

Nature of Gravitation.

The *Structural Intuition* of Gravitation in the Framework of Early Modern Mechanical Philosophy*

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As is generally known, Newton's notion of universal gravitation surpassed various theories of particular gravities in the early modern age, as represented mainly by Kepler and Hooke. In his seminal work "Hooke and the Law of Universal Gravitation: A Reappraisal of a Reappraisal" Richard S. Westfall argues that Hooke could not reach beyond the concept of spatially bounded particular gravities, as he deployed the method of analogy between the material principle of congruity and incongruity and the extension of gravitational spheres and their action at a distance. However, the doctrine of universal gravitation does not exclude the nature of particular gravities; it is predicated on the notion of an *infinite* expansion of individual-gravitational spheres and their uniform nature, namely the mutual and centripetal attraction. In my treatise I attempt to reinvestigate the nature and structure of gravitation, as established historically in the framework of Newtonian Classical Mechanics, by a method of *structural intuition*. It examines how the structural intuition, as represented in the celestial-mechanical intuitions of Hooke and Kepler, could unfold into an innovative process within the context of early modern mechanical philosophy, attaining thus a historical significance and legitimacy as against the prevailing Newtonian method of geometric-mathematical axiomatization of mechanical principles. It also explores the actual demonstrative features of the tidal phenomenon with regard to its lunar- and solar-gravitational causation, which has been considered to date to be an important piece of empirical evidence for the theory of universal gravitation.

Keywords: universal gravitation, particular gravities, structural intuition, gravitational sphere, structure of gravitation, tides, gravitational repulsion

1. Particular Gravities

Newton's notion of universal gravitation reputedly disclosed two specific traits of this natural phenomenon, namely the attraction of all heavenly bodies to one another and its infinite extension in space. In essence they describe the nature of gravity, in which both its structure, i.e., the centripetal-vectorial attraction, as well as its centrifugal expansion is implied. In other words, the spatial structure of universal gravitation seems to correlate with its *presumed* universal nature. However, the image of the cosmos that can be developed from the Newtonian concept of universal gravitation does not represent the force of gravity as a structurally uniform

***Acknowledgements:** I am grateful to Prof. Dominik Perler and Prof. Martin Kemp for their ongoing support of my research in the area of early modern mechanical philosophy. I wish to thank Mrs. Vinita Balasubramanian and Dr. Robert Crellin for reading and correcting the first draft of this treatise. I also wish to acknowledge and thank Gerda Henkel Stiftung Düsseldorf, Germany, for their support of my postdoctoral research at the Humboldt University Berlin and at the University of Cambridge.

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phenomenon. The universality of gravitation indicates its infinite or boundless expansion, but it includes the polycentric nature and structure of gravitation, i.e., the *particular gravities* of countless celestial bodies. The nature of gravitational attraction and its centripetal structure had already been observed by other scientists of early modern astronomy such as Kepler, Roberval, and Hooke, albeit within the framework of particular gravities. Newton's accomplishment lay in going beyond the doctrines of particular gravities—especially the one by Hooke—by redefining the nature and structure of gravitational extension and action at a distance. In doing so, the autonomy of particular gravities was subsumed under the hegemony of a universal gravitation.

In his seminal essay “Hooke and the Law of Universal Gravitation: A Reappraisal of a Reappraisal,” Richard S. Westfall (1967) proves convincingly that Hooke, contrary to the view of many historians of science, was never able to develop the idea of universal gravitation.¹ Hooke was able to conceive not only the centripetal pull of gravity that holds the parts of each heavenly body together—a view also held by Kepler and Roberval—but also the gravitational action of celestial bodies at a distance, which was apparently propaedeutic to Newton's universal gravitation. Nevertheless, Hooke seemed to remain fixed to his original notion of particular gravities; he could not go beyond it to reach the concept of universal gravitation:

In 1674 Hooke concluded his *Attempt to Prove the Motion of the Earth* with a passage invariably (and justly) cited by those concerned to defend his claim to the theory of universal gravitation.... “This depends upon three Suppositions. First, That all Coelestial Bodies whatsoever, have an attraction or gravitating power towards their own Centers, whereby they attract not only their own parts, and keep them from flying from them, as we may observe the Earth to do, but that they do also attract all the other Coelestial Bodies that are within the sphere of their activity; and consequently that not only the Sun and Moon have an influence upon the body and motion of the Earth, and the Earth upon them, but that ♀ also ♀, ♂, ♃, and ♄ by their attractive powers, have a considerable influence upon its motion as in the same manner the corresponding attractive power of the Earth hath a considerable influence upon every one of their motions also”. (Westfall 1967, 247)

With this observation Hooke apparently anticipates to a larger extent the Newtonian law of universal gravitation by introducing most of its main features, namely the individual gravitational action at a distance and the mutual attraction of all celestial bodies. However, it does not state an infinite expansion of gravitational attraction. According to Hooke, every celestial body attracts every other celestial body that is located within its *gravitational sphere*. Premises such as spatially bounded gravitational spheres and their effects on celestial bodies residing in them suggest only particular gravities and not a spatially unbounded universal gravitation. Westfall traces this limitation in Hooke's observations to one of the methodological analogies with which Hooke attempts to demonstrate the nature and structure of gravitation in purely mechanical terms, namely the principle of congruity of matter (especially between fluids) and gravitational attraction:

Certainly the passage is remarkable. Certainly it appears to state a principle of universal gravitation. That is, to us, familiar with Newton, it appears to state such a principle. Does it do so in fact? Several phrases that Hooke used suggest rather that he thought in terms of particular gravities, though not to be sure in exactly the same terms as Kepler and Roberval. Celestial bodies have an attraction towards “their own Centers” by which they attract “their own parts”. They attract other celestial bodies “within the sphere of their activity” as well, and exercise on their motions “a considerable influence”. The phrases recall at least the principle of congruity. (Westfall 1967, 247-48)

Hooke, as his observations clearly signify, holds the view that gravity is primarily a phenomenon relating to matter. For the primary function of gravity is to hold the parts of a celestial body together. Hooke has a distinct notion of a gravitational sphere surrounding the material sphere of celestial bodies. Such gravitational spheres are spatially bounded and belong to individual celestial bodies. This leads to the assumption that there

are different spheres of gravity by which celestial bodies attract each other. Although Hooke does not expatiate on the materiality of such a gravitational sphere surrounding a celestial body, his notion of celestial bodies acting at a distance seems to have evolved from the principle congruity which he identifies with gravitation. For the gravitational sphere in Hooke's considerations is apparently a form of extension of the material sphere of celestial bodies and is characterized in the same way by its spatial boundedness.

The spatial boundedness of particular gravitational spheres is the only fact in Hooke's observations, from which Westfall concludes that Hooke, unlike Newton, was able only to develop the idea of particular gravity. Apart from that, Hooke could anticipate all other traits of a universal gravitation that Newton axiomatised, namely the mutual attraction of all celestial bodies and its centripetal, i.e., polycentric *structure*, as discussed above. In the Newtonian concept of gravitation, the extension of the gravitational force and its action at a distance are spatially infinite and, as such, universal. This clearly distinguishes universal gravitation from Hooke's idea of mutual interactions of individual gravitational spheres. However, Newton conceives of universal gravitation as being composed of particular gravitational spheres that extend infinitely. That is to say, the Newtonian notion of universal gravitation does not exclude the existence of the particular gravitational spheres of celestial bodies in the cosmos. Now the action at a distance of celestial bodies extends to infinity—a notion within the framework of universal gravitation that goes beyond our imagination. Although Newton was not able to find an explanation for the cause of gravitational action, i.e., attraction at a distance, he was firmly convinced of, and content with, the fact that gravity exists. For all the static and dynamic phenomena on Earth prove the existence of gravity and its action at a distance. What Newton was inclined to believe in and, at the same time, battled against was his own notion of unbounded extension of gravity and its action at infinite distances, as expressed in one of his letters to Bentley (Hesse 1955, 340).

If, according to Westfall, the infinity of particular-gravitational extension is the only fact which invalidated Hooke's claim to the discovery of universal gravitation and authenticated the Newtonian idea, it remains to date neither sufficiently justified nor proven. Empirical or experimental evidence for the action of gravity at *infinite* distances is clearly an impossibility. The sole justification for the infinite expansion of particular gravity, upon which Newton tacitly constructed his axiomatic notion of universal gravitation, seems to be the infinite reduction of the gravitational force in its *centrifugal* expansion. It is demonstrated mathematically in *Principia* that the strength of the gravitational force decreases centrifugally according to an Inverse-Square Law. Although we are convinced of the apodicticity of this mathematical demonstration, empirical or experimental evidence for the infinite expansion of gravitation, i.e., its action at infinite distances, will remain an unattainable goal for us.

It was Robert Hooke who first suggested—before Newton—that all celestial bodies within the solar system attract each other. The leap from this given assumption to the idea of an infinite expansion of universal gravitation in Newton's *imagination* seems to have been based on a belief rather than on knowledge. At this point we have to look for the conceptual models and structures, already developed in the Newtonian system of celestial mechanics, that must have predetermined or even fabricated such an axiomatic conviction. In his spontaneous discovery of universal gravitation with its infinite expansion and unending centrifugal diminution of strength, Newton seemed to be influenced by two axiomatic principles (that he himself had invented), namely the unending expansion of absolute space and the principle of infinitesimals. Both principles can only be conceived by an *a priori* intuition, i.e., they can be neither empirically perceived nor experimentally proven. While, according to Westfall, the *material* principle of congruity prevented Hooke from going beyond the concept of particular gravities (in order to reach the concept of universal gravitation), Newton seemed to have

constructed his axiomatic notions of the existence of universal gravitation *tacitly* on other geometric-mathematical principles, without, however, any empirical evidence. The marked divergence between Hooke and Newton in their conception of the spatial extent of the gravitational spheres can be attributed to the fact that while Hooke primarily inclined towards physical and experimental sciences and relied thereby more on empirical methods, Newton sought geometric-mathematical demonstration of mechanical principles. For Hooke, the axiomatization of physical principles should have a mechanical-material basis and be, as such, supported by empirical and experimental evidence. The geometric-mathematical axiomatization of physical principles was for Newton a clear scientific strategy to go beyond the unfounded ideas and suggestions (“guesses” as Newton referred to them) of other scientists in astronomy such as Kepler and Hooke, and to thus establish his status as a discoverer. But it was a necessary strategy in the field of celestial mechanics as most celestial phenomena and their structures are invisible or just barely perceptible and can, therefore, only be perceived intuitively and demonstrated mathematically. Nevertheless, the premise that all celestial bodies within the solar system attract each other seemed to be quite inadequate to project gravity beyond the solar system to an endless universe and, as a consequence, to postulate the law of universal gravitation. The mathematical principle of infinitesimals obviously underlies the axiomatic speculation that heavenly bodies attract each other at infinite distances in space. The speculative idea of an infinite and structurally centrifugal diminution of the force of gravity according to an Inverse-Square Law seemed to have supported the axiomatic notion of the infinite expansion of particular (centrifugal) gravitational spheres in the universe.

