3

Discovering Gravitation

The nature of gravitation was accounted for by Aristotle (383–322 BC). Bodies comprised four elements: fire, air, water, earth. These elements could interchange, one being transmuted into the other. Each one sought an 'end'. This accounted for its tendency to move. Thus, fire moves upwards, whereas other elements move downwards. Everything seeks an end and has a final cause. Bodies gravitate because they seek to reach the centre of the earth.

Aristotle's philosophical notion about the nature of the force of gravity prevailed for eighteen centuries. Then man's understanding of the behaviour of bodies under the action of gravitation developed rapidly. The techniques of experimental research began to develop. The concepts of vectors, both force vectors and velocity vectors, and new mathematical skills emerged alongside the discovery of the telescope. The motions of heavenly bodies could be analysed in detail and found to be subject to behaviour patterns indicating compliance with Nature's laws, the laws of physics.

A Dutch military engineer Stevinus (1548–1620) is credited with the discovery that a uniform chain laid over a double incline must rest in equilibrium if its ends are in the same horizontal plane. What the long part gains in weight it loses in that only a part or component of it is effective downwards. Hence emerged the difficult idea of what we call a vector component. About the same time Galileo (1564–1642) discovered the vector properties of velocity. The prevailing notion was that a body could have but one velocity at once. Galileo established that a body could have two separate components of velocity which varied independently. Galileo also helped to correct the idea that all bodies slowed down when not acted upon by force.

It was erroneously believed that a constant force on a body would produce a constant motion. Hence the need to demonstrate that bodies of different weight fall at the same rates. Stevinus reports such an experiment:

> . . . The experiment against Aristotle is this: let us take (as I have done in company with the learned H. Jan Cornets de Groot, most diligent investigator of Nature's mysteries) two leaden balls, one ten times greater in weight than the other, which allow to fall together from the height of thirty feet upon a board or something from which a sound is clearly given out, and it shall appear that the lightest does not take ten times longer to fall than the heaviest, but that they fall so equally upon the board that both noises appear as a single sensation of sound. The same, in fact, also occurs with two bodies of equal size, but in the ten-fold ratio of weight.
>
> *De Beghinselen des Waterwichts*, Simon Stevin, 1586*

Galileo used a pendulum to show that the time of swing does not depend upon the amplitude of the swing and then argued mathematically that this implies that gravity is increasing the speed of the bob by equal amounts in equal times, the discovery of the acceleration of the earth's gravity.

When some Dutchmen discovered the telescope, Galileo quickly made a series of revolutionary discoveries in astronomy. Then Kepler (1571–1630) formulated his laws of planetary motion, demonstrating that their orbits are elliptical. To account for the force acting on the planets governing their motion, Kepler chose magnetism. It was Newton (1642–1727), several years later, who was to introduce the concept of universal gravitation. His idea was that there is a single universal force, the force of gravity. Gravity acts between all elements of matter in proportion to the product of their masses and in inverse proportion to the square of the distance between them. This relationship introduces the Constant of Gravitation G, a universal constant, verified as such by Newton by comparisons made for three systems:

(*a*) The actions between the sun and a planet, treated mathematically as two point bodies with the planet moving in an elliptical orbit about the sun as focus,

---

* Quoted from *Science Past and Present*, by F. Sherwood Taylor, Heinemann, London, 1945, p. 82.

(*b*) The actions between the moon and the earth, as two finite spheres, and

(*c*) The actions between the earth and a small body close to its surface, treated as a point body close to a large sphere.

Newton had to apply then-complex mathematical principles to verify his law for the general case, and his law of gravitation stands as one of the cardinal achievements in the history of science.

Although Newton succeeded in relating the various effects and associating them all with one phenomenon, he did not explain the nature of this phenomenon. Newton did not claim to understand the origins of the force of gravity. He studied its effects on the motions of bodies. His discovery was the Constant of Gravitation G and its universal character, but he could not understand why G was a constant, nor, indeed, could he evaluate G in his time. Its evaluation depended upon knowledge of both of the interacting mass quantities. Astronomical masses could not be measured. They are estimated today from our knowledge of G.

