THE ORIGIN OF THE MOON AND SOLAR SYSTEM

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Abstract. The Rb^{87}-Sr^{87} ages of many of the lunar rocks suggest that the fundamental differentiation took place 4.5×10^9 yr ago and that remelting occurred without exchange of the rubidium and strontium with the surroundings. The Apollo A rocks are an exception to this. They appear to have acquired rubidium without all of the Sr^{87} produced during the first aeon. Also in the remelting about half of the radiogenic leads were lost to the surroundings probably the soil by a vaporization process. We interpret these results to mean that remelting occurred in a system that was nearly closed to the surroundings and that the high early concentrations of radioactive elements in highly insulating surroundings made this possible.

1. Introduction

The problem of the origin of the solar system is a very old one, and many very competent people have made suggestions in regard to the origin. The problem involves physics, astronomy and chemistry. Most problems of the stars involve the properties of gases only, but the problem of the origin of planet Earth and its satellite, as well as the other planets, involves such low temperatures eventually that liquid and solids appear. With this, complicated problems of chemistry must be considered. Today, there is no unanimity of opinions in regard to this problem.

The general facts in regard to the system are well known. The system has very nearly a planar structure; the orbits of the planets and satellites are nearly circular; the division into terrestrial planets, major planets, asteroids and comets are very obvious, and the increased spacing of the planetary orbits roughly represented by Bode's law have been recognized for many years. The early theories of origin have been reviewed very well by Jastrow and Cameron (1963) and the chapter by Cameron and ter Haar is especially pertinent. Also, a review by Woolfson (1969) and a number of papers edited by Marsden and Cameron (1966) give excellent summaries of the many ideas in regard to this problem that have been presented during the past years, decades and centuries. Most theories have involved highly complex mathematical discussions, and these certainly are necessary, but the complexity of the subject is so great that these can hardly be adequate. Much observational data must be secured, and I, personally, have tried to concentrate my efforts in this direction. In particular, I have naturally looked for chemical evidence while trying not to violate physical laws and physical and astronomical evidence. The physical facts are also very complicated involving magnetic effects, strength of materials etc., in addition to the gravitational fields.

2. Some Chemical and Physical Properties of the Sun and Planets

The isotopic composition of the elements of higher atomic weights are within the

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limits of error – the same in the Earth, meteorites and Moon. There are small differences in these abundances in the case of the lightest elements, e.g. H, Li, C, N, O, but these variations are generally explained as due to chemical fractionation of the isotopes. This means that these objects have been formed from the same nuclear synthetic events, and, hence, that the meteorites, Moon and Earth must be derived from the same fundamental mixture of elements and that appropriate fractionation processes must have occurred to produce any observed differences in composition. We cannot be certain that the Sun belongs to the same synthetic process, since exact measurements of abundances of the isotopes cannot be made. However, it is generally assumed that this is true. Thus, the assumption of two sources of material, i.e., one for the planets and another for the Sun, is generally assumed not to be true. This conclusion applies to the following discussion, and we believe that planetary objects have been derived from solar-type material.