2. Structural Intuition

In order to reconsider the truth of unending and unbounded expansion of gravitation, this natural phenomenon should be brought back to its immediately tangible terrestrial foundations by reexamining the purely geometric-mathematical speculation in the methodological axiomatization of this law in the light of a *mechanical-structural intuition*, and corrected if necessary. For the *image* of universal gravitation was originally developed from the immediately perceptible traits of terrestrial gravity in the context of classical Newtonian mechanics. The centripetal structure of the gravitational attraction directly experienced on the Earth is attributed to the particular gravitational spheres of celestial bodies in space. Although the later established Einsteinian cosmology (or Einstein’s relativity principle) explicitly focused on the peripheral gravitational curvature of space, a centripetal structure of particular gravitational attraction was implied in it, i.e., in the causal explanation of this gravitational phenomenon.

Terrestrial gravity can be *seen* in many static and dynamic phenomena. From the static *mass* of bodies or the verticality of static forms on Earth to many dynamic phenomena such as the free fall of objects to Earth, the *structure* of gravitational force can be perceived intuitively. That is, in most terrestrial-gravitational phenomena a centripetal structure—as the cognitive mode of gravitation—is visually perceived or *visualized*. In comparison with other mechanical phenomena, the material-bodily mediacy and causation in the gravitational phenomenon cannot be experienced empirically, i.e., in a visual or tactile form of sensation. The cognition of the gravitational force is therefore based on an intuitive understanding of its centripetal structure, which is restricted to the mechanical *effect* of the gravitational field. The purely mechanical and physical causality of the centripetal gravitational action at a distance is beyond our cognition. The structure of gravity is derived invariably from various terrestrial gravitational phenomena in a visual-intuitive process; it is necessarily a *structural intuition* of an unseen force phenomenon on Earth.

The concept of structural intuition, which refers to both the static and the dynamic structures, was introduced into the current scientific discourse by Martin Kemp. Kemp introduced his basic idea of “structural intuition” in several articles published in the journal *Nature*, and later in a lecture on *Structural Intuitions in Art and Science* (16 December 2002).² In the introduction to his work *Visualizations* (2000), which is a collection of his essays published in *Nature*, Kemp discusses his concept of structural intuition. According to Kemp, visualization, or the “act of seeing,” is fundamentally a structural intuition which, as such, could develop into a tool of primary or *pre-logical visual understanding* of phenomenal structures:

Looking across the wide range of images in this book, the immediate impression is diversity. But underneath the varied surface run some constant currents in our human quest for visual understanding. The most enduring of these currents is our propensity to articulate acts of seeing through what I am calling “structural intuitions”. There is always a danger in offering a compact phrase as a summary of a complex concept, but its deliberately double reading retains openness that works against its becoming too formulaic. It is double in the sense that the “structures” are both those of inner intuitive processes themselves and those of external features whose structures are being intuited. (Kemp 2000, 1)

Kemp emphasizes two essential features of structural intuition that relate primarily to the epistemology of this fundamental notion: structural intuition constitutes first of all a visual and, as such, a pre-verbal understanding, and secondly it implies the *resonance* between inner intuitive processes and the external phenomenal structures that are perceived intuitively. This resonance between inner-intuitive and external-phenomenal structures refers to a process of epistemological intuition, constituting a subjective *insight* into the external phenomenal structures, and is, as in the case of intuitions in celestial mechanics, predicated on their immediately sensory or merely visualized *presence*. In “structural intuition” Kemp observes the binding or synthesizing function of an epistemological principle built upon a constant resonance between the structures of internal-subjective intuitions and that of the perceived external-physical phenomena: “The structures of the external world within which we need to operate ... are those with which the internal structure of intuition has been designed to resonate, continuously reinforcing and retuning themselves in a ceaseless dialogue of matching and making” (2000, 1-2).

The intuition of external mechanical structures is inevitably a free spatial intuition. Both the (invisible) latency of static as well as the visibility of dynamic structures in the phenomenal world ultimately relate to free-spatial structures, as shown particularly in the vectorial representations of forces and their constellations. In a dynamic phenomenon such as the free gravitational fall of objects, the vertical structure of the gravitational force becomes *visible*. From this direct experience and from the intuitive idea of the sphericity of the Earth, the centripetal nature and structure of terrestrial gravitational attraction is derived by a *dynamic structural intuition*. But when we try to infer the centripetal structure of gravity solely from static phenomena such as the invisible latency of gravitational force within the Earth holding its parts together and from the sphericity of the Earth, we reduce the material form of the Earth to a *free-spatial* geometrical form of a sphere whose radius vectors represent the *structure* of centripetal-gravitational attraction. Similar to the gravitational phenomenon, the structure of an inertial motion—as a linear and uniform motion—is *visualized* by free-spatial dynamic-structural intuition, regardless of whether these intuitions are based on the immediate visibility of an earthly phenomenon or merely on the mental image of a truly free-spatial celestial phenomenon. The *resonance* between internal-intuitive and external-phenomenal structures which constitutes the epistemological principle of structural intuition results primarily from a modal or structural identity of free space between its merely *a priori* representation and its *a posteriori*, i.e., tangible reality. The apodicticity of *a priori* intuitive cognition of static and dynamic structures can be attributed to this structural or rather ontological identity of free space on which

both the *a priori* visual intuitions as well as the real existence of these *phenomenal* structures are predicated. The intuition of mechanical structures as free-spatial structures is necessarily preceded by a primary intuition of free space in which alone they *occur* or can be constructed. That the linearity and uniformity of a *real* inertial motion can be conceived, i.e., visualized, in an *a priori* structural intuition is based on the fact that this dynamic structure—as a free-spatial structure—does not manifest any modal or ontological difference between its *a priori*-intuitive conceivability and its *a posteriori* reality. The subjective-intuitive design and objective-phenomenal emergence of this and similar mechanical structures follow the same geometric and mechanical principles, all of which constitute free-spatial-structural principles.³

Structural intuition thus constitutes an epistemological method that does not impose an *a priori*-intuitive visualized structure on phenomenal reality, but *looks* cognitively into the visible and unseen, i.e., latent structures in phenomena. This method is basically an intuitive co-determination of phenomenal structures from the principle of modal and ontological resonance between internal-intuitive and external-phenomenal structures. As an epistemological tool, structural intuition enables us critically to reexamine the intuitive and deductive knowledge underlying the axiomatic foundations of sciences such as mechanics and optics.

3. Structure of Gravitation

Using the method of structural intuition, let us try to reexamine the above problem of infinite or boundless extension of particular gravities that Newton attributed to his notion of universal gravitation. The structure of terrestrial or lunar gravitation can be intuitively derived, i.e., visualized, from the verticality of static forms and constructions and the dynamic fall of objects to Earth as well as from the sphericity of these celestial bodies. From these two facts or premises (that can be reduced to free-spatial geometrical forms), we are able to visualize the structure of terrestrial or lunar gravitation in a geometric intuition:⁴

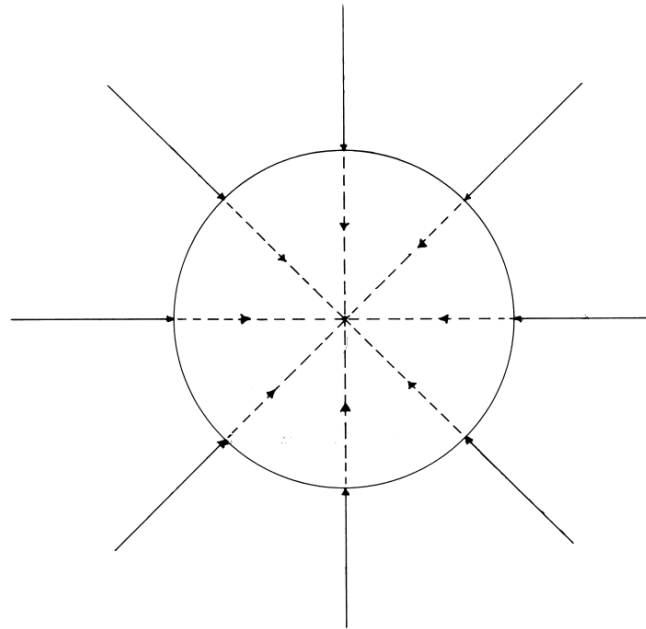


Fig. 1. Structural Intuition of Gravitation.

This structural intuition relates solely to a geometric-vectorial force structure. However, the nature of

gravity or its material causality cannot be perceived intuitively, as discussed earlier. Gravity is conceived here not as a material, but merely as a mechanical phenomenon; i.e., this natural phenomenon transcends the contextuality of physics as material science. The intuitive visualization of gravitational force structure apparently has only the *domain of effect* and not the domain of the essential, i.e., material causation (of gravitational force) at its disposal. In other words, the geometric-mechanical representation of gravity *masks* its true physical or phenomenal reality (which is inexplicable in the framework of mechanical philosophy) in a scientific contextuality. In classical Newtonian mechanics the mechanical-structural intuition of forces operates largely with geometric-mechanical figuration of forces *within the domain of effect* as represented in geometrical vectors and their various compositions and constellations. However, according to Newton, the gravitational effect alone, whose mechanical cause is unknown or not knowable, proves the existence of gravitational force and can be accepted as a sufficient premise for all true deductions of gravitational phenomena in the context of Classical Mechanics.

