

The formation of the moon philosophy essay



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The Big Bang Theory has come about to be the widely accepted model for the formation of the Universe. Approximately 13 billion years ago, all of space and matter was contained in a single point which triggered a massive explosion, which came to be known as the Big Bang. From this explosion arose nebulae, embryonic matter which were responsible for the formation of various cosmic systems such as the solar system within the Universe. When a cloud of interstellar gas and volatile matter contracted to form a flattened disk owing to its spin, the core contracted to form the protosun from which the Sun evolved into its life cycle as a star governing our Solar System. From the accretion that followed post sun formation, the gases of the sun condensed into solid materials. Such solids collided leading to the formation of larger coagulated particles, known as planetesimals, which eventually formed the planets that orbit around the Sun. Being a host to several planets and satellites orbiting the planets, the Solar System consists of “ 167 moons orbiting 8 planets besides several other likely moons orbiting the giant planets, dwarf planets and asteroids” as documented by NASA (Davis, 2011). This document discusses one such planetary satellite system - the Earth and the Moon within the Solar system.

To understand the formation of the Moon and eventual coupling with the Earth, the Big Bang gives us clues on the conditions that existed at the time of formation of the Universe. Volatile matter and gases condensed and constantly collided as they formed larger particles. The explosions and the spin during the formation epoch resulted in massive impacts when objects collided with other objects in the vicinity - a very hostile environment in

early evolution. Such conditions have been accounted for in theories that have been proposed for the formation of the Moon.

This document discusses the mechanisms of Moon formation. Within each discussion is included the factors going in favour or against the proposed theory. Further sections discuss the evolution of the Earth-Moon system. The impact of Moon formation on Earth is also presented, and considering the fact that the duo make up a dynamic system, the evolution of the Earth's rotation rate, the geophysical and climatic effects and how these are influenced by Moon are also outlined.

Predominantly there have been five theories that have withstood the tests of the scientific community in claiming the most appropriate Moon formation mechanism. The fission theory accounts for the separation of an object from the Earth which eventually became the Moon. The Earth's gravitational field captured an object which led to formation of the Moon in the capture theory. The condensation theory involves the formation of the Moon and Earth condensing from the same nebula forming the Solar System. Interaction and subsequent evolution of the Earth-orbiting and Sun-orbiting planetesimals led to the formation on the Moon in a scenario known as the colliding planetesimals theory. Finally, within the impact theory or the ejected ring theory, one can see that a Mars-sized object struck Earth and ejected material that formed the Moon.

EARTH AND MOON IN NUMBERS

For any theory to be accepted as the most appropriate for mechanism of Moon formation, it must be able to account and explain the geophysical

parameters and physical characteristics of the present Earth-Moon system. The Moon's mantle is similar to that of the Earth, however its core lacks the Iron content that the Earth exhibits; a fact that can be partly verified from the relative densities. In the case of the Moon it is 3.34 grams per cubic cm to that of Earth's 5.52 grams per cubic cm (Hawaii University Web, 1996). Further important parameters are listed herewithin, courtesy of the NASA Moon fact sheet page. NASA (Williams, 2010) documents that,

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The Moon to Earth mass ratio is 0.0123 and that of volume is 0.0203

Moon has a current revolution period of 27.3217 days

It is at an inclination to the ecliptic at 5.145 degrees

It exhibits a recession rate from Earth of 3.8 cm/yr at a current mean distance from Earth of 378,000 km

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Lunar missions such as the Apollo 11, 12, 14, 15, 16 and 17 (Smith, 2010) have confirmed that the Moon's rocks do not constitute volatile matter, a clue to substantiate the parched and very dry surface of the Moon. This could also imply that it was exposed to more heat in comparison to Earth's surface which harbours water in liquid form. A study of the isotopes of Oxygen on Earth and that of Moon suggests that in their identity lies the evidence for the Earth and Moon to have formed at a similar distance from the Sun (Smale, 2010).

FISSION THEORY

The advent of moon formation theories from a scientific standpoint eclipsed mythological perceptions in the late 16th and early 17th centuries. Galileo, with the invention of his telescope, pointed to the Moon and started studying its features and made several scientific observations. By this time, the notion of Earth-centric system was overthrown and the Sun-centric system came to be widely accepted with arrangement of planets and satellites around the Sun.