Hydrogen and helium make up about 97 or 98% of the Sun by mass, conventional solids about 0.25%, and the remainder consists of carbon, nitrogen, oxygen and inert gases other than helium of which neon is the most abundant. Thus, there is one gram of solids in 400 g of gas, and, hence, the Earth and its component of solar gases would have somewhat more mass than Jupiter. One cubic centimeter of solids must be separated from about 10 m^3 of gas at STP. In order to produce the terrestrial planets, an immense settling process is needed, which must have occurred at such temperatures that terrestrial type, rocky materials were present as liquids or solids. Though high temperatures were probably present during the condensation of the Sun and Planets, lower temperatures must have been present at some stages of the process. Also, gases have been lost to some extent from the major planets, though this loss has not been so very nearly complete as is the case for the terrestrial planets. The problem of the extent of loss of these substances from the major planets is quite complex, but we can conclude that Uranus and Neptune must have lost much gaseous material while little may have been lost from Jupiter and Saturn. The gases which have been lost almost completely from the terrestrial planets are H_2, He, C as CH_4, N_2 or NH_3, H_2O, Ne, other inert gases and possibly some of the more volatile elements which are condensed into rocky materials at lower temperatures. These gaseous substances were probably lost before planets of the mass of the Earth or Venus had accumulated because of the difficulty of removing gases of higher atomic weight than helium from these planets due to their high gravitational fields. It is just possible that strong magnetic fields sweeping over these planets would remove ionized atoms and molecules from their atmospheres. In this case, ionization by far ultraviolet light from the Sun is required for many of the constituents, and it is not certain that this would be very effective. It should be noted that ionization potentials of the abundant gases, e.g. H_2, N_2, H_2O, and Xe, are very high, i.e., 15.427, 15.576, 12.60 and 12.127 respectively, and will require very short wavelengths of light to produce ionization. Even small amounts of interplanetary gases will absorb this light. It is far from certain that the primitive Sun emitted intense light of the required wavelengths and that this light would reach planetary atmospheres sufficiently to permit magnetic fields to sweep them away. The problem is very complex involving the solar spectrum, the amounts of gas between the Sun and planet, the ionization of molecules, the recombinations of ions and electrons, the efficiency of removal by a magnetic field of unknown intensity and probably other difficult variables. Perhaps I am lazy and mother nature is not, but I prefer the loss of gases before strong gravitational fields develop. It seems likely to me that gases were lost from the region of the terrestrial planets and from Uranus and Neptune before the great gravitational fields had developed, that the planets accumulated from smaller objects from which gases had been lost to space, and that the terrestrial planets had accumulated by relatively small solid objects.

Considerable variation in chemical composition with respect to the more non-volatile consituents exists in the terrestrial planets and the meteorites. The densities of the terrestrial planets and the Moon estimated for low temperatures and pressures vary considerably, and we suppose that this is due to a variation in the proportion of the abundant high density element of iron either in its elemental or combined state. The estimated iron to silicon atomic ratios in various objects are presented in Table I. The iron ratios are those generally accepted some years ago. More recently, the oscillator strengths for iron lines have been revised downward, and, thus, the solar abundance has been raised until the estimated iron to silicon ratio is approximately unity. However another study by my colleague, Brueckner (1971), indicates that for some of the solar iron lines, the damping constant used is in error, and that the abundance of iron must be lowered again until the sun (corrected) value may be about correct. Cowley (1970) has insisted upon the importance of this. These calculations apply only to the strong lines, but abundances from weak lines may be in error due to blends with other weak lines. This makes an error in the observed abundances which is always on the high side. (This has been called to my attention by John Ross.) Whatever the final conclusion may be, considerable fractionation of the chemical constituents has occurred with the Moon and Mercury being at opposite extremes for planetary objects and with great variations in the meteoritic compositions also being present. Low density silicate material must have been lost during the accumulation of Mercury, and if the higher

TABLE I

	Fe/Si
Achondrites	~ 0.0–0.3
Sun (uncorrected)	0.12
Sun (corrected)	0.25
Moon	0.3
L chondrites	0.59
Mars	~ 0.6
H chondrites	0.81
Type I Carb. chondrites	0.89
Earth	1.0
Venus	~ 1.0
Mercury probably	< 3

abundance of iron, i.e., an iron silicon ratio of unity, is correct, then high density iron must have been lost from the Moon or the interior of the Moon contains some percentage of low density materials such as water or carbonaceous substances. In view of the low water and carbon content of the lunar surface, I am not enthusiastic about this interpretation, but I cannot definitely exclude it as a possibility.