For the material causality of gravitational attraction and action at a distance remain unknown, making the idea of a real gravitational sphere that surrounds the solid Earth and its *infinite centrifugal diminution* in space even more difficult to comprehend. The gravitational sphere should therefore be imagined, i.e., intuitively visualized as a sphere of action in free spatial extension, whose strength or intensity diminishes centrifugally in accordance with an Inverse-Square Law. The infinite extension of Earth's gravity can be imagined only along with a centrifugally infinite dilution of the terrestrial gravitational sphere which constitutes its centrifugal extension, as discussed above:

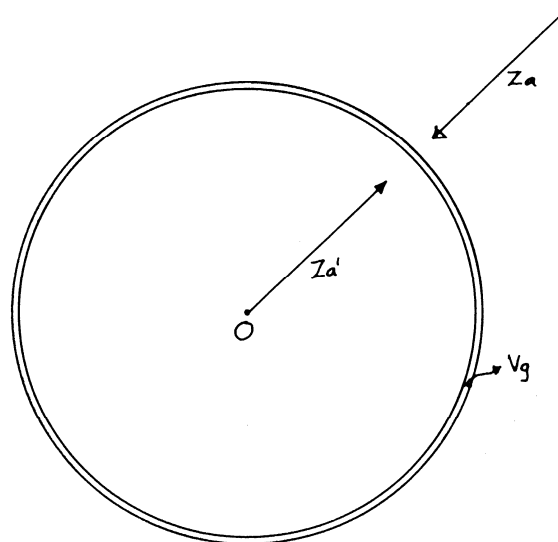


Fig. 2.⁵ Gravitational Bounds.

Z_a = Centripetal Attraction; $Z_{a'}$ = Centrifugal Extension; V_g = Gravitational Bounds

The infinite or boundless extension of a centripetal force cannot be visualized in a structural intuition, particularly when this force has a *centrifugal* diminution. It can be seen here how the nature of particular gravity is opposed to the *structure* of its infinite expansion, a notion that has been speculated on in the context of universal gravitation. The only empirical and experimentally proven fact in this process of structural intuition is the centripetal pull of gravity which directly discloses the nature and structure of this force phenomenon, and not its infinite diminution and expansion that are speculated largely *mathematically* in

universal gravitation. With this fact as a starting point we will not reach an intuitive notion of infinite universal gravitation, but only the idea of a particular and spatially bounded gravitational sphere.

There is no historiographical evidence of whether Hooke explicitly took the centripetal attraction of gravity in his intuitive understanding of particular gravitational spheres into consideration, or whether Newton merely overlooked or ignored the nature of gravity as he hastily came to the conclusion of universal gravitation from the given premises of particular gravitational spheres and their mutual attraction. According to Westfall, Hooke's intuition of particular gravity was based on the principle of congruity of material substances, especially that of fluids; i.e., for Hooke, gravitation and congruity of material substances constitute analogous, or rather identical, phenomena. Newton, in contrast, appeared to be influenced by the ideality of geometric-mathematical forms in his intuition of universal gravitation, for example a force vector that, as a free-spatial geometrical form, can extend infinitely. In addition to the directly observed mechanical effects such as the gravitational fall of objects to Earth, Newton seems to have drawn on geometric-mathematical speculations of a universal extension of gravity.

In Newton's system of classical celestial mechanics the doctrine of universal gravitation created a more or less scientific context which was drawn rather upon a belief—on speculative accounts of this doctrine—and under which all the evidence of terrestrial and celestial gravitational phenomena was subsumed. The early modern notions of particular gravities, especially those of Hooke, were overtaken by the doctrine of universal gravitation and subsequently, in the process of its historical establishment, suppressed or marginalized.

To extricate the gravitational phenomenon from all the scientific beliefs that relate more to the speculative ideas of its nature and structure, it is necessary to treat gravity again as a purely mechanical phenomenon by deriving it from mechanically tangible evidence alone. Hooke's idea of the mutual attraction of heavenly bodies presupposed the existence of particular gravitational spheres within which gravitational attraction takes place. However, the given empirically observed and experimentally proven facts that speak for such a nature of particular gravitational attraction in the cosmos are restricted mostly to terrestrial-mechanical phenomena. The nature of the mutual attraction of gravitational spheres has been derived from them. The other evidence in celestial mechanics such as the anomalies observed in planetary movements is, strictly speaking, hardly sufficient to project the nature and principle of attraction of particular gravitational spheres to all possible gravitational spheres of celestial bodies within the solar system and to define the nature of their mutual *relation* as an attraction. In this way, a belief seemed to underlie Hooke's ascription of mutual attraction to celestial bodies that lay within the bounds of the solar system. For Newton, the nature of gravitation as attraction, by which all particular gravitational spheres are connected together in space, was an important premise for his geometric and mathematical demonstrations of Kepler's laws of celestial mechanics and for the inverse-square law of gravitation originally proposed by Hooke. However, the geometric-mathematical demonstrations in *Principia* do not suffice to elevate the notion of the unbounded extension of gravitation from a doxastic to an epistemic status.

4. Tides as Gravitational Phenomenon

The fact that Newton, with his theory of universal gravitation, was able to explain the terrestrial-mechanical phenomenon of tides is still held to be the most pertinent empirical evidence for the existence of universal gravitation and for legitimizing Newton's theory. For Newton, the tidal phenomenon proves the gravitational attraction of the Moon and the Sun on Earth. As is generally known, Newton inferred the gravitational attraction of the Earth on the Moon from a direct experience, namely the free gravitational fall of objects to Earth. In

Newton's intuition earthly gravitation extended beyond its impact on nearby objects on Earth to the heavenly bodies at infinite distances, from which the idea of universal gravitation was born. For empirical proof of universal gravitation in which all heavenly bodies attract each other, it was necessary empirically to observe and confirm the attraction of other celestial bodies on the Earth. The two celestial bodies that can demonstrate such reciprocity of gravitational attraction are primarily the Moon and the Sun—the former by its proximity to Earth and the latter by the strength of its gravity. In *Principia* Newton demonstrated how tides can result from the lunar-gravitational attraction on the oceans on Earth. This empirical evidence proved to be extremely convincing, especially when Newton could explain how the spring tides are caused by the combined gravitational pull of the Moon and the Sun on Earth. Newton's theory of tidal phenomena is normally presented in textbooks of mechanics as follows:

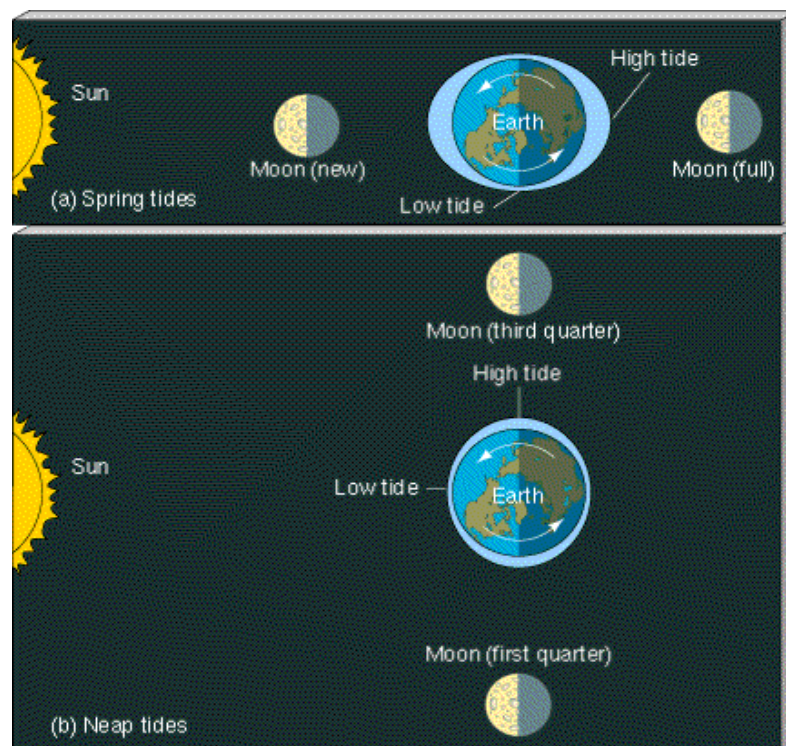


Fig. 3. Tidal Phenomenon.

Fig. 3 shows the bulging of the surface of oceans (and possibly, large lakes) by the varying effect of lunar and solar gravitational attraction, thus resulting in the spring and the neap tides. The (Newtonian) law of inertia explains the emergence of the tidal phenomenon on the other side of the Earth. According to Newton, the lunar- and solar-gravitational pulling of water causes high tide on oceans that are nearer to the Moon and in alignment with the Sun, and low tides on oceans lying further away, as represented in this figure. When, due to the rotation of Earth, the effect of lunar gravitational attraction on oceans recedes, it produces a low tide. In *Principia*, Newton demonstrated how the regular diurnal recurrence of the tidal phenomenon, of high and low tides, on ocean or sea shores can be explained through the principles of celestial mechanics, namely the law of universal gravitation and the law of inertia, along with exact calculations of the positions and constellations of the Earth, Moon, and the Sun.

Newton's explanation of the lunar and solar gravitational effect on ocean tides is based on the principle of

hydrostatic equilibrium. Here it appears that Newton draws on a *naive* analogy between the terrestrial gravitational attraction which causes the vertical fall of solid or fluid objects to Earth, and the equally vertical, i.e., centrifugal rising of water on oceans—in the form of an upward bulging of ocean surface—due to the combined effect of solar and lunar gravitational attraction. In the history of the research on tides, there were numerous undertakings to seek other terrestrial-mechanical causes for this natural phenomenon, both in addition and also in opposition to the generally accepted explanation of Newton. Many anomalies were discovered in the tidal phenomenon at different places on Earth that seemed to contradict Newton's law of tides and its ability to predict their nature convincingly. But the unfailling periodicity of the diurnal and regular recurrence of the tidal phenomenon and its *causal* relation to the celestial-mechanical constellation between the Earth, Moon, and the Sun clearly show that tides and the exact frequency of their formation can ultimately be traced back to the combined gravitational effects of the Moon and the Sun on oceans.

As fig. 3 illustrates, the upward bulging of the ocean surface by the gravitational attraction of the Moon and the Sun is a hydrodynamic phenomenon. For water is a fluid whose surface cannot be lifted overall evenly by the vertical, i.e., centripetal attraction of a gravitational force.⁶ The rising of ocean or sea level in the form of an upward bulge (supposedly during a high tide) cannot occur at its edges or periphery, i.e., on shores, but is likely out to the sea where the water is deeper. Besides the hydrodynamic-structural principle that determines the behaviour of ocean surfaces during tides, the depth of water in the ocean constitutes a crucial fact. According to the law of gravitation, the deeper, more massive water bodies in oceans are more strongly attracted than the shallow waters on shores. The tidal phenomenon, however, occurs on sea shores mostly in a succession of high and low tides.