G was estimated in about 1740 by the mountain measurements of Bouguer. In the experiment the deflection of a plumb-line from the vertical due to the side-ways gravitational attraction of the mountain was observed. The difficulty was to evaluate the size and density of the mountain. Later, in 1797–8, Cavendish, using the torsion balance, was able to measure the force of attraction between two small bodies in the laboratory and thereby determine G.

Still the nature of the force of gravity was not understood. Then in 1836 Mossotti proposed a theory of some interest. He suggested that there existed electrical charge which was mutually repulsive and that mass was also mutually repulsive. Further, mass and charge had an affinity for one another. This attraction effect between mass and charge was assumed to be somewhat greater than the repulsive force, giving an overall attraction which represented gravity. Weber and Zollner later developed this idea. They regarded molecules of mass as associations of positive and negative electricity and imposed the condition that the force of attraction between charge of opposite polarity is somewhat greater than the force of repulsion between charge of like polarity.

Such was the speculative state of man's understanding of gravitation, when things began to go wrong with the basic law of gravity. The cosmos was withholding its secrets and the laws governing the motions of heavenly bodies evidently had some finer points which needed examining. This we will come to presently in Chapter 6 when we discuss Einstein's theory of gravitation. For the moment, it is appropriate for us to take stock of how physical science had really been developing since the end of the sixteenth century. Gravitation had captured the scene in the astronomical field, but essentially there are three other important scientific topics to follow in our quest to understand cosmology. The unseen aether medium is one of prime importance. The development of electrical science is probably even more important than the progress in mechanical science. Then there is the question of the source of energy sustaining the universe. Besides these, gravitation is merely a secondary issue, and not a foundation on which to build an understanding of the physical nature of the cosmos.

Descartes (1596–1650) published in 1644 his *Principles of Philosophy*, which contained his expositions on mechanics, on what he termed the 'visible world', and also the subject 'of the Earth'. Descartes advocated belief in an aether medium of which all parts are in motion. He envisaged a plenum composed of eddies, whirlpools or any kind of turbulent motion. Gravitation was attributed to some special substance which entered a body and had the property of seeking to reach the centre of the earth. The sun's energy source posed a more difficult problem. He likened the sun to a flame but could not understand how the sun was sustained in the absence of surrounding air and a source of fuel. At the end of the 22nd section of part 3 of his work he writes:

> We do not see that the sun is dissipated by the surrounding substance; this is why we have no way of judging whether it needs sustenance like the flame; and at all times I hope I may come to see in the future that it is still similar in that constantly material enters it in one form and leaves it in another form.

Given an aether medium one might wonder why Descartes could not have looked to this for his source of solar energy. This would have raised the difficulty that all astronomical bodies might need to be fiery infernos as well, but answers to this difficulty may be there to be found if one accepts the aether medium.

Naturally, ideas about the aether were based on mechanical analogies. Electricity, as the really fundamental property, could not be countenanced. With the development of Newtonian mechanics there was scope to analyse models of the aether medium. The progress made in understanding optical phenomena and the properties of solid and fluid substances was such that the mechanical aether was to the fore. Therefore, as electrical science developed and particularly as magnetic phenomena were discovered, it seems that every effort was made to explain the aether's electrical phenomena in terms of mechanics.