It seems most likely that some large objects of approximately lunar size were present during the accumulation of the planets. If the planets accumulated from small objects or from gases, one would expect that their axes of rotation would all be nearly perpendicular to the ecliptic plane or more probably to the planes of their orbits, and the orbits would all lie nearly in one plane. This is only true for Jupiter. The Earth, Mars, Saturn and Neptune have axes tilted relative to the verticle to their orbits by 23° to 29° and Uranus by 98°. Venus rotates in the reverse direction to the orbital rotations. Mercury's rotation has been modified by tidal action from the Sun. Collisions of fairly large objects of about the mass of the moon are an obvious explanation of these facts. Objects colliding with terrestrial planets should have lost their atmospheres while those which collided with the major planets may have retained all or part of their gaseous atmospheres. Incidentally, at this point in our discussion, such objects might make it possible for one of them to be captured by the earth and thus supply a very unusual satellite moving in an orbit about its primary whose plane apparently could never have coincided with that of the Earth's equator.

3. One Model for Solar System Origin

I have adopted a model for the origin of the solar system which starts with a Sun probably of greater diameter than it has at present, and a flat nebula extending out to the farthest planet. It is assumed that the contraction of the original rotating mass of gas threw off a disk of gas and dust when it contracted to form the Sun. Solids would settle to the median plane of such a nebula if turbulence did not persist. Gravitational instability would occur in such a layer of gas, and it should break up into spheres of gas. Kuiper (1951) first used such a model to make protoplanets which were of planetary size plus the solar component of gas. I argued against this since it appeared difficult to construct a very few large objects of this kind, and also especially because of the difficulty of dissipating such enormous masses of gas from the planets, e.g., a mass of Jupiter approximately from the Earth's or Venus' protoplanet. Mostly, it appears that this type of nebula is assumed by others though the processes of further development, i.e., the gravitational instability mechanisms, are generally not used. I have argued that such instability may have produced approximately lunar sized objects, i.e., objects having the mass of the Moon plus its proportion of solar gases, and, thus, total masses in the neighborhood of $2.2–3.7 \times 10^{28}$ g. (See Urey, 1966). The escape of gases from objects of this mass should be considerably more plausible than from the Earth with its component of solar gases. Others have assumed that accumulation of sizeable solid objects in the solar nebular should be possible and that the gases were dissipated leaving these objects which then accumulated into the planets. (See Hartmann (1971) for example.) Indeed, it seems likely that both mechanisms may have occurred, and also that much dust and fragmented material may have escaped to space with the gases that must have been lost to space in order that the sun could lose its excessive angular momentum. The dissipation of gases to space probably occurred by the rotating primitive intense magnetic dipole field of the Sun. Thus, processes capable of producing considerable numbers of objects of lunar mass and smaller can reasonably be postulated for the earlier development process of the solar system.

4. Recent Data From the Moon

(1) The surface of the Moon has been fashioned physically by the collision of many objects which have produced many craters, possibly, in fact, many layers of craters and the great circular maria. Volcanic craters of small size are certainly present, and great flows of lava or volcanic ash have filled many craters and the shallow maria. I, personally, doubt the existence of great calderas, but many students interpret some craters in this way. This great bombardment of the Moon must have occurred before the oldest rocks of the Earth were laid down either as sediments or as molten silicates, since these rocks show little signs of having been formed from fragments produced by great collisions, and it would be impossible to bombard the Moon without bombarding the Earth at the same time. Thus, the intense bombardment of the Moon occurred earlier than 3.5 aeons ago. This conclusion is confirmed by the ages of the rocks which will be discussed later in this dissertation. (See Gilbert, 1893.)

