NEWTONIAN VISION:
Its Origin, Significance and Problems

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* Newton once said that he was able to achieve what he did because he had stood "on the shoulders of giants." It was rarely that Newton acknowledged the specific contributions of others so that this statement itself, which was perhaps made out of modesty, could also have been an attempt to pacify Robert Hooke, with whom he had quarrelled a number of times, and who charged Newton of plagiarism in connection with the inverse square Law of Gravitation.[1]

Hooke had mentioned the idea of the inverse law to Newton in the 1670's but his charge seems unfair, for there is evidence that Newton himself had arrived at it somewhat earlier, that is, in the 1660's and more importantly, it was only Newton who mathematically derived it from the quantitative statement of the centripetal force and Kepler's Third Law, and thereby also related it to observations But that his predecessors and contemporaries contributed vastly to the development of the Newtonian vision is undeniable.

Science has been, by and large, a collective enterprise, and it is increasingly become so. One thing more than any other that a study of the origins of Newtonian vision shows is this collective contribution which led to it. At the same time the philosophical and methodological issues which Newton's work raised three centuries ago, with the publication of his Principia, have continued to remain issues up to our own day and age But neither the fact that he stood on the shoulders of giants nor the problems and the controversies his work raised impair in any way the significance of the monumental achievement of Newton's scientific genius. What these indicate is the immensity of the task that he faced and the magnitude of the change that his work finally brought about.

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[1] cf. *Encyclopaedia of Philosophy*, ed. Edwards, Paul. The Macmillan Company & The Free Press, New York (1967) Vol. 5. p. 490.

Sometime in 1664, when he was twenty-two years of age and was studying at Cambridge, Newton began a notebook on *Quaestiones Quaedam Philosophicae* (Certain Philosophical Questions) and immediately under this title subscribed the words: *amicus Plato, amicus Aristoteles, magis amica veritas,* which translates : "Plato is my friend, Aristotle is my friend, but my best friend is truth "[2] This statement seems to throw some light on the development of Newton's thought. For although Francis Bacon (1561 - 1626) in his *Novum Organum* (1620), emphasized nearly a half century earlier the usefulness of the inductive method for gaining new knowledge, and although on the European continent the basis of the scientific revolution was already being laid by such intellectual giants as Copernicus, Kepler, Galileo and Descartes, the English universities had remained conservative. Cambridge, to which Newton went as an undergraduate, still clung to Aristotelianism; Oxford for some time even after Newton.

Newton's maxim quoted above shows the close acquaintance he had with the thought of Plato and Aristotle, More significantly, as we shall see, it also suggests that he has also come into contact with the revolution that was taking place in continental Europe, for he now distinguishes truth from what Plato and Aristotle had taught, and pledges himself to truth, As is well known, what Newton ultimately did was to replace the Aristotelian world-view with a new one – the Newtonian.

A world-view provides or lays down the basic principles and concepts which orient the way in which one understands the universe and functions within it. The change in world-view that Newton brought about resulted in the greatest conceptual revolution in the history of Western society.

It is the crises encountered by the old vision so strongly influenced by Aristotle which made men look for a new one. The Aristotelian world-view pictured a "two-sphere" universe, i.e. a universe which combined a celestial sphere with a terrestrial sphere. For Aristotle (384-322 B.C.) and the other ancients of the West, different concentric spheres carried the Moon, the planets including the Sun, and the stars. Every point inside this sphere was full of matter - for existence of any vacuum was an impossibility in the Aristotelian conception. Outside the sphere carrying the stars there was nothing, no space, no matter. The greater part of the Universe was thought to be filled with aether, the celestial element, which fills the space between the sphere of the stars and the sphere carrying the lowest celestial body–the Moon. Aether, being the celestial element, was pure and unchangeable, transparent and weightless. The concentric spherical shells carrying the stars and the planets rotated, which accounted for the celestial motions, and these shells as well as the stars, planets, the Sun and the Moon were made of aether. Aristotle needed fifty-five celestial spheres to account for the celestial motions. These spheres were in contact with each other and the motion of the consecutive spheres in contact provided the drive for the whole system. The sphere of stars, the outermost sphere, drove its nearest interior neighbour, the outermost of the seven homocentric spherical shells that moved Saturn. It moved the next

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[2] cf. *Encyclopaedia Britanica*, 15th edition Macropaedia, Vol. 13, p. 17.

shell of Saturn and this process continued until the motion was transmitted to the lowest celestial sphere - the sphere of the Moon

The original conception of Aristotle did not last in the same way and from about the beginning of the Christian era through the Middle Ages a very simple version of this view was believed by the people. This version had one shell for the stars and one for each planet, and thus allowed a nest of eight spheres to fill the entire celestial region.[3]

Astronomers calculated the distances of the celestial spheres from the Earth, and it was known in the Middle Ages that the celestial region was very large in comparison with the terrestrial region. that is, the space below the (underside of) the Moon's sphere. But this fact did not reduce the importance of the terrestrial region, as it was man's abode, the nucleus of the entire system - and, after all, all this was made for man !