The works of Rene Descartes (1596-1650) such as *Principia Philosophiae* suggests that as the Earth grew by amassing smaller objects in its path, a cloud of dust and debris that surrounded it coalesced to form the Moon. In his works, he described that lumps of debris moved about in a spin and they coalesced over time; the heavier masses staying at the center of the spin gathering smaller masses revolving in the circumferential periphery. Although there were some sporadic old school believers of the Earth-centric system, their voices were strong enough to overthrow his Sun-centric approach and his theories on Moon formation were hence dismissed. However, two centuries later, Geroge Darwin (1845-1912), the son of Charles Darwin picked up on the cold trail of Descartes' theory and proposed that the Moon seperated itself from the Earth by studying its orbital motion going back into time.

He believed that Moon and Earth were once a single cosmic object and as proto-Earth started to spin, its unbalance led to part of its mass being spawned off due to asymmetry to form the Moon. In an investigation, continuing on a similar theory, British geologist Osmond Fisher proposed for <https://assignbuster.com/the-formation-of-the-moon-philosophy-essay/>

the first time that the gash left behind in the Pacific Ocean is due to separation of an object that eventually formed the Moon (Mathez & Webster, 2004). Just as Darwin proposed how a spinning proto-Earth liberated material to form the Moon, the region of liberation could well have been the Pacific Basin if one observes the Earth in this region devoid of water (Smale, 2010). A schematic illustration of this theory is shown below in Figure 1.

Figure 1: Moon is spun off from proto-Earth (Source: CWRU Web, 2011)

The theory lends itself very well to Moon's rocks being similar to those found in the Earth's crust, but when the current rotation rates of the Earth-Moon system are considered and interpolated back in time, there is no evidence suggesting that there was such a rapid spin capable of liberating Moon off of the proto-Earth. This critically questions Darwin's assumptions and calculations of orbital motion of the Moon.

It also fails to account for "the orbital tilt of the moon and lack of volatiles" (University of Maryland Web, 2005). As far as Fisher's proposals are concerned, Mathez and Webster (2004) dismiss his findings by saying that "...we now know that it is impossible because the Pacific Ocean formed over only the past couple of hundred million years..." a clear disagreement with the timeline of the Moon formation.

Although Scott and Durisen (1984) document that "...recent numerical simulations of fission instabilities in rotating fluid masses give results which are consistent with some requirements of the fission hypothesis for the origin of the Moon..." an area where this theory fails is in explaining the large

angular momentum that is required to eject material the size of current Moon. In a thorough research involving quantitative geophysics and geology Lliboutry (2000) aptly argues that "...even if the whole angular momentum is taken by a single planet, a bit larger than the Earth, this is still very far from the counteracting of gravity by the centrifugal force. A tremendous tidal force would have been necessary, which could only result from the proximity of Jupiter. But it does not account for the creation of this large angular momentum..."

A conclusive rebuttal of this theory came from the works and calculations of Harold Jeffreys. Although Jeffrey was a keen advocate of this theory with his earlier findings, he studied the resonance of the oscillations of combined fluid masses of the Earth and the Moon, because this was the original state of the object before the Moon was spun off. For the Moon to spin off a certain friction is required to create a precise geometry to make the system just unstable enough to liberate Moon from proto-Earth and Jeffreys was able to measure that and found it to be inconsistent with original assumptions thereby invalidating the theory. In his 1930 paper, he noted "...it has always been recognised that the validity of this theory depends on the smallness of friction; for friction necessarily fixes an upper limit to the amplitude of an oscillation attainable by resonance..... this friction can now be estimated; and it turns out to be sufficient to invalidate the theory..." (Jeffreys, 1930).

In summation, although similarities in physical characteristics between the Earth and the Moon were explained very well in this theory, the energy and angular momentum schemes needed to cause loss of the material do not

agree with the current spinning of the Earth rendering the theory implausible.

CAPTURE THEORY

A vacuum in the scientific community since Jeffreys rebuttal of fission theory finally ended when Horst Gerstenkorn and Harold C Urey revived it with a new approach in the 1950s; namely the capture theory involving capture of the Moon owing to Earth's gravitational potential. As an expert in Chemistry and having won the Nobel Prize for discovery of deuterium, Urey took a physiochemical approach and did not pay so much attention to details of the mechanism of capture. On the other hand Gerstenkorn looked closely at Moon's historical orbit and recession rate from Earth.