(2) In 1968, Muller and Sjogren (1968) showed from studies of the movement of the orbiters that very marked mass concentrations exist below the surface of the Moon mostly in the circular maria regions. These were detected by observing the velocities of the orbiters as they passed over the visible side of the Moon. As the orbiter approached Mare Imbrium, for example, it was accelerated. As it left this region, it was decelerated. By very careful and detailed calculations, they were able to estimate the excess mass over what should have been present if the Moon's density did not vary with angular position, i.e., with latitude and longitude, and if the excess mass was near the surface. Thus, for Mare Imbrium, the excess mass is 1.6×10^{21} g. If this mass had a density 10% greater than that of the surrounding material, its mass would be $1.6 \times \times 10^{22}$ g, and, with a total density of 3.7 g cm^{-3}, it would cover Great Britain to a depth of 21 km or the State of California to a depth of 12 km. These masses are truly very large. If due to volcanic effects, the transports of material required to produce them would compare with the largest volcanic effects on Earth. Furthermore, they would not be supported by the outer rocks of the Earth. A positive gravity anomaly exists on the Island of Hawaii, but it stands in a depression on the ocean floor. Thus, the Earth's surface is sinking under this load. If the anomaly was measured from about 100 k above the Earth's surface, it is probable that no anomaly would be observed. Other anomalies, both positive and negative, exist on the Earth, but they are probably due to the great convection cells in the Earth's mantle which also move the continents about the Earth's surface and push up the great mountain chains as

well. Convection cells within the Moon are also postulated, but these have no relation to the positions of the circular maria. The outer parts of the Moon must be very rigid and must have been very rigid throughout all of lunar history, since the maria were formed probably approximately 4.5 aeons ago.

If we assume that the objects that fell on the Moon to produce the circular maria were moving with about the escape velocity of the Moon, i.e., they were moving along with the Moon about the Sun at about the same distance, and if we use formulae for the relation of the required energy to produce these maria with their observed diameters, we find that these calculated masses agree fairly well with the masses estimated by Muller and Sjogren (1968). Several of us have proposed this as their origin. Others propose complicated volcanic effects to produce them, and I definitely do not agree with these models. However, the important point to be made at this time is that in order to support these mascons, the Moon must be sufficiently rigid, and, hence, be at a rather low temperature in its outer parts, and must have been so throughout its history.

(3) The evidence from the Turkevich *et al.* (1967) analyses on Surveyors 5, 6 and 7 showed that the lunar surface was highly differentiated, and the chemical analyses of samples returned by Apollos 11, 12 and 14, as well as the spectrographic studies of McCord (1969), completely confirmed this data and added much detailed information in regard to this question. Basalts, anorthosites and very acidic rocks have been recognized, and the indications are that these very highly differentiated rocks must have been produced from a partial melting of some parent silicate rocks or to crystallization of a melted pool of silicate melt. The concentrations of minor elements show that the basalt rocks and soil must be only a small fraction, i.e., a few percent, of the original parent material, if it was of approximately meteoritic composition. The composition of these rocks are in all cases, it seems, somewhat different from terrestrial rocks, though the differentiation process must have involved fractionation between liquid and crystalline phases of silicon, aluminum, magnesium, calcium, iron etc. and oxide melts. If the parent material was of approximately meteoritic composition, very large increases in the concentrations of many minor elements have occurred. Also, the more volatile elements are missing to a marked degree as are also the siderophile elements. Thus, at some time, these volatile elements must have been lost by a high temperature process, i.e., possibly 1500 °C, and liquid iron must have trickled through some liquid material removing the siderophile elements. In fact, the lunar surface, at least, must have been melted at some time.

(4) The lunar seismic data are most interesting and puzzling in many ways. The seismologists suggest that the lunar surface consists of highly fragmented materials to a depth of possibly 20 km with no indication of discontinuities. Lava flows in the shallow maria may have been broken up by the lesser collisions that have occurred in great numbers in the maria. Possibly this problem would be solved by information from the great circular maria where deep layers of lava should exist, i.e., if the smooth material is indeed lava and not finely fragmented material of the general composition of lava flows. The seismic data indicates that the surface is highly fragmented to

considerable depths as is to be expected if the great craters are due to collisions.