Newton's explanation seems to be founded on an inadequate or rather inconsistent structural intuition of the tidal phenomenon. If we, in our intuitive visualization of the tidal phenomenon, focus on the *structure* of the lunar and also terrestrial gravitational attraction along with the shape of these celestial bodies and the exact hydrodynamic-structural behaviour of water in oceans, we would wonder why the gravitational (upward) bulging of the sea surface in an instance of the tidal phenomenon produces *at first* a high tide at the seashore, followed by a low tide. Let us now try to reexamine the *possible* structural intuition of the tidal phenomenon by means of a few hydrodynamic models. First, we will try to *visualize* the tidal phenomenon caused by the mere vertical attraction of lunar gravitation on a flat ocean surface. We are not considering the exact centripetal structure of (lunar and terrestrial) gravitation and the sphericity of ocean surfaces on Earth here.

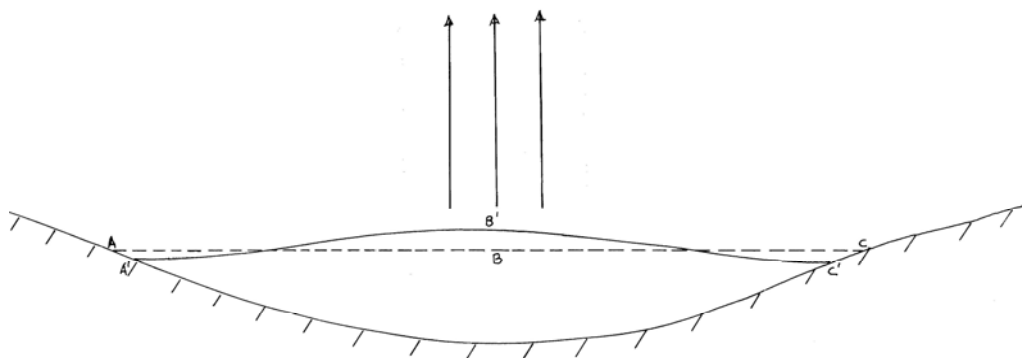


Fig. 4.

Fig. 4 represents the section of a sea or a large lake. *ABC* (broken line) shows the original horizontal water

level. *A'B'C'* shows the deformation of the water surface when the water body is *attracted* by lunar gravity. It creates a bulge towards the middle of the sea and, as a consequence, the sea recedes at the shores resulting *at first* in a low tide. This behaviour of the water body or this deformation of the water level under the effect of lunar gravitational attraction can be explained, on one hand, by hydrodynamics and, on the other hand, by the fact of the deepening of sea towards its middle part where it is subject to a much stronger lunar gravitational pull, as well as by the suction of water from the shores due to this gravitational upwards bulging of the ocean surface. In this representation of tides, some of the structural characteristics, in terms of the original premises, that are decisive for the tidal phenomenon are not taken into account, namely the centripetal structure of the lunar and terrestrial gravitational attraction and the original spherical form of the sea surface in accordance with the sphericity of Earth—a structural characteristic that can again be traced back to terrestrial gravity. Here we observe how the tidal phenomenon, even without these premises, occurs differently as it is normally experienced. When the sea surface bulges *upwardly* due to the combined effect of lunar and solar-gravitational attraction, it should invariably result in an ebb, i.e., falling tide at shores.

We determine the behaviour of the water body in this model of the tidal phenomenon intuitively by taking the fluid mechanical properties of water into account.⁷ An empirical observation of this phenomenon, i.e., the deformation of the water level by the gravitational attraction of the Moon and the Sun, would be a difficult undertaking. As the sea or ocean surface bulges only slightly in the tidal phenomenon, it is—also due to the initial sphericity of the ocean surface and its enormous area over which the tidal bulge of water stretches—almost impossible to observe. But an analogous natural phenomenon demonstrates clearly the above discussed intuition of tides, namely the *Tsunami*. The first stage of a Tsunami is the emergence of a huge bulge of ocean surface due to an earthquake in the ocean bed. While the ocean surface is *supposed* to bulge upwards by the combined gravitational pull of the Moon and the Sun in a tidal phenomenon, a Tsunami deforms the ocean in a similar form by the water waves released by an earthquake. Apart from this difference, both phenomena are structurally analogous, i.e., they are comparable in their hydrodynamic-structural effects. Since the upward bulging of the ocean surface in Tsunami, as compared to the analogous formation in oceans during tides due to the gravitational pull, is not a gradual but a sudden occurrence, the resulting behaviour of the ocean surface on the shores can also be observed quickly, in a short period of time. The very first and most important symptom of the Tsunami is the relatively rapid recession of the water level along *the affected coastline*. At some coastlines (which are not far from the epicentre of the earthquake in the ocean bed) a significantly large withdrawal or recession of the ocean level—up to 100 meters—is observed in a short period of time. This directly observed natural phenomenon is clearly not analogous to a high tide, but to an ebb tide at ocean shores.

Both in the case of tides caused by the *celestial* (or extraterrestrial) attraction of the lunar and solar gravity on oceans, as well as in a Tsunami emerging from an earthquake in the ocean bed and the subsequent upward pressure of water waves, no volumes of water are produced and added to the ocean. The original volume of water body remains more or less constant within the range of Tsunami or tides, so that the upward bulging or curvature of the ocean level has to be compensated by a low tide at the shores. Rivers and lakes flood when additional volumes of water from streams and small rivers are added to them during a heavy and prolonged rainfall, as discussed earlier. Floods in rivers or lakes occur clearly in form of an *even rise* in water level and cannot be compared with the flood at shores during high tides.

Now we are facing a critical problem. When tides—especially the spring tides—are caused by a combined

gravitational attraction of the Moon and the Sun on Earth's oceans, they should necessarily occur in a *succession of ebb and flood* on shores—and not vice versa. But tides on shores are not normally observed in a succession of ebb and flood (analogous to the Tsunami), but conversely in a succession of flood and ebb. Corresponding to the observed succession of flood (high tide) and ebb (low tide) on shores during tides, the structure of the deformation of ocean surfaces—under the combined *effect* of the lunar and the solar gravitation—should be *visualized* differently, i.e., conversely. During tides, the ocean level on shores can rise in a flood or high tide only when lunar and solar gravitation together bring about a *downward or concave bulge* on the ocean surface, as shown in fig. 5.

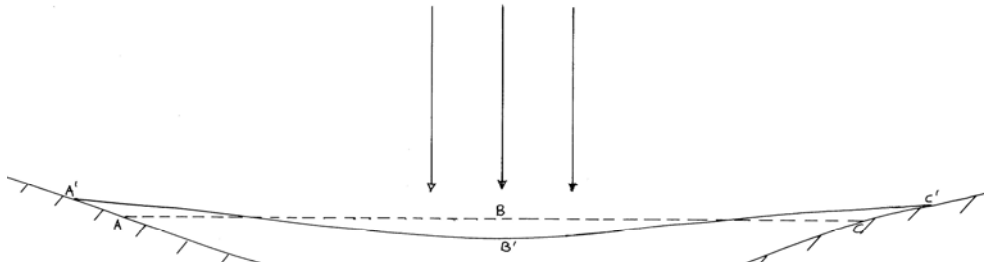


Fig. 5.

Fig. 4 represents the tidal phenomenon on a flat sea surface due to the mere vertical and parallel pull of lunar gravitational attraction. Even with these assumptions—without considering the true structure of the gravity and the sea level—we are able intuitively to visualize the hydrodynamic behaviour of the sea surface, i.e., the mode of deformation of the sea level under lunar gravitational attraction. However, if the centripetal structure of (terrestrial, lunar, and solar) gravitation and sphericity of the sea level on Earth as well as the sphericity of the Moon are taken into account in our structural intuition of tidal phenomena, we will see how the above-observed aspects of tides under the influence of lunar, solar, and terrestrial gravity become much more evident. The following model represents the true sphericity of the sea or ocean level on Earth and that of the surface of the Moon, both approaching each other *tangentially*, as well as the centripetal structure of gravitation.

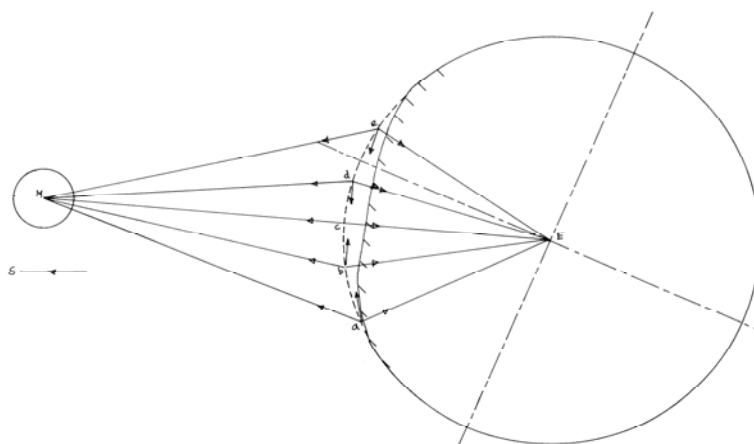


Fig. 6. Centripetal-Vectorial Structure of Lunar and Terrestrial Gravitational Attraction on the *Spherical* Sea Surface.

Fig. 6 shows the actual centripetal-vectorial structure of lunar and terrestrial gravitational attraction on the sea whose surface, just like Earth's surface, is spherical due to the centripetal pull of terrestrial gravitation. From this almost exact structure of the gravitational attraction, it is easier to infer or intuitively imagine how an upward bulge on the sea level brings forth first the withdrawal of the water and thus a low tide at sea shores. At the intersecting points of the centripetal-gravitational vectors, namely the points a , b , d , and e , the resultants of the lunar and terrestrial gravitational forces are directed towards the center of the curvature c . Due to the sphericity of the Earth and the Moon, the gravitational force of the Moon is reduced from c to e and from c to a —i.e., from the centre of the tidal bulge to the shores or from deep to shallow sea. In accordance with the sphericity of sea surface, the upward tidal bulge should spread equally in all directions—i.e., in a circular form. Water from the periphery of the tidal bulge is drawn towards its centre. Water at shores is drawn easily—as compared to that of deep sea—as the sea is shallow at shores with the distributed mass of water being relatively low. The following figure represents the hydrodynamic behaviour of the sea when it bulges upwardly due to the lunar-gravitational pull.