The scientific community investigating formation of Moon at the time was on a two fold path: one which dealt with the exact mechanism of formation and the other which debated whether the captured Moon was originally a cold body or was captured in a hot and deformable state. The theory was dismissed by Kaula and Harris (1973) in which they argued that a currently nearly rigid Moon to have been captured is implausible.

On the exact mechanism of formation, Gerstenkorn studied the orbit of the Moon and calculated its prehistoric orbit whilst noting that the tidal effects could have played a major role in affecting lunar orbit. He realized that going back in time meant that contrary to current orbit of Moon receding from Earth, Moon's orbit a few billion years ago would have been much closer; implying that a retrograde hyperbolic orbiting object, moving in the direction opposite to that of Earth's spin, was captured by the effect of

Earth's tides to effect a prograde new motion. Urey also advocated tidal effects to be a likely factor for required energy dissipation noting "...the very short period of time for the formation of maria indicated by the surface features of the moon is quite in accord with the hypothesis that the moon was captured by the Earth late in the process of the formation of the Earth by the capture of smaller objects..." (Brush, 1996).

Urey's assumption of a capture late in the stages of Earth formation was the basis of his "cold moon" approach. His geophysical and chemical approach to the subject led him to conclude that the lunar maria in their present form could have only been formed by primordial water wells transferred by Earth during the capture, and over time we now see a parched Moon's surface. A hot Moon at the time of capture would have to indicate a totally different current Moon's surface.

Gestekorn differed in this approach, in that he proposed the hot moon capture, and found the support of Alfven, Cloud and Singer who also investigated the same possibility (Malcuit & Winters, 1977). They believed that an imperative precursory to planetary formation was a hot and deformable body eventually achieving a spherical shape owing to spin and settling in orbit.

Malcuit and Winters (1977) comprehensively studied the works of aforementioned scientists and proposed that deformable bodies could provide evidence to effect capture as opposed to rigid bodies. They proved that if the Moon were elastic and warm enough, then this renders a certain energy of dissipation required sufficient enough for capture even in a single

encounter in the vicinity of the Earth's orbit. Contrary to Urey's proposal of maria formation, Malcuit suggests that as the Moon was captured by the Earth, the tidal effects pulled the Moon's surface and ejected hot and volatile material, some of which fall back onto the lunar surface and created lava lakes forming the craters that we see today. This is illustrated in figure 2 below.

Figure 2: Malcuit's schematic of Capture Theory (Source: Denison Web, 2010)

Dutch (2009) argues the Malcuit and Winters proposal by suggesting that the exactly precise distance and speed required for the gravitational capture to take place is highly improbable although it can deduce the current arrangement of Moon's orbit around the Earth's orbital plane. Further research in this field was taken up by Sorokhtin and Ushakov (1989) who postulated that the capture is possible only if one accounts for planetary spin-up during the process of capture of the Moon and also predicted subsequent orbit of the Moon and noted "...the process of the Protomoon capture and destruction, should finally spin the Earth up in the prograde direction.....the Moon, together with other satellites (then still abundant in the near-Earth space) under the influence of tidal perturbations began only to be repelled and to move away from the Earth..." In this proposal, they had accounted for the Moon's recession from the Earth's orbit that we see today.

By this time, the aspect of Roche limit had crept into the arguments from the scientific community. Sorokhtin and Ushakov's model did not unfortunately account for the fact that the object would undergo destruction if it came well into the Roche limit of the gravitating body. The capture theorists then

started to ask the same question - if capture theory was not possible, then how is it that all other satellites have been formed orbiting their companion satellites? This was a reasonable question, because observation of other Moons in the solar system surrounding other planets were actually captured asteroids and not objects that formed in place with an original planet.

Khilyuk et al (2007) incorporated Roche limits into this theory and proposed that in the event of the proto-Moon captured by the Earth, it would induce a forward spin to the Earth. Pursuant to this event, they were able to account for not just stabilisation of the Moon captured but also account for scarcity of Iron in the Moon in comparison to the Earth as they note, "... at Roche limit, the molten Proto-Moon began disintegrating. The closest to the Earth hump fell on the Earth's surface, bringing the molten Iron of the Moon's core. This, in particular explains the extreme scarcity of Iron in the Moon rocks. The Moon itself formed from a silicate matter (with a low iron content) of the outer tidal hump of the destroyed Proto-Moon..." (Khilyuk et al, 2007). By this time, the hot and deformable Moon was favoured opposed to Urey's cold Moon approach.