(5) Various ages of the lunar surface have been determined. The mixing times of the soils as determined by the effects of cosmic rays give very little information in regard to the early history of the solar system which is the principle theme of the present discussion, though the effects of cosmic rays may produce great difficulty in understanding the data bearing on this early history. The Rb^{87}-Sr^{87}, U^{238}-Pb^{206}, U^{235}-Pb^{207} and Th^{232}-Pb^{208} data are not complicated by the cosmic ray effects, but lead under the highly reducing conditions represented by the presence of liquid iron (at the melting point of iron (1535 °C) or somewhat lower than this temperature) is fairly volatile and may move from one phase to another as seems to have occurred. The K^{40}-A^{40} ages are plagued by the loss of A^{40}, if even moderate heating for long periods of time has occurred.

Two types of ages have been determined and discussed. The fundamental equation for the time elapsed during which the concentrations of the parent and daughter radioactive elements have not changed is

$$\left(\frac{Sr^{87}}{Sr^{86}}\right) = \left(\frac{Sr^{87}}{Sr^{86}}\right)_i + \left(\frac{Rb^{87}}{Sr^{87}}\right)(e^{\lambda t} - 1)$$

where the ratios without subscripts are the present measured ratios, the subscript, i, indicates the initial ratio, λ is the decay constant, and t is the time elapsed. Similar equations for other parent/daughter relations can be written. If the initial ratio is known or thought to be known, as for example from meteoritic studies, t can be calculated, and this is known as the *model age*. If the initial rubidium to strontium ratio is not known, but variable ratios of rubidium to strontium occur in different crystalline masses in a rock, the variable values of the measured ratio (Sr^{87}/Sr^{86}) can be plotted against the measured ratio (Rb^{87}/Sr^{87}), and then the slope of the curve, which should be a straight line, is equal to $(e^{\lambda t} - 1)$, the value of t can be calculated, and the intercept on the (Sr^{87}/Sr^{86}) axis is the value of the $(Rb^{87}/Sr^{87})_i$. The age calculated in this way is known as the *isochron age*.

(6) The isochron ages of the Apollo 11 rocks by the Rb^{87}-Sr^{87} method are close to 3.65 aeons, and of the Apollo 12 rocks about 3.3 aeons. The 12013 rock has an isochron age of 4.0 aeons. The model ages run near 4.5 aeons. The model ages by the uranium-thorium lead ages are about 4.65 aeons, but the isochron ages vary rather badly and do not agree with the Rb^{87}-Sr^{87} ages. In another paper presented at this symposium, my colleagues and I find that consistent results can be secured if about one-half of the lead isotopes produced during the time between the initial melting and the second melting, about one aeon later, was lost by evaporation into the soil. The initial melting time by the U-Pb method then becomes 4.5 aeons instead of 4.65 aeons. The K^{40}-A^{40} ages, when corrections for loss of A^{40} are made, give very similar results. For our present purposes, we note that the times of the first and second meltings are about 4.5 and 3.3–4.0 aeons ago respectively. These times for the first melting are close to those for the ages of the meteorites and the earth, and they substantiate the initial arguments for a great age for the Moon. We must conclude that an early melting

occurred, followed by a cooling and freezing of the surface in order to support the great collisional craters and mascons, and then a remelting occurred about one aeon later. It is necessary to conclude that that first melting occurred when the radioactive heating was greater than it was an aeon later by about 40%. This is an important problem in devising a history for the Moon.

Meteorites contain rare gases which indicate that they had cooled to sufficiently low temperatures to retain xenon gas before certain radioactive elements had decayed to such low concentrations that their daughters could not be detected. Thus, I^{129}, with a half-life of 17 million yr, decays to Xe^{129} which appears in excess in some meteorites. Excess Xe^{129} has not been observed in lunar samples. If it did, this would indicate that the Moon, as a non-degasing body, would be older than the Earth since terrestrial Xe shows no excess of Xe^{129}.

Fission of uranium and atoms of higher atomic weight fission spontaneously to atoms of lower atomic weight, and among these are Xe^{134} and Xe^{136}. Slight excesses of these have been observed by Marti (1971), but they are so slight that no confidence can be placed in the observations. At present, we have no evidence from these xenon observations that these elements were present in lunar material.