The terrestrial region itself was filled with the four elements, earth, water, air and fire These formed into four concentric spherical layers. Earth, the heaviest element, was at the centre of the universe, the concentric layer of water was next, and those of air and fire followed in that order to extend up to the sphere of the Moon. But although this was the natural position of terrestrial elements in accordance with the Aristotelian laws of motion, the terrestrial sphere gets disturbed. The motion of the Moon's sphere pushes the fire below, setting up currents which make the four terrestrial elements mix, and mix continuously. in various propotions, giving rise to different substances on Earth.

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[3] In the original Aristotelian system each planet had a number of concentric spheres (e g. Satnrn had seven) that carried it and rotated in opposite directions etc., this being necessary to account for the retrogade motion of the planets In the system of eight spheres, which was the simplified version of the original Aristotelian system. each planetary shell was thick enough for the planet to be at its inner surface when closest to Earth and at its outer surface when farthest from the Earth. The seven planetary spheres explained the average motion of the planets which, in the order of increasing distance from the Earth which was the centre were Moon, Mercury, Venus. Sun, Mars, Jupiter and Saturn. Planetary astronomers used epicycles, deferents. eccentrics etc. to account for each planet's motion within its thick shell.

The system of homocentric spheres is different from the system of epicycles and deferents which replaced the homocentric system and was used by Ptolemy. The simplified version of the Aristotelian system referred to above, which used one spherical shell for stars and one for each planet, might have evolved as a sort of a 'cross' between the original Aristotelian system and the system of Ptolemaic epicycles and deferents.

As to what made the outermost sphere - sphere of the stars - to move was variously answered; some maintained that angels were pushing the outermost shpere. There were other interpretations, for example. like that of Dante, who wrote, "... beyond all these (crystalline spheres) the Catholics place the Empyream Heaven ... And this is the reason that the Primum Mobile (or ninth sphere) moves with immense veloctiy; because of fervent longing of all its parts to be united with those of this most quiet heaven makes it revolve with so much desire."

The ninth sphere, referred to in the quotation from Dante seems to have been added to the eight spheres of earlier cosmology by the Moslem astronomers. (The account given here is mostly based on Kuhn's *Copernican Revolution* (see footnote 12). See pp. 79-80 and pp. 111-113).

Aristotle taught that every body, when moved, sought to regain its natural position. This was the natural motion of a body, whereas any other motion leading to change of position was ascribed to externally applied forces and was "violent" motion. Since pure earth was the heavy element, heavy bodies naturally moved towards the Earth, which is at the centre of the universe. This conception was associated with the idea that the universe was finite and had no vaccua.

The original Aristotelian conception as well as its simplified versions which men believed from about the beginning of the Christian era could be looked upon as the "two-sphere" conception of the Universe, in the sense that it consisted of a "celestial sphere" as different from the "terrestrial sphere", with the celestial being divine and changeless, and the terrestrial being the area where change, birth, decay and corruption take place.

Greek science, which was lost to the West from the early Middle Ages, reached European scholars through Arabic translations after about the tenth century. In the thirteenth century St. Thomas Aquinas amalgamated the Church doctrine with the Aristotelian universe. And it was this world-view, this amalgamation, which the scientific revolution had to overthrow to pave the way for a new world-view. The Aristotelian universe, inspite of the two-sphere view which had different laws operating in the celestial and terrestrial spheres, had also a unified conception of the two systems, in that the celestial motions cause the terrestrial changes.

The world-view that preceded the scientific revolution was thus based on the authority of Aristotle and the scriptures. It was also based on empirical observation or sense-perception, as the Ptolemaic System as well as Aristotle's own records of observation suggest. Of course, such observations and other conceptions were linked or co-ordinated by a lot of reasoning and interpretation used to develop the world-view in question.

At Cambridge Newton had read Aristotle, in particular, his *Physics*, in the light of its interpretation by 16th century scholastics. But by about the end of the second year of his stay there he appears to have been dissatisfied with what he read and understood of the world view presented therein The change seems to have come in around 1664 - about the time that he decided in favour of friendship with truth over his devotion to both Plato and Aristotle. By this time he had given up the exclusive diet of ancient works and their commentators and turned to reading the moderns. From this time on we find his genius blossoming, as he gradually came to know the scientific writings of the men of his century. From them he took whatever tools o methods or concepts he could use to develop his own view.

The most prominent scholars whose works he read were Galileo and Descartes He made notes on Galileo's *Dialogue on the Two Great Systems of the Worl* and Descartes' *Principles of Philosophy.* He had read Euclid's *Elements* earlie in 1663 and following this he mastered Descartes' *Geometrie.* In addition to these Newton also read Walter Charleton, an expert on ancient and modern atomism, an Pierre Gassendi, the Frenchman who revived atomism. He also read the philosophica writings of Thomas Hobbs and Henry More and mastered the works of Robert Boyle and Robert Hooke And hardly need we mention that Newton acquainted himself with Kelper's work.