Yet again, we have another theory providing clues on the current Earth-Moon system orbital arrangement and shed light into the physical properties of the Moon. However, the prospect of a capture close to Roche limit or within it and yet surviving destruction renders this theory unlikely; further questioned by critics who think that it does not take into account the violent conditions that existed 4.5 billion years ago, which would have only led to further scattering and destruction of an approaching object.

CO-ACCRETION THEORY OR DOUBLE PLANET HYPOTHESIS

Although Urey's chemical and geophysical approach led him to believe that the differences in composition of the Earth and the Moon could be due to the fact that they were formed at different distances in the capture theory, the probability of such a capture necessitated a rethink in the scientific community. The hot and cold moon approach in itself compounded the theory, if the exact mechanism was not already enough to baffle.

The advent of co-accretion theory heralded the prospects of the Moon and Earth to be formed from the same nebular material or the primordial swarm from their respective proto-planets. The size of the Moon in comparison to the size of the Earth is relatively larger compared to the sizes of other satellites and their planets. Hence, assuming such a relatively larger Moon as initially having formed from a proto-planet would be a reasonable approach.

Figure 3 illustrates how such a theory is possible. The cloud of matter leading to the formation of the proto-planet and planetesimal was in the vicinity of other smaller planetesimals which were still drawing gases and matter around them. The theory proposes that one such protoplanet or more aptly called the proto-moon drew material from this cloud forming the proto-Earth and eventually became the proto-Moon and formed the Moon.

Figure 3: Schematic of Co-accretion theory (Source: w2u Web, 2010)

While this theory eliminated issues regarding the dynamics of capture or fission, the compositions of the Earth and the Moon and the differences found in them (refer to "Earth and Moon in numbers" section) were not very

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well explained. If the Earth and the Moon formed from the same primordial matter, then they would have to exhibit the same composition, but that is not true as we know the differences today. However, this theory can explain the similarity of oxygen isotope content in the Earth and the Moon (Dalrymple, 1994).

We recollect that the Moon to Earth mass ratio is 0.0123 or 1:81. Ruskol studied the probability of Earth and Moon forming from primordial matter and availability of enough primordial matter to lead to the masses and sizes of the Earth and Moon that we see today and dismissed this theory by concluding that (Ruskol, 1962),

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We can assert definitely that the Earth-moon system did not originate as a double planet from some double embryo. It would be impossible, in this case, to obtain observed mass ration of its components 1:81, because the growth of the bodies which have begun to grow simultaneously leads to masses of the same order, and

The formation of the Moon after the formation of the Earth is also quite improbable, because-at this time-the Earth's zone has already been depleted, and no more matter was available for the formation fo satellites.

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Galileo's invention of the telescope and his observations of the Moon back in 1609 fascinated the scientific community and alike for hundreds of years on how the Moon came about to be the satellite of the Earth. The theories of fission, capture and co-accretion championed this cause for a long time, but <https://assignbuster.com/the-formation-of-the-moon-philosophy-essay/>

in their assumptions and predictions, failed to match verifiable data from the rock samples of lunar missions. Questions on dynamics of capture and differences in Earth and Moon constituents were thrown open yet again for further possibilities of Moon formation.

THE COLLIDING PLANETESIMALS THEORY

Violent conditions existed at the time of formation of the early solar system.

The planetesimals orbiting the Earth collided with other planetesimals orbiting the sun. This theory proposes a scenario where such a collision between Earth and Sun orbiting planetesimals ejected debris which condensed to form the Moon. It is widely accepted that, early in the history of formation of our Solar System, there were several asteroids, meteorites and objects alike orbiting and even bombarding the Earth as remnants from the Big Bang. Being very distinct to the fission, capture and co-accretion theory, it still involves a stage where at some point in time, the debris from impact of planetesimals had to condense around the Earth and settle in an orbit around the Earth. This chain of events requires a certain precision and the likelihood of a settled orbit is only possible if the collision occurred at a certain distance from Earth. If it were too close, the aspect of Roche limits and consequences would creep in, and if it were very far, then the dubious capture previously rejected would have to be initiated.

