moon. In combination with measurements of the radioactivity of the moon, measurement of the heat flow can provide theoretical limits for the initial thermal state of the moon.

The placing of a tidal gravimeter on the surface of the moon will permit measurement of the tides raised on the moon by the gravitational action of the earth. In addition to the variation of gravity due to the direct actions of the earth (and of the sun), there is a variation resulting from the elastic distortion of the moon. The amplitude of this distortion determines the bulk elasticity of the moon, while the phase lag of the displacements fixes the anelastic properties of lunar matter.

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Eradication of Infectious Diseases

"Control" is an unending operation. After "eradication," no further effort is required.

T. Aidan Cockburn

"Eradication" of infectious disease as a concept in public health has been advanced only within the past two decades, yet it is replacing "control" as an objective. The meaning of the term varies with the user, and the difficulties of achieving eradication, in any form, are usually underestimated. In this article (*1*) my own definition of eradication is offered, the difficulties common to all schemes of eradication are discussed, the significance of animal parasites in this connection is outlined, and brief comments are offered on selected eradication schemes.

Definition

In my definition, eradication is the extinction of the pathogen that causes the infectious disease in question; so long as a single member of the species survives, then eradication has not been accomplished. The definition implies action on a world-wide scale, but world eradication has not yet been achieved for any infection. "Regional eradication" implies a basically unstable situation, because at any time the infection may be reintroduced by carriers or vectors from outside. The occurrence of occasional small episodes of infection in a cleared area does not invalidate the claim that regional eradication has been achieved in that area, provided the infection was imported. For areas where vectors are present but without the parasite, one may still claim eradication—as, for example, in Sardinia where there are anopheles without the *Plasmodium*, and in the United States where there are *Aedes aegypti* without the yellow fever virus. In South America, yellow fever virus cannot be eradicated, since it is endemic in the monkey population of the forest; however, eradication of the domestic vector *A. aegypti* from the continent is under way, and this situ-

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