At the end of the nineteenth century the concept of mass stood alongside the concept of electric charge. They were used jointly in explaining physical phenomena. The idea of Weber and Zollner about the uneven interactions of charge and mass as an account of gravitation is typical of this intermixing of properties to explain fundamentals. Rather than explaining gravitation, it would be more direct to explain mass itself in terms of electric charge. Alternatively, the object should have been to explain electric charge in terms of mass properties. However, not knowing what either is in terms of the other, and not knowing what gravitation is either, the undaunted physicist goes on in his attempts to relate phenomena. He runs the risk of explaining a cause in terms of its effect rather than solving his problems the right way around. But to achieve any logical relation is progress. This brings us to the work of Helmholtz, who took note of the fact that gravitation itself could be a source of energy. He propounded the theory that the contraction of matter forming the sun releases energy and is the source of the sun's heat. This idea has now captured the imagination of the astrophysicist. It has taken on a different form in the concept of 'gravitational collapse' and leads to the fantasies of 'black holes' in space. We will come to this later. In the meantime, we examine the beginnings on which this concept is founded.

At this stage, the writer interjects the thought that at a time when the aether was accepted by physicists the logical energy source was the aether itself. Otherwise, we merely assume the existence of matter, derive energy from its coalescence, and are left with the ultimate problem of still explaining the origins of matter and the energy needed to set it apart in the first place.

Also, it is appropriate to interject another observation addressed to those readers who remain sceptical about the aether medium and treasure their thoughts about four-dimensional space. The point concerns the stability of motion under Newton's law of gravitation. I quote from the work of a science historian:*

> Laplace (1749–1827) was the supreme mathematician of Newton's planetary theory. The greatest single missing link—and a great one it was—which he supplied in Newton's work was his partial proof that the system would be a stable one; but it was his prodigious power in dealing with both the detail and the general features of the subject which gave him his characteristic place in scientific history.

Laplace died 100 years after Newton. Newton's theory, it seems, needed confirmation on a point of stability and it took so long a time before someone realized and resolved the difficulty. Now, one may wonder whether anyone has bothered to check the stability of the near-elliptical orbits of the planets in Einstein's four-dimensional space using Einstein's modification of Newton's law of gravitation. The passage of time since the inception of Einstein's Theory is no warranty that this point has been checked. On the contrary, one can begin to wonder all the more on reading the following:

> Have you ever wondered why ordinary space is three-dimensional? Although this may seem to be a ludicrous question, it has been the subject of considerable thought by scientists and philosophers since the time of Aristotle. . . . However, you do not need to worry that space has been five dimensions without you knowing because general physical arguments have revealed that three is the only combination that works.

Dr. Ira Freeman has recapitulated the reasoning in a translation of W. Büchel's article 'Warum hat der Raum drei Dimensionen?'

---

* *Science Since 1500*, by T. Pledge, H.M. Stationery Office, London, 1939, p. 71.

(*American Journal of Physics*, Vol. 37, p. 1222). Dimensions larger than three can be discounted if we accept that the gravitational force varies as the inverse square of the distance between two masses. This law, originally derived by Newton, will only allow for stable elliptical planetary orbits if spatial dimensions are three or less.*

It is difficult to imagine how Relativity's very small change in the law of gravitation from the form postulated by Newton could permit the remarkable step of introducing a new fourth space dimension. Perhaps a Laplace is needed to rescue Relativity.

Laplace proposed a nebular hypothesis in 1796. Quoting from a 1835 edition of his work:

> . . . the atmosphere of the Sun originally extended beyond the orbits of all the planets, and . . . it has gradually contracted itself to its present limits.†

Laplace was, of course, concerned with the formation of the planets, but that is not our immediate interest here. It is the application of Laplace's idea by Helmholtz which is of concern. Helmholtz's work dates from 1854:

> When the nebulous chaos first separated itself from other fixed star masses . . . an immense dower was bestowed in the shape of the general attraction of all the particles for each other. The force, which on the earth exerts itself as gravity, acts in the heavenly spaces as gravitation. As terrestrial gravity when it draws a weight downwards performs work and generates kinetic energy so also the heavenly bodies do the same when they draw two portions of matter from distant regions of space towards each other. . . . When, through condensation of the masses, their particles came into collision and clung to each other, the kinetic energy of their motion would be thereby annihilated, and must reappear as heat. . . . Calculations show that, assuming the thermal capacity of the sun to be the same as that of water, the temperature might be raised to 28,000,000 of degrees, if this quantity of heat could ever have been present in the sun at one time. This cannot be assumed, for such an increase of temperature would offer the greatest hindrance to condensation. It is probable rather that a great part of this heat, which was produced by condensation, began to radiate into space before the condensation was complete. But the heat which the sun could have previously developed

---

* *New Scientist*, February 19, 1970, p. 343.