There have been variations of this theory that have also been proposed, ever since the collision mechanisms surfaced in the investigations. One scenario is where debris surrounding the Earth lent itself to the formation of the Moon. The debris is sought to have come from the collision of planetesimals that didn't hit the surface of the Earth, but disintegrated during their

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approach whilst colliding at low Earth orbits. Ida et al (1997) asserted that such a scenario could be possible if the disk of debris was to be located around the Earth just outside the Roche limit, and would result in the Moon settling on a nearly circular orbit in the equatorial plane. This was further confirmed by a consecutive study by another team headed by Ida (Ida et al 2000). The second scenario is while Earth was in its proto-Earth stage, colliding planetesimals in the vicinity accreted to form the proto-Moon, which eventually formed the current Earth-Moon system.

The collision theory brought with it the prospect of answering cratering, a result of bombardment in early stages of Earth-Moon formation, something which the previous theories did not focus much on. It was only after the 1960s, when the lunar missions included terrain studies, mare samples and crater geology yielded clues about the surface of the Moon not known since. Data from samples clearly mismatched most known assumptions and predictions from past hypothesis.

If the planetesimals that collided and led to the Moon forming debris, it is likely that this material is different from the proto-Earth and hence come about to account for the differences between the compositions in the surface and the core. The dry parched surface can be explained by late formation of the Moon around the Earth. The occurrence of this event around the Earth's orbit could also explain the orbital plane of the Moon. As noted earlier, the question this theory fails to answer is how a large Moon came about in currently observed orbit, if it was already proved earlier that capture is highly unlikely.

GIANT IMPACT THEORY OR EJECTED RING THEORY

The Origin of the Moon conference in Kona, Hawaii in October, 1984 welcomed a new approach to the investigations of Moon formation (Stevenson, 1984). The scientific community probed the possibility of a large object impacting Earth and ejection of debris following this event led to formation of the Moon in orbit around Earth.

Research prior to this conference from Cameron et al (1976) and Hartmann et al (1975) led support to this theory; initially proposing that the ejected debris was a result of a massive collision in an eccentric orientation with the Earth. Cameron (1997) investigated further and concluded that it was difficult to identify an impact that could result in the current Earth-Moon configuration.

During the early stages of the Solar system when Earth was not fully evolved, its surface and mantle was still elastic and deformable. At this time, a Mars sized object was on a collision course with the Earth. It is estimated that this object struck the Earth at about 2 kilometers per second (Mathez & Webster, 2004). Soon after impact, the ejected material which was also hot and deformable was released in a trajectory around the Earth and over time accreted to form the Moon. Some material from the impacting object fell back to add to the already existing mass of the Earth. The impact resulted in increasing the rotational speed of the Earth and also influenced its tilt about its rotational axis. The energy involved in the impact would dictate the degree to which the matter in impacting bodies vaporised the constituents; it is estimated that this was sufficient to melt the volatiles and silicate

materials but not so much as to alter the cores of the two bodies - a good indication in the differences within the cores.

The hot material that was ejected provides clues on how the Moon evolved to become a satellite with a parched surface. The orientation of the object in collision course can account for the orbital settlement of the Moon that eventually formed in orbit around the Earth. The difference in compositions and densities of the Earth and the Moon can also be explained as coming from an alien object impacting Earth and not material being spawned off of it. While acknowledging that the Moon formed in the vicinity of the Earth, it is reasonable to correlate the oxygen isotopic composition between the Moon and the Earth. All these observations made the theory to be acceptable by the scientific community in the conference of 1984. However the nature of the massive impact on Earth's then deformable surface and subsequent bombardments on the surface of Moon (as evidenced by craters we see today) have removed any evidence that could be used to test this theory. Figure 4 shows a schematic of the ejected ring theory.

Figure 4. Mars sized object struck Earth and ejected material that eventually formed the Moon (Source: Freedman and Kauffman, 2007)

Since the impact theory has been favoured by the scientific community, ongoing research refines several parameters: the exact age of the Earth at the time of collision, the origin and size of the Mars sized object, the precise angular momentum required to account for the energies involved leading to the formation of the moon and the stage in Earth's evolution for this to have occurred. Numerical modeling and simulations continue to strive to constrain

the giant impact theory model. The lunar missions by NASA such as LCROSS, Moon Mineralogy Mapper, Mini-RF and Smart 1 also continue to gather data to help us better understand the properties of the Moon and through that one can gain valuable information about formation and evolution of the Moon.