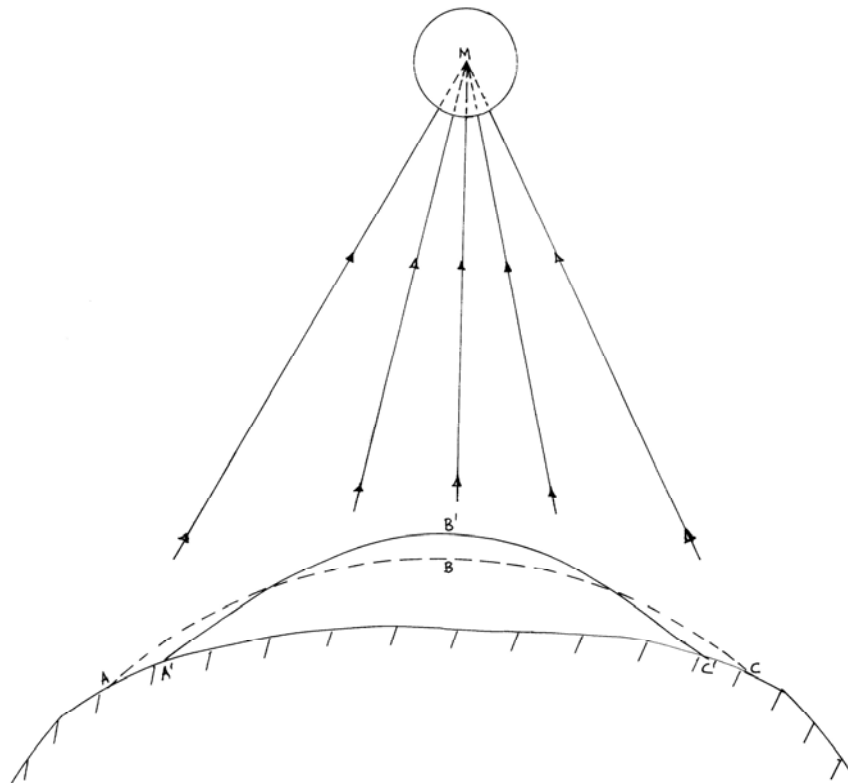


Fig. 7. Deformation of the Spherical Sea Surface under Lunar-Centripetal Gravitational Attraction.

ABC shows the actual spherical form of the sea surface and $A'B'C'$ its deformation, i.e., the upward bulge of the sea by the lunar-centripetal gravitational attraction. Because of this upward bulge the sea recedes on shores, thus resulting in a low tide. If, on the contrary, a high tide or a flood should emerge first on shores (followed by a low tide), the lunar-gravitational action should be repulsive, causing a downward bulge or depression on the sea surface as shown in fig. 8.

As discussed before, the upward or downward bulge of the originally spherical sea level is not easily observable. The only empirical evidence available is the temporal succession of high and low tide. A somewhat

analogous but common phenomenon would be the waves on seashores, which are brought about by the pressure of a strong sea wind on the sea surface. Unlike a high tide, sea or ocean waves do not produce a stable flood even for a short period of time on shores, but the dynamics of the tiny flood on shores and its emergence through the intense pressure of wind on the sea surface can be directly observed in a short period of time.

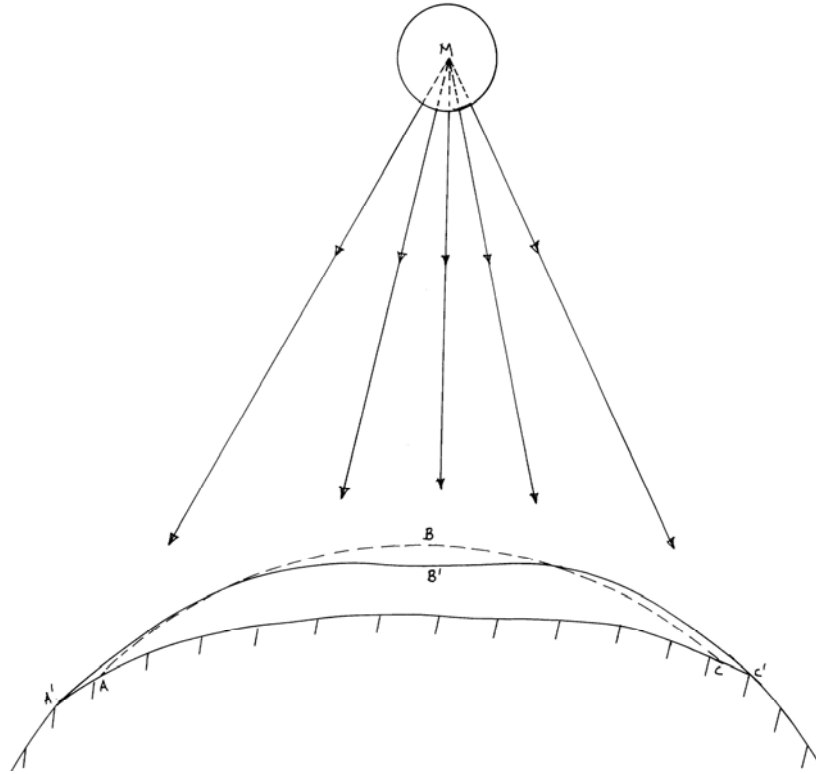


Fig. 8. Deformation of the Spherical Sea Surface under Lunar-Centripetal Gravitational *Repulsion*.

In their intuition of the tidal phenomenon, Newton and his followers seemed to have imagined an upward bulge of sea surface that extends up to seashores, as the common representations of the tidal phenomena due to the lunar and solar attraction (as in fig. 3) show. This proves to be a fitting example of how, in order to confirm a speculative notion in haste, a directly observed natural phenomenon, namely the rise of sea level on shores during tides, is extrapolated, i.e., extended from shores to the deep sea, without taking sufficiently into account the mechanical, i.e., gravitational and hydrodynamic structures, underlying the tidal phenomenon. The entire sea surface cannot rise evenly under the lunar and solar attraction, firstly because the volume of the water bed is enormously heavy so that no extra terrestrial gravitational force can lift it entirely against the terrestrial gravitation, and secondly because the centripetal structure of lunar and terrestrial gravity and the sphericity of the Moon and the Earth will cause an upward bulge of sea surface that spreads in all directions—in the form of a circle on the spherical surface of ocean and, as a result, draws the shallow water from the shores more easily than the water from deep sea. An entire extension of the upward bulge of sea surface up to the sea shores would presume a different *structure* of lunar gravity, as shown in fig. 9.

The lunar-gravitational structure shown in this figure presupposes that the gravitational sphere of the Moon surrounds the ocean surface in the form of a concave spheroid. This is clearly contradicted by the centripetal structure of lunar gravity.

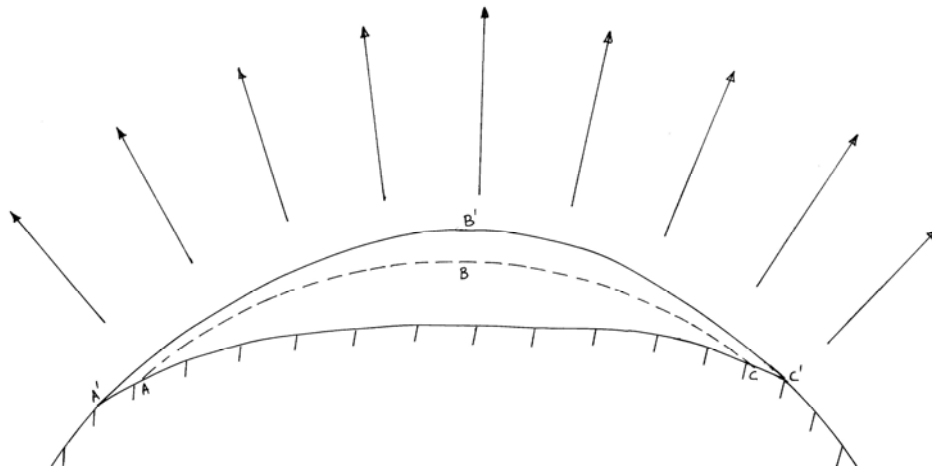


Fig. 9.

Besides all these facts that apparently speak for a gravitational repulsion (that alone can bring about the observed succession of high and low tide), there is yet another hydrodynamic phenomenon which cannot be explained through the generally accepted theory of tides. Once again we refer back to the structural analogy between tides and Tsunami. Deliberately overlooking the fact of the necessary receding of sea level on shores (which distinguishes the Tsunami from the tidal phenomenon) during the upward bulging of the sea surface, we assume that the upward bulging of sea surface—in accordance with Newton's explanation—extends up to the shores, thus initially producing a high tide. Due to the rotation of Earth the effect of lunar gravity on the sea surface changes, i.e., ceases to exist. This leads necessarily to the dissolution of the upward bulge of the sea and consequently to a *second phase of flood or high tide*—and not a low tide—on sea shores. A similar phenomenon has been observed during Tsunami, in which a huge flood occurs on coasts after the dissolution of the substantial upward bulge of sea (caused by an earthquake in the sea bed). In analogy to this oceanic, i.e., hydrodynamic phenomenon in a Tsunami, there should be a succession of two phases of floods during tides—and not a succession of high and low tide as normally observed. But when the tides are caused by a lunar-gravitational repulsion on the sea surface—as we could visualize the behaviour of the sea surface during tides by the appropriate gravitational- and hydrodynamic-structural intuition, it is easy to understand how a high tide occurs first and is followed by a low tide when the downward bulge of sea surface (supposedly caused by lunar-gravitational repulsion) is dissolved.