† Quoted from *Science Past and Present*, by F. Sherwood Taylor, Heinemann, London, 1945, p. 195.

by its condensation, would have been sufficient to cover its present expenditure for not less than 22,000,000 of years of the past.*

We well know, today, that the earth is older than this by a factor measured in hundreds. Hence, Helmholtz's theory has no place in modern opinion. One may, nevertheless, wonder what Descartes' whirlpools in the aether would make of the chaos of all this energy coming together to form the sun. Might, perhaps, the aether contrive to form itself into a rotating unit, a whirlpool, co-extensive with the form of the sun and absorb some of the energy released by the gravitational compaction of matter?

The Constant of Gravitation has only been measured on this our earth. Newton has shown it to be a universal constant in this our solar system. We assume that the self-same value of the constant applies throughout the universe. We make this assumption even though it leads us to believe that some stars are so dense that tons per cubic inch are inadequate units for convenient expression. In the solar system we are dealing with bodies whose densities fall within the densities of the substances used by Cavendish in his experiment to measure G. What if G is different when the density becomes really high? Then, our ideas about the white dwarf stars, for example, will need drastic revision. We do not know exactly what gravitation is and so we assume G to be a universal constant throughout the whole universe and apply it to all matter concentrations however dense. With a very dense star we are then led to realize a problem. As the energy of the star is spent by radiation it will eventually have to cool down. Then its matter must regain a more normal density because the temperature will have originally stripped electrons from its atoms and permitted the tight compaction and the recovery process must lead to its physical expansion. As Eddington puts the problem:

> An intolerable situation—the star could not stop losing heat, but it would have insufficient energy to be able to cool down!†

---

* Quoted from *Science Past and Present*, by F. Sherwood Taylor, Heinemann, London, 1945, p. 196.

† *The Nature of the Physical World*, by A. S. Eddington, Cambridge University Press, 1929, p. 204.

Work has to be done against the force of gravity in the expansion process. It does seem so absurd that a star could find itself in such a plight. Eddington said that the answer to the difficulty came from the development of new statistical mechanics. Another answer could be that the ever-present aether, being an energy source itself, helps the star out of its difficulty. If there is an aether it seems likely that it will play a role in communicating gravitational force. Force is measured in terms of an energy gradient. If there is no energy available, then there can be no energy gradient and so no force. Gravitation is not guaranteed by Newton's law. If gravitation is a secondary property of the aether medium, the lack of energy will rule out the action of any force. The star will expand and the aether will react to assert gravitation, drawing upon whatever energy sources it has available to feed the energy requirements.

This may lead us to the thought that changes in the gravitational compaction of matter and the deployment of the energy involving the prospective aether may occur with earthquakes. With the overall compaction of a large body of stellar dimensions the energy density may become so great that the aether may be able to absorb the energy. For the earth, however, we may expect not so much an energy exchange, but an angular momentum exchange. Conservation of angular momentum is a consequence of a central law of force such as Newton's Law of Gravitation. Thus if the effect of the earthquake is to decrease the effective radius of the earth and reduce its moment of inertia, the earth will begin to rotate faster. If the earth is permeated by an aether medium which rotates at the same angular velocity, then this too will rotate faster.

This chapter has not taken us much further in our quest. It has served its purpose in bringing us to wonder whether gravitational potential energy has an exchange relationship of some kind with energy stored in the aether medium and possibly with energy associated with aether rotation.

This idea will be turned to good account in the next two chapters.