(7) No general magnetic dipole field associated with the Moon has been detected. However, the rocks which were last melted some 3.5 aeons ago do have detectable magnetic moments. Also, local magnetic fields up to 100 gamma have been detected. This means that these surface rocks were in magnetic fields as they cooled through the Curie point, and that local areas of some kilometers in dimensions at least do retain magnetic fields. This means that at some time, when these rocks cooled through the Curie points (770 °C for metallic iron) a magnetic field was present and estimated to have had an intensity of about 1000 gammas or 0.01 Oe. It seems that no field of such intensity exists on the Moon, and, hence, the field that did exist has disappeared.

5. Model for the Moon's Early History

The rigid Moon required by the mascons, and the melted Moon required by the chemical differentiation indicate that the Moon was accumulated at low temperatures, and that its surface was melted by some external source of heat while the interior remained relatively cold. Then the surface cooled down sufficiently to support the craters which were produced by collisions following this cooling off period. A rather high thermal conductivity of crystalline rocks made this possible even though radioactive heating was at a maximum at this time. The mascons are probably supported on the interior rigid material. The collisional processes produced a highly fragmented layer with a low thermal conductivity which made it possible for the decreased amounts of radioactive elements to produce melting about one aeon later. The differentiation of the lunar surface rocks occurred during the initial melting, and the subsequent cooling process, i.e., the differentiation of the surface materials, occurred during the very early processes on the Moon. Subsequent processes changed the chemical compositions only in a minor way. Reduction of some of the iron occurred in this first melting, and it settled into a lower layer and carried the siderophile elements with it. This metallic layer is very probably the highly conducting layer which has been detected by Sonett *et al.* (1971) from the flow of solar winds over the lunar surface. This iron layer may have been cooled below the Curie point of 770 °C during the early cooling period, and, hence, it would have remained highly magnetized if an intense solar dipole field was present at this early time. This may have caused the magnetization of the rocks an aeon later, and heating since then may have raised this metal layer above the Curie point so that the dipole field has disappeared though the surface rocks retain their magnetized characteristics.

The melting processes of 3.2–4.0 aeons ago may be due to collision melting during the smaller collisions on the Moon as suggested by Gold, or to collision melting due to the mare collisions, though in this case the masses that produced the maria must be stored somewhere for an aeon. Possibly a catastrophic event in the asteroidal belt produced objects which fell on the Moon to some extent.

My colleagues and I suggest a possible remelting about an aeon after the first melting and show that this is possible, providing the initial melted layer was about 200 km in thickness. Sonett *et al.* estimate the depth of the highly conducting layer as about 250 km. It is assumed that the highly radioactive basalt and highly silicic and radioactive rock 12013 material lies in layers about 20 km below the surface, and that the collisions which followed the initial solidification broke up the surface layers producing a highly insulating layer. (The details of this work were presented at the Newcastle conference, and will be published in the Apollo 12 Conference Report by Urey *et al.*, 1971.) Radioactive heating in the course of about one aeon produced a flood of lava, or more probably ash, which covered the shallow maria and left rocks with isochron ages of 3.2–4.0 aeons.

6. The Origin of the Moon

Up to the present, it seems that no one has changed his mind in regard to the origin of the Moon, and we can only conclude that all evidence from the space program is indecisive in regard to this question. The escape from the Earth requires that a primitive Earth with high angular momentum accumulated and then separated into the present Earth and Moon. This has been discussed by many authors since George Darwin proposed this at the end of the 19th century. No really satisfactory solution of the problem has been secured. However, it seems that we cannot exclude this origin.