These facts regarding the tidal phenomenon should appear evident to anyone who is acquainted with the hydrodynamics and the nature and structure of gravitational attraction. Why were they overlooked in the modern history of tidal research since its origins in Newton's *Principia*? We may find two specific reasons for this, namely a *false image* of the original tidal phenomenon that has been established historically, and the almost paradigmatic conviction of the *singular* nature of universal gravitation in terms of a centripetal attraction. Since the success of the Newtonian explanation of the tidal phenomenon in *Principia*, the hydrodynamic deformation of the sea surface during tides, as shown in fig. 3—a standard image of the tidal phenomenon in almost all the textbooks of mechanics—is visualized in a manner which is neither appropriate nor precise. In contrast to the conventional image of the deformation of oceans or seas during tides, the surface of the Earth is not completely covered by oceans (though the equator, shown here as the periphery of the circular cross section of the Earth, lies largely in oceans). The sea level is actually the lowest level on Earth's surface, surrounded by land, whether low

or high terrain. The usual representation of the tidal phenomenon (as in fig. 3) gives the impression that through the lunar-gravitational attraction on one half of the globe (as represented on the equatorial plane of the Earth's cross-section), the upward bulge of seas extends up to the shores and consequently withdraws water only from the longitudinal periphery of the globe (which is not affected by the lunar attraction and where it leads to a low tide). Oceans, seas, and large lakes that are affected by tides should be considered individually, since they are separated from one another by the surrounding land and mountains. *For this, we first and foremost need to focus on the surface of oceans or seas and their contours, i.e., shores on Earth, as seen from above—like in an architectural plan—instead of representing the tidal deformation of oceans on an elevation or equatorial or other cross-sections of Earth.* That is to say, we should intuitively visualize the tidal phenomenon on spherically extended surfaces of seas and their shores which lie at the lowest level on Earth and surrounded by higher land and mountains. However, the fallacy of the conventional representation of tidal phenomena based on the Newtonian theory can easily be demonstrated in an equatorial cross-section of the Earth (or plan of the Earth as seen from a point above one of the poles) showing the actual *cross-sectional* extension of the ocean levels surrounded by *higher* land terrains and mountains. Fig. 10 shows a model of such a cross-sectional view of the Earth, although not in exact proportions. If this or a similar cross-section is used in the demonstration of tidal phenomena, it would show a different result, i.e., a succession of ebb and flood tides:

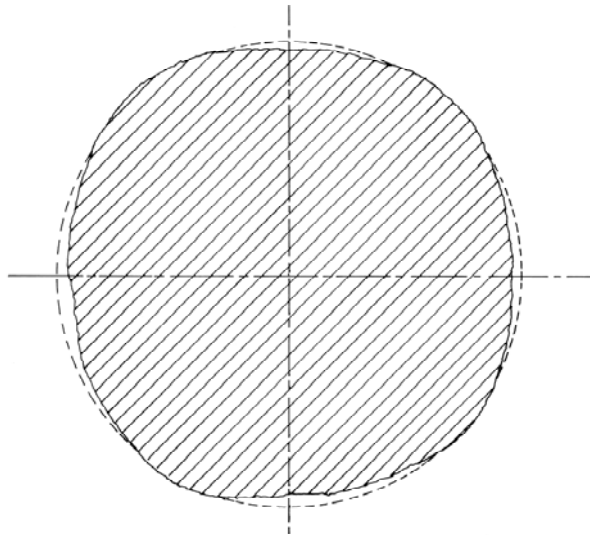


Fig. 10. A Representational Model of Earth's Cross-Section.

If the Earth's gravity can cause and maintain the sphericity of vast ocean surfaces, the water body of oceans as a whole is subject to the laws of hydrodynamics (as demonstrated in Tsunami), i.e., to the gravitational formations and deformations.

During the upward bulging of the sea surface in deep sea during tides, the shallow water at the nearby seashore will recede first, before the rising of water level at the tidal bulge leads to the withdrawal of water from more distant areas of deep sea and shores. Here we cannot simply assume that the upward bulge of the sea surface on a specific area of the sea draws water from distant areas of deep sea that are relatively unaffected by the lunar attraction, and sends it as a tidal wave to the nearby shores. The lunar-gravitational attraction that causes the upward bulge of sea level and maintains it for a short period of time must also necessarily prevent the simultaneous dissolution of the upward bulge of the sea in tidal waves that brings about a high tide on

shores. Moreover, the sphericity of the Earth and the Moon and the centripetal structure of their gravitational attraction presuppose a centrifugally-circular extension of the upward bulge of the sea level during tides, in which all areas of the sea—both at deep sea as well as at shores—near the periphery of this circular extension of the upward tidal bulge of the sea will be equally affected. As a consequence, water is drawn from deep sea areas, while at the shores the sea level recedes.

The idea of universal gravitation is predicated solely on the nature of attraction in gravitation. The fact that two particular gravitational spheres of the heavenly bodies—similar to magnetic and electromagnetic spheres—can also repel each other was excluded from the axiomatization of universal gravitation. The main premises of Newtonian celestial mechanics, from which Kepler's laws in the *Principia* were demonstrated mathematically, were the principle of inertial motion of the planets, the law of universal gravitation, and the inverse-square law of gravitational attraction. The mutual attraction of particular gravitational spheres that may lead to the collapse of the universe (to a centre) was thereby counterbalanced by the inertial-tangential movement tendency of the orbiting celestial bodies and the endless expansion of the universe. In order to confirm universal gravitation Newton was looking for empirical or experimental evidence in the context of terrestrial mechanics. All natural objects on the Earth are subjected to centripetal gravitational attraction. The tidal phenomenon or the succession of flood and ebb at the sea shores and its frequency in accordance with the position and constellation of the Moon and Sun appeared, however, to demonstrate a reciprocal extra-terrestrial, i.e., solar- and lunar-gravitational attraction on seas. The rising of sea level at shores during high tides seemed to have been hastily equated to the lunar-gravitational lifting of sea level on Earth. Newton seemed to have focused merely on a celestial-mechanical causation of the tidal phenomenon, namely the rise of sea level due to the combined gravitational attraction of the Sun and the Moon, thereby overlooking the actual hydrodynamic behaviour of sea surfaces under the gravitational pull when he attributed the phenomenon of high tide (i.e., rising of sea level on shores during tides) to the *supposedly* upward bulging of deep sea surface.

To sum up, if we could integrate in our intuitive visualization of tidal phenomena the nature of terrestrial and lunar gravitational attraction and their centripetal structures together with the sphericity of the Moon and the Earth—and likewise, the sphericity of the sea—as well as the hydrodynamic-structural behaviour of the water body under gravitational attraction, we would realize that the lunar- and solar-gravitational attraction on the Earth's oceans, seas and lakes can only lead to a succession of low and high tides. Since the actual tidal phenomenon occurs conversely—in a succession from high to low tide, it seems that tides are caused by an extra-terrestrial gravitational *repulsion* on the surface of oceans and seas. In other words, if the observed succession of high and low tides are caused by the lunar- and solar-gravitational effect on Earth, the nature of such an effect has to be a repulsion and not, as commonly thought, an attraction. This fact, which appears quite obvious both in our immediate experience as well as in our intuitive visualization, seemed to remain unnoticed or strategically overlooked in the history of tidal research. For it is fundamentally opposed to the hegemony of universal gravitation to which, unlike other analogous forces acting at a distance such as magnetism or electromagnetism, only the nature of attraction is ascribed. Is there any reference to gravitational repulsion in the modern history of research on the tidal phenomenon which considers it as a possible cause of tides on sea shores? A striking example would be a cursory observation by Sir George Howard Darwin in his seminal work "The Tides": "It would seem then as if the tidal action of the Moon was actually to repel the water instead of attracting it, and we are driven to ask whether this result can possibly be consistent with the theory of universal gravitation" (1899, 161-62).⁸

However, Sir Darwin did not elaborate on this important point further in his work. As is well known, he tried to subsume this clearly observed anomaly in Newton's demonstration of the tidal phenomenon under—instead of contrasting it with—the law of universal gravitation.

If the effect of the Moon on the tidal phenomenon is determined more by gravitational repulsion than attraction, the legitimacy of the law of universal gravitation according to which celestial bodies only attract each other can be called into question. This does not necessarily relate to an (unknown) causality of gravitational attraction at a distance or to the question whether gravity is, in line with the Newtonian Classical Mechanics, a mechanical phenomenon or to be determined, following Einsteinian Relativity, primarily as a geometrical construct. It is the nature of the action between two gravitational spheres in their mutual interaction in space which ought to be re-examined. This constitutes a problem in the domain of gravitational effects which can be treated only in the context of classical mechanics. That the tidal floods or the succession of high and low tides can emerge only by a mechanically repulsive force on ocean or sea surface would appear to us as evident as an everyday phenomenon such as the momentary rise of water level on the shores of a narrow backwater when a relatively large boat passes through the canal (in which the downward-curved lower part of the boat presses down on the water surface). The hydrodynamic principle of the tidal flood or high tide can be explained only by means of a repulsive force pressing down on to the sea surface.

5. Interaction between Gravitational Spheres

The nature of the gravitational force as a centripetal attraction is determined principally by the free fall as well as by the mass of objects as experienced or felt within the gravitational spheres of celestial bodies. This applies—in a limited sense—also to a magnetic field in which iron is attracted to a magnet. However, magnetic or electromagnetic fields are bipolar in nature and therefore attract or repel each other. Although gravity as a force acting at a distance is more or less analogous to magnetism or electromagnetism, only the nature of attraction has been ascribed to it. We become aware of the centripetal-attraction of particular gravitational spheres by constantly experiencing the effect of terrestrial gravity on us and on surrounding objects. But we can hardly observe directly the nature of interaction between two particular gravitational spheres in space—whether it is always a mutual attraction or can also be a mutual repulsion. The appearance of *De Magnete* in 1600 by William Gilbert initiated widespread speculation about a plausible analogy between magnetism and gravity, particularly in the context of early modern classical mechanics. Johannes Kepler made an attempt to ascribe the bipolarity of terrestrial magnetism to the nature of gravity in order to explain the libration of planets in their elliptical orbits. Kepler tried to explain the periodic approach of the planet to the Sun on its way from aphelion to perihelion and its mysterious distancing from the Sun—on the way from the perihelion to the aphelion of its elliptical path—by an alternating bipolar-gravitational attraction and repulsion of the planet towards a unipolar gravitational force (or field) of the Sun:

... every planetary body must be regarded as being magnetic, or *quasi*-magnetic; in fact, I suggest a similarity, and do not declare an identity. It must be assumed also that the line [axis] of this force [*quasi*-magnetic for the planets] is a straight line having two poles, one retreating from the Sun, the other pursuing it. This axis, through an animal force, is [constantly] directed approximately towards the same parts of the Universe. As a result, the planet, carried along by the Sun, turns towards the Sun, first its retreating [repelling] pole, then its pursuing [attracting] pole. As a consequence we have the increase and decrease in libration. I cannot conceive any other means [of producing it]. For both in retreating from, and approaching, [the Sun, the planet] does so according to the measure of the angle which the line [drawn] from the Sun to the centre of the body [of the planet] makes with the axis [of the planet], and this *ceteris paribus*. This is what I have

previously said in the geometrical hypothesis: it is attested by observation, that the planet performs librations, and particularly that during libration it moves slowly in the vicinity of the apsides of the epicycle, and more quickly in the mean positions; whereas in its *raptus* round the Sun, it moves slowest at aphelion, the quickest at perihelion. (Koyré 1973, 252-53)