EVOLUTION OF THE EARTH-MOON SYSTEM

The heat resulting from the impact of a Mars sized object on early Earth essentially reduced or eliminated any moisture and volatiles trapped in the ejected debris. While this ejected debris fastened Earth's rotation, it accreted to form the Moon at about 4. 467 Gya (Hartmann, 1978). The debris originally formed a disk of material while it was flung out of Earth post collision; some of which fell back into Earth and the outermost portion of which accreted to form the Moon. The evolution of the Moon did not stop there. The Moon since then has been continually been bombarded with several objects impacting onto its surface, craters and big mare which are evidences for this bombardment. A study of the core of the Moon in relation to its geometric center has revealed that it is off center, and that the portion of the Moon's crust facing Earth is thinner than the opposite side (University of Maryland Web, 2005).

Since the Moon has been in orbit around Earth, it has been inducing gravitational forces on the surface of the Earth, almost elastically bulging it. This is seen in the form of the waves in the oceans. When this happens, there is friction between the moving layers; i. e. the surface of the Earth and water bodies. As a result of this, Earth's rotation is slowing down, but since the Earth and the Moon are tidally locked, an equitable result is the

recession rate between the Earth and the Moon. We have earlier noted that the recession rate is about 3.8 cm/year. The Laser Lunar Ranging experiments also report the same value (Dickey et al, 1994).

Some critics have not favoured this theory saying that the recession between the Earth and the Moon could have been so low going back in time that they would be close enough for the Moon to have disintegrated well within Roche limit even before its accretion into a geosynchronous satellite. It would be reasonable to believe that tidal coupling may change over a period of time if one accounts for change in volume of water content on Earth which in turn is governed by global warming, adverse climatic conditions, etc. In addition, as the Moon distances itself from Earth due to recession, tidal forces will decrease gradually. However the recession will stop at some point when the rotations of the Earth and the Moon will be locked, which means they would have reached equilibrium. We can see how the Moon has influenced Earth's rotation and therefore length of Earth day. We also know that the inclination of the Earth due to impact has resulted in the seasons we experience today.

Besides the tidal theory, other alternative theories such as the velocity-dependent inertia model have been proposed by Ghosh (2000) to suggest why the rotational speed of an object is reduced due to the influence of a larger object in the vicinity. The analogy goes that if the Sun can induce a braking potential on Earth, it can also do the same to other spinning objects. So Ghosh proposed that the depreciation in Earth's spin and Moon's orbital motion is not just inherent to tidal theory but also to Solar inertial forces.

Recent Science has uncovered the existence of dark matter (DM) and dark energy in summing up the constituents of the Universe. A theory incorporating DM was proposed by Pan. Pan (2005) in his dark matter field fluid model brings in a fresh perspective to the constraints of the classical Earth-Moon system. He proposes that if DM were to be considered, then the classical model would no longer be valid since one must also incorporate the DM and dark energy in the energy equations governing the transfer of energy in fluid and field properties of Moon formation. To validate his theory, Pan used the length of the terrestrial day to show it would change in either models. The model predicted that the length of the terrestrial day would be about 19.2 hours approximately 900 million years ago and this is in concurrence with the predictions of Sonett et al (1996). This is also in agreement that if the Moon spun the Earth faster soon after its formation, the length of the days would be lesser, as also day light.

LUNAR INFLUENCES ON EARTH

We have seen so far how a companion object in the form of Moon has altered several key parameters of Earth; rotation rate and length of day, Earth's tilt and seasons, tidal coupling and ocean waves, and rotation speeds and atmospheric wind interactions. Tidal forces are reciprocal, which means that even Earth distorts the lunar surface, however the lunar surface is rigid and hence exhibits negligible influence on it. The Moon itself has nearly equal rotational period around its own axis and orbital period around Earth, again due to gravitational locking. This means we see the same region of the Moon from Earth. As mentioned earlier, this synchronization for the Moon has happened over billions of years and for a similar phenomenon to happen

with the Earth and the Moon, a conservation of angular momentum must be observed. Only then can they have the same rotational and orbital period (University of Tennessee Web, 2010).

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