Various suggestions of the double planet hypothesis have been made. This hypothesis meets with many difficulties. For example, the growth of two bodies moving about each other requires a very nice balance of centrifugal and gravitational forces during the period of growth. Ringwood (1970) has suggested a modification of this origin that the Earth formed at very high temperatures with an extensive atmosphere of volatilized, rocky material including the elements found in the Moon's surface. This atmosphere is supposed to have condensed and the rocks so formed to have accumulated into the Moon. This is far from being a simple model. The condensing vapor must have been more than 2.89 Earth radii above the Earth, since this is the Roche limit, and no accumulation into the Moon could have occurred unless the solid objects condensed from the vapor beyond this limit. What the chemical composition of both Earth and Moon might be would be difficult to estimate. Possibly the loss of volatiles might result from this model in some way if an escape mechanism for vapors could be devised. However, to me the greatest objection to this model is that Venus, a planet of comparable mass and distance from the Sun, not only does not have a Moon but indeed rotates slowly in the opposite sense to the Earth. Thus, the two planets must have had very different specific angular momentum. If the terrestrial planets all had Moons similar to that of the Earth, it would have been recognized by everyone, including Galileo, that some double planet mechanism, escape from the primary or condensation near the primary was such a probable origin that there would have been no arguments against some such origin. It seems most improbable that Ringwood's mechanism could be true for the Earth/Moon system, and that no approximation to this would be true for Venus.

The capture hypothesis presents serious difficulties for capture of the Moon by the Earth requires the loss of the energy of capture in some way. Gerstenkorn (1967) has presented a vary carefully calculated process of capture in an initially reverse orbit. Urey and MacDonald (1971) suggest capture by collision with other objects moving in orbits near the Earth. Both mechanisms are very special, and one could hardly expect this to be a regular event. It does require that many lunar type objects were present in order that the probability of capture by one planet would be reasonable. Also, capture by Venus of such an object may account for the reverse rotation of Venus, as suggested by Singer (1970), and the tilts of the axes of the planets could be produced by such objects. Thus, a limited number of massive primitive objects could account for this irratic characteristic of the planets. However, the Moon must have accumulated elsewhere, and a problem is presented by the curious low density of the Moon which indicates that the abundance of some high density element, i.e., iron, is lower than it is in the terrestrial planets. Small amounts of water or carbonaceous materials in the lunar interior or a lower abundance of iron in the primitive solar composition is required. For many years, the iron-silicon ratio in the Sun was estimated to be about $\frac{1}{10}$ to $\frac{1}{5}$, but, recently, this has been revised to about 1. However, this result is disputed by some experts in the field, and a certain conclusion cannot be reached at present.

7. The Moon and the Origin of the Solar System

The review of data on the Moon is reviewed because it may have a special importance relative of the origin of the entire system. Thus, if the Moon has been captured by the Earth, it is a more primitive object than the Earth and other planets, and being near the Earth, the thorough investigation of this primitive object is possible. Of course, it may be that Ceres and other asteroids are the primitive objects, and, if so, the intense investigation of these objects should be made even though it will require many years to do so. It may be that both the Moon and larger asteroids are primitive objects, and, of course, it may be that neither are such objects.

The investigation of Mars will be very interesting, especially if life is present or has existed in the past on this planet. However, we can expect little evidence in regard to the early history of the system, since it seems probable that water has been present on Mars. The planet is red, probably due to trivalent iron which has been oxidized from the ferrous state by water. This means that sedimentary rocks will be present with all the attendant difficulties in understanding early planetary history that this entails. It will be interesting to determine, if we can, whether the planet was formed in an extremely hot condition or at a more moderate temperature, and whether the planet has a core. However, the many detailed questions that we ask in connection with Moon's ancient history for the most part cannot be answered by detailed investigation just as is true for studies of the Earth.

The recent space studies have added many details in regard to the structure of the major planets and their satellites, but little in regard to their origin. Jupiter looks like a miniature solar system with its axis of rotation tilted only three degrees from the verticle of its orbital plane and a system of satellites with orbits lying closely to the equatorial plane. The other planets do not resemble closely this character of Jupiter at all. The marked tilts of the axes relative to the planes of their orbits again suggest the presence of some massive objects which accumulated into these planets.

Many factors of immense complexity exist in regard to the origin of the system, and many observational details are needed before we can reach definite conclusions in regard to these problems. Possibly no general agreement is possible, and, in a way, we may never know!

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