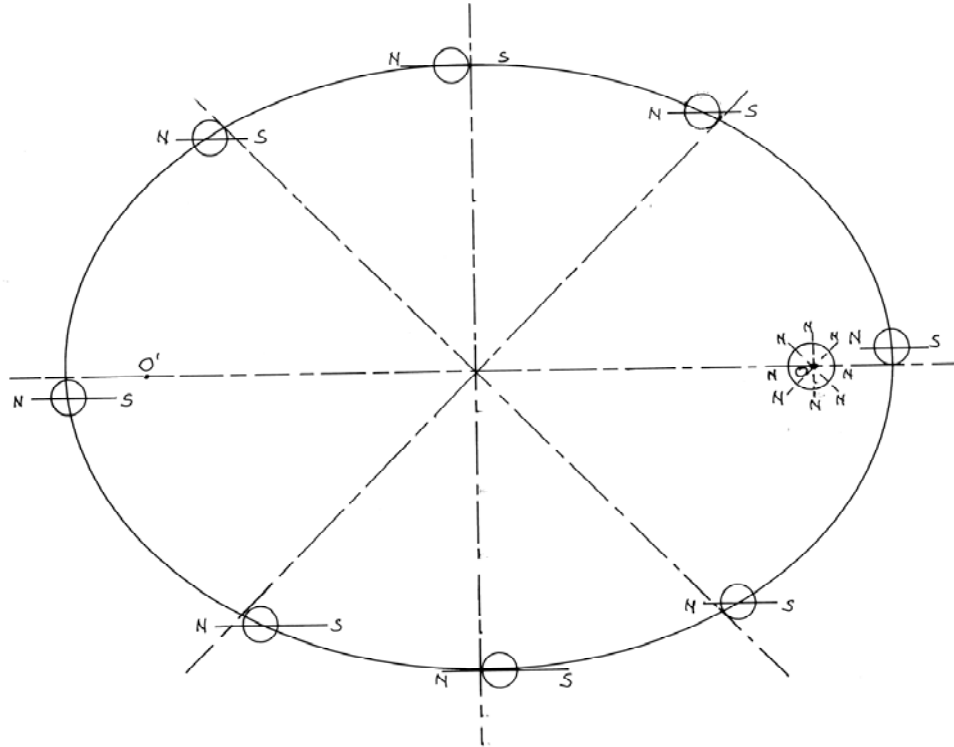


Fig. 11.⁹ Kepler's Explanation of Planetary Libration.

The idea of gravitational repulsion was not explicated in the previously discussed analogy by Hooke, but the principle of incongruity between matter points to an analogous principle of gravitational repulsion. While Hooke tries to explain the phenomenon of gravitation on the basis of the principle of congruity, which, through its nature of attraction, holds the parts of the celestial bodies together, it seems that his observation refers primarily to a principle of incongruity through which incongruent matter draws and defines its bounds against others:

In the brief pamphlet on capillary action with which he inaugurated his public career, Hooke advanced a principle important for the understanding of his later conception of gravity. The rise of water in narrow glass pipes, he asserted, is due to a decrease in the pressure of air on the water inside the pipes. The decrease in pressure arises from "a much greater inconformity or incongruity (call it what you please) of Air to Glass, and some other Bodies, than there is of Water to the same." Conformity or congruity he defined to be a "property of a fluid Body, whereby any part of it is readily united or intermingled with any other part, either of itself or any other Homogeneous or Similar, fluid, or firm and solid body: And unconformity or incongruity to be a property of a fluid, by which it is kept off and hindered from uniting or mingling with any heterogeneous or dissimilar, fluid or solid Body." To support the existence of such a principle, Hooke cited a number of phenomena. As a property of fluids it was well known; as many as eight or nine different fluids could be made to swim on each other in separate layers without mixing. Water stands on greased surfaces but sinks into wood; mercury, on the other hand, stands on wood but sinks into several metals. Incongruous fluids cannot be made to mix; when they are shaken together, they remain separated in drops. Thus water in air forms into spherical drops, and air in water into spherical bubbles. The pamphlet concluded by enquiring "Whether this principle well examined and explain'd, may not be found a co-efficient in the most considerable Operations of Nature?" (Westfall 1967, 244)

While the bounds of matter are extended through the principle of congruity, incongruent matter draws its bounds, i.e., demarcates against others, as most of the examples given in these observations of Hooke suggest. Both phenomena point to an ontic demarcation of matter, from which Westfall correctly concludes that Hooke's analogy could only attain the idea of spatially bound particular gravities and not the notion of a boundless universal gravitation. But Hooke's analogy seems also to demonstrate a gravitational repulsion. Particularly the incongruity between fluids shows how matter draws its bounds (of extension) against another incongruent matter through a principle of repulsion. The spherical formation of water in air and air bubbles in water refer to the centripetal structure of the demarcation of matter which is, as such, analogous to the above discussed demarcation of particular gravitational spheres.¹⁰ Hooke extends the principle of material demarcation, which he derives from the material principle of congruity and incongruity, beyond the bounds of celestial bodies into the surrounding ether that similarly draws its bounds against free space. This clearly shows that Hooke could envisage spatially bounded gravitational spheres beyond the material bounds of celestial bodies. His conception of the origin of universe was predominantly based on the principle of incongruity. (Westfall 1967, 249)

Matter defines its limits of extension both by the principle of congruity as well as by that of incongruity. Hooke's intuition has a characteristically material basis. As a committed empiricist and experimental philosopher, Hooke tended to derive the principle of gravitation from a material principle (of extension) and was therefore not able to go beyond the concept of particular gravities, as Westfall emphasizes. Newton's intuition of universal gravitation, i.e., the infinite extension of particular gravitational spheres, obviously had a mathematical basis. However, there are ample references in *Principia* and *Opticks* to how Newton originally sought to derive the principle of gravitation from material principles such as cohesion, chemical affinity, etc. and had—with regard to the material-bodily extension and the phenomenon of elasticity—a clear notion of a material force of repulsion (Boas 1952, 500 ff.). The idea of repulsion appears in Newton's notion in the form of a possible mechanical explanation of the force principles underlying the material embodiment, through which Newton, on the one hand, tries to establish an experimental basis for the unknown material causation of (inner-material and outer-bodily) gravitational attraction and, on the other hand, opposes all the speculative attempts in early modern mechanical philosophy—especially by the atomists—to explain the force of gravitational attraction at a distance:

NEWTON admitted that attraction might appear occult, since it was inexplicable; but he felt that it was better to explain cohesion by a force which, though its cause was unknown, could be shown to exist experimentally, than to explain it by the naive concept of hooked atoms, or by what he considered the genuinely occult property of relative rest between the parts. Similarly, it was nearer the truth, and a more empirical method of approach, to explain the elasticity of the air by postulating a force of repulsion between the component particles, rather than to imagine that the particles were shaped like hoops or springs. (Boas 1952, 510)

While analogizing between the chemical affinity or sympathy of certain substances—particularly acids—and the physical or material phenomenon of attraction, Newton comes close to the above discussed analogy between congruity and gravitational attraction as proposed by Hooke: "... in 1675 NEWTON was writing that 'some things unsociable are made sociable by the mediation of a third'; and in his letter to BOYLE he stated, 'There is a certain secret principle in nature, by which liquors are sociable to some things and unsociable to others'" (Boas 1952, 514).

And in his interpretation of the chemical solution—a phenomenon that is analogous to the congruity between fluids—Newton represents a theory of repulsion besides a theory of attraction as is to be particularly

observed in the elasticity of fluids:

Alongside his theory of attraction NEWTON developed a very important theory of repulsion. At first he had used attraction of different degrees to account for chemical solution; that is, particles of the solid were presumed to be more strongly attracted by the particles of the solvent than they were by one another, so that the cohesion of the substance was destroyed and it dissolved. Later he accounted for the diffusion of the solute particles by supposing a force of repulsion to exist between them once they were far enough apart so that the cohesive force of attraction was no longer operative.... The elasticity of fluids could best be explained in terms of repulsion between the particles. (Boas 1952, 515)

In this way, Newton explains the material extension of the body by the principles of attraction and also by that of repulsion of elementary material particles—such as atoms or molecules. For elasticity, a property of solid, fluid, and gaseous objects can be explained only by the repulsion between the particles of matter. The bodily extension results equally from the objective principles of attraction and repulsion. However, such coexistence between the principles of attraction and repulsion is restricted to the materiality of bodies; beyond the limits of the material body there is a sphere of attraction that extends to infinity:

... in the Opticks he clearly believed that elastic fluids did indeed consist of mutually repellent particles. Particles in general had powers of attraction and of repulsion; for,

“As in Algebra, where affirmative Quantities vanish and cease, there negative ones begin; so in Mechanicks, where Attraction ceases, there a repulsive Virtue ought to succeed.”¹¹

Each particle was surrounded by a sphere or area of attraction; where this stopped, a sphere of repulsion succeeded; beyond this again, there was a second sphere of attraction, that of gravitation, extending outward indefinitely. (Boas 1952, 515-16)

The immediate conclusion that can be derived from this strategic conception of Newton would be an assumption that the seemingly immaterial sphere of gravity has only the nature of (centripetal) attraction—as compared to the material extension of bodies where a principle of material repulsion is latent. In this way, the physical principles of attraction and repulsion are again subsumed to an all-encompassing or *catholic* principle of universal gravitation and its nature of attraction.

The material principle of congruity and incongruity from which Hooke derives the principle of gravity differs significantly from this Newtonian approach. Hooke’s observation of the principle of congruity and its analogous nature to that of gravity clearly indicates that this principle also relates to a gravitational sphere surrounding the material extension of celestial bodies. Although Hooke does not explicitly mention a repulsive gravity, we can conclude from his observation of the principle of incongruity between the *spheres* of material substances that, using the principle of incongruity, the gravitational sphere of a celestial body can draw boundaries against the gravitational sphere of another celestial body. While Newton visualizes—in a rather geometric-mathematical intuition—a sphere of immaterial and infinite, i.e., universal attraction beyond the sphere of material bodies and their latent principle of material repulsion, Hooke seems to envisage gravitational spheres surrounding celestial bodies within the strict framework of mechanical philosophy which is based on material principles alone. Applying the material principle of congruity and incongruity in his analogy—within his mechanical philosophy—Hooke was not able to reach beyond the limits of particular gravities to the concept of a universal gravitation in his visualization of the mutual interaction of gravitational spheres, as Westfall emphasizes.

Now it should be examined whether there is a principle of incongruity which operates between gravitational spheres and whether they, as a result, can also repel each other. Analogous phenomena of forces acting at a

distance such as magnetism and electricity are also characterized by repulsive force-fields (between similar poles), as can be demonstrated experimentally. If the same poles of two magnets are brought closer together, we experience how their magnetic spheres repel each other, in which they can glide against each other on an invisible boundary plane between similar magnetic poles. From this directly experienced phenomenon, we are able to deduce two distinct facts of magnetic action at a distance: firstly, in the mechanical phenomenon of repulsion at a distance, the magnetic spheres draw their bounds against each other, and secondly this magnetic repulsion and demarcation are analogous to the material phenomenon of incongruity. We directly observe in magnetism and electricity a remote-acting repulsion and demarcation of their fields, but we are not prepared to attribute these characteristics to an analogous phenomenon such as the action of gravity at a distance. For if we assume that gravitational spheres, similar to magnetic or electric spheres, can also repel and draw accordingly *spatial* limits against each other, we can imagine them and their action at a distance only within the framework of particular gravities, and not within the prevailing context or paradigm of infinite universal gravitation.

It is evident from the principle of repulsion that it defines the real expansion of gravitational spheres and their boundedness more clearly than the principle of attraction, as centrifugal repulsion is structurally analogous to centrifugal expansion. But we have previously discussed how centripetal (gravitational) attraction counteracts centrifugal extension—both material and gravitational—and draws its *spatial* limits. In this way, both the principle of centripetal gravitational attraction as well as that of centrifugal gravitational repulsion does not—in the framework of Classical Mechanics—speak in favour of infinite universal gravitation, but points to spatially bound particular gravities. Moreover, the fact of gravitational repulsion seems to be supported by the empirical characteristics of tidal phenomena discussed earlier. If these facts are incorporated into the framework of Celestial Mechanics, they will reinterpret some of the basic assumptions of Classical (Newtonian) Celestial Mechanics that are built on the axiomatic notion of universal gravitation. One example is the so-called gravitational lock between the Moon and the Earth: the rotational period of the Moon and the orbital period of the Earth-Moon system happen to be of the same length so that the Moon shows the same face, i.e., hemispherical surface which is directed—or locked—constantly to the Earth. It is assumed—in accordance with the principle of universal gravitation—that the Moon and the Earth are interlocked due to mutual gravitational attraction. But it can arise also due to a constant gravitational repulsion that could possibly exist between the Moon and the Earth, especially if we take the above-discussed tidal phenomenon into account. Or perhaps, in accordance with Hooke, a different and more plausible speculation might be that the Earth's gravitation in its entirety attracts the Moon which is situated within its much larger gravitational sphere, while the relatively smaller (particular) gravitational sphere of the Moon repels the Earth. If we apply such a principle of gravity to the other celestial-mechanical structures, we will have to replace the traditional notion of universal gravitation—in which the celestial bodies only attract each other—by another principle of alternating gravitational attraction and repulsion between celestial bodies.

The repulsion of particular gravitational spheres in space would clearly define their extension and existential autonomy from each other. This would also provide a simple solution to an unsolved problem within Newtonian Universal Gravitation. If all the heavenly bodies in space attracted each other, the universe would collapse into a (central) point. The bounded extension of the particular gravitational spheres, chiefly ensured by a repulsive nature of gravity, would act against such a possible collapse of the universe. By means of a repulsive gravitational incongruity between the particular gravitational spheres a stable and sustainable extension of the universe would be maintained. Newton was aware of the absurd consequences of universal

gravitation when he postulated it and ascribed to it only the nature of attraction (or the attraction of all heavenly bodies against each other). Moreover, he could not believe that heavenly bodies attract each other at infinite distances, as he admitted in his letter to Bentley.¹² However, he maintained his belief in the singular nature and the unlimited expansion of universal gravitation. The post-Newtonian scientists of mechanics campaigned for a paradigmatic establishment of universal gravitation—as a universal law. That we, despite all these unreasonable premises, persist in this doxastic principle of celestial mechanics and try to maintain it historically seems to demonstrate more of a psychological tendency than an epistemological conviction. In their basic nature human beings tend to the idea of attraction that characterizes most of the operations of their lives and environment, even though the modern image of the individual unfolded from a philosophy of differentiation and boundedness of existence.

Notes

1. See Westfall, 1967, 245: “From the very day in 1686 when Edmond Halley placed Book I of the Principia before the Royal Society, Robert Hooke’s claim to prior discovery has been associated with the law of universal gravitation. If the seventeenth century rejected Hooke’s claim summarily, historians of science have not forgotten it, and a steady stream of articles continues the discussion.... The judgement Lohne cites with approval from Vavilov appears to summarize the current estimate of the issue—in the seventeenth century only Newton could have written the Principia; nevertheless Hooke first sketched out its program. What with all the knocks he has received both alive and dead, one feels guilty (and perhaps superfluous) in assuming the role of ‘debunker’ at this late date. Apologetically draped in sackcloth then, head covered with ashes (and with whatever it is one dons for superfluity) I venture softly to suggest that Hooke has received more than his due. There is no question here of justifying Newton’s behaviour toward Hooke. Wholly lacking in generosity as it appears to me, Newton’s behaviour neither deserves nor can receive justification. The question turns rather on Hooke’s scientific theories. Granting always his lack of demonstrations, historians have been prone to interpret his words in the light of Newton’s demonstrations. A close examination of Hooke’s writings does not sustain the interpretation. Contrary to what is generally asserted, he did not hold a conception of universal gravitation. And if he announced the inverse square relation, he derived it from such a medley of confusion as will not allow his claim to priority.”

2. Kemp gave this lecture on 16 December 2002 in a lecture series with the general theme *Iconic Turn*, which has been held since summer semester 2002 by Hubert Burda Foundation at the Ludwig-Maximilians University in Munich. <<http://netzspannung.org/tele-lectures/series/iconic-turn/>>. See also Kemp, 2004, 382-406. <<http://netzspannung.org/tele-lectures/series/iconic-tur>; <http://netzspannung.org/tele-lectures/series/iconic-turn/>>.

3. In my recently published treatise “Natur und Struktur der Kräfte,” I discussed how the apriority and apodicticity of structural intuitions in geometry, mechanics and optics are based on a modal and ontological identity between the *a priori* representation and the objective existence of free space. See Thaliath, 2010, 47-78.

4. In this way, the verticality of the dynamic-gravitational falling of objects or of the static phenomena on Earth and the sphericity of the Earth’s surface have been considered together in the structural intuition of terrestrial gravity. The early modern history of classical mechanics gives us many examples of such structural intuitions of mechanical phenomena. For example, Johannes Kepler pursued more or less the same intuition to explain the centripetal structure of terrestrial gravitational attraction. Kepler even extended this hypothesis in a thought experiment, in which he states that if the Earth were not a sphere and had an irregular surface, the objects would not fall centripetally-vertical, i.e., to the centre of Earth, but irregularly at different places. See Koyré, 1973, 194: “If the Earth were not round, heavy bodies [coming] from various directions would not go straight towards the central point of the Earth, but [would go] to different places.”

5. See Thaliath, 2010, 142.

6. Example for the *uniform rise* in water level would be the floods in rivers and lakes, which usually come from heavy and prolonged rainfall as well as by the melting of snow on mountains. Tides are different from floods as they are not just caused by the mere addition of water from other sources.

7. Not only the structures of mechanical forces or movements that can easily be represented in geometrical, i.e., vectorial forms, but also material properties such as the elasticity of solid bodies, viscosity or surface tension of fluids, etc. can become *objects* of structural intuition. In further considerations of structural intuition Kemp refers to the example of a football match in which players could judge the *structure* of ball movements intuitively and subsequently kick the ball in the right direction. This intuition is based amongst other things on a certain *intuitive-habitual* understanding of material properties such as the elasticity of the air enclosed in the ball, surface friction of the playground, air resistance, etc.. See Kemp, 2000, 1-2.

8. See also Brownlie, 1900, 471.

9. This representation is a modification of the model of circular planetary orbit as given in the work of Westfall. See Westfall,

1977, 10. Kepler's "solution" refers to an *epicyclic* planetary motion that, however, can clearly be represented in an elliptical orbit. In a circular path, the problem of the variation of the planetary distance from the Sun is not represented.

10. For the particular-gravitational demarcation, which is to be inferred from Hooke's analogy and interpretation of the principle of congruity and incongruity, see Thaliath, 2010, 129-43.

11. See Newton, *Opticks*, 5th ed., Query 31, 1931, 395.

12. See Hesse, 1955, 340.

Works Cited

Boas, Marie. "The Establishment of the Mechanical Philosophy." *Osiris* 10 (1952): 412-541.

Brownlie, Alexander. "The Science of the Tides: A Study in Physical Geography." *Journal of the American Geographical Society of New York* 32.5 (1900): 471-77.

Darwin, George Howard. *The Tides*. Lectures delivered in 1897 at the Lowell Institute Boston, MA. Cambridge, MA: Houghton, Mifflin and Co., 1899.

Hesse, Mary B. "Action at a Distance in Classical Physics." *Isis* 46.4 (1955): 337-53.

Kemp, Martin. *Visualizations: The Nature Book of Art and Science*. Oxford: Oxford UP, 2000.

---. "Wissen in Bildern: Intuitionen in Kunst und Wissenschaft." *Iconic Turn: Die Neue Macht der Bilder*. Ed. Christa Maar and Hubert Burda. Köln: DuMont, 2004. 382-406.

Koyré, Alexander. *The Astronomical Revolution: Copernicus-Kepler-Borelli*. Ithaca, NY: Cornell UP, 1973.

Thaliath, Babu. *Natur und Struktur der Kräfte*. Würzburg: Königshausen & Neumann, 2010.

Westfall, Richard S. *The Construction of Modern Science*. Cambridge: Cambridge UP, 1977.

---. "Hooke and the Law of Universal Gravitation: A Reappraisal of a Reappraisal." *The British Journal for the History of Science* 3 (1967): 245-61.