Mathematician Abraham De Moivre, who knew Newton well, says that Newton persevered in attempting to understand Descartes' geometry and by dint of that effort, gained a clearer understanding of Cartesian geometry.[4]

The period 1663-1666 was thus Newton's formative period. By the end of this period he had laid the foundations of all the three fields in which he excelled, viz. the discovery of the binomial theorem and the differential calculus (method of fluxions) in Pure Mathematics, the work in Optics which analysed white light into colours and made him come up with the corpuscular theory of light and the work in Mechanics where he integrated the dynamics of the celestial and terrestrial bodies.

Every school-boy today learns the four pricipIes on which the Newtonian world-view is built, three Laws of Motion and the universal Law of Gravitation. It is this world-view, this vision, which I intend to review briefly here. In what follows, I will therefore not dwell with his great work in Optics and his contributions to Pure Mathematics, except when these are relevant to the main theme. Newton also dabbled in Alchemy and Theology and I shall have occasion to mention the latter again as it also had some role to play in the development of his world-view.

As Newton did stand "on the shoulders of giants" it is not surprising that most of the ideas that go into the four principles on which Newton founded his world-view are ascribed to others. Let us begin with Descartes and consider what part he seems to have contributed to the origins of Newton's vision.

By the time Newton immersed himself in modern Physics, that is, around 1665, the Aristotelianism that was outlined earlier was falling apart. Copernicus had sent the Earth into orbit and Kepler and Galileo had stabilized the helio-centric view. Descartes (1596-1650) had come up with a world view to replace the dying Arsitotelianism. Part of this consisted of his theory of vortices. Descartes considered space as a plenum of an all-prevading fluid. Certain portions of this fluid were in a state of whirling motion, as in a whirlpool or eddy of water. Each planet had its own eddy in which it whirled round and round, as a straw is caught and whirled in a common whirlpool. And Descartes explained gravitation as settling down of bodies towards the centre of each vortex.

Although Newton grew up when this view was spreading, this part of Cartesianism did not constitute the influence of Descartes on Newton. It was Descartes' mechanical approach to nature which Newton embraced, though again, not fully. According to Descartes' view phenomena are created by particles of matter in motion acting on each other. It is this aspect of Cartesianism which influenced Newton in his general approach to scientific activity. Newton thought that all explanation should be mechanical. A shining example of his approach in this respect is his work in

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4. Cohen, Bernard, 'Mathematics, the Childhood of Isaac Newton's Science' in *Scientific American*, (January 1968) p. 139.

Optics - particularly the corpuscular theory of light. We know that his great system ultimately failed to give a mechanical vision of the world, for gravitation incorporated action at a distance, and he lamented over this. We shall return to this problem later.

Newton also benefitted immensely from Descartes' Analytic Geometry. Without what he gained from it Newton probably could never have written the *Principia* or made his greatest discoveries. Moreover, the deductive approach that Descartes used in his research and exposition probably had some effect on Newton. For the *Principia* is presented in the form of a deductive system.

Leaving such general influence, Newton is indebted to Descartes for his First Law of Motion. It is surprising that a number of writers of the highest standing have made the mistake of thinking that Newton's First Law of Motion was formulated by Galileo. Bertrand Russell, for example, has written.

> "Galileo unified the earth and heavens by his single law of inertia according to which a body once in motion will not stop of itself but will move in a constant velocity in a straight line . . ." [5]

and R. E. Peirls, in his *The Laws of Nature* writes :

> "The most fundamental law of mechanics is then the Inertial Law of Galileo which states that if left to itself a body will move with uniform velocity in one and the same direction".[6]

But the first law is not Galileo's. For Galileo thought that inertial motion is in a circle and not in a straight line, although writers like Paul Feyerabend seem to suggest that Galileo perhaps subscribed to both these ideas on different occasions. [7] The first law occurs very clearly in Descartes in his *Principles of Philosophy*. Under principles of material things, Descartes listed the following rules ;

> The first law is: Every reality, in so far as it is simple and undivided, always remains in the same condition so far as it can, and never changes except through external causes. Thus . . . If it is at resting one thinks it will never begin to move, unless impelled by some cause. Now there is equally no reason to believe that if a body is moving its motion will ever stop, spontaneously that is, and apart from any obstacle. So our conclusion must be : A moving body, so far it can, goes on moving.
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> The second natural law is: Any given piece of matter considered by itself tends to go on moving, not in any oblique path, but only in straight lines. [8]

Bernard Cohen, a contemporary Newtonian scholar, mentions that Newton copied out an English version of the principles of inertia from Descartes' *Principles of Philosophy*

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[5] Russell, Bertrand - *Unpopular Essays*, London, Allen & Unwin (1950) p. 170.

[6] Peirls, R. E. - *The Laws of Nature*, New York : Charles Scribner' s Sons (1956).

[7] Feyerabend, Paul - *Against Method*, London, Verso (1983) p. 96.

[8] Descartes - *Philosophical Writings*, trans. Anscombe, E. and Geach, P. T. London, Nelson (1969) pp. 216-17.

when he read it during the formative years, and this only later became the First Law of Motion.[9]

If some of the origins of Newton's work are thus traceable to Descartes some are no doubt traceable to Galileo. Galileo himself mentions his following the method of Euclid in his demonstrations so Descartes might not be the only percursor in the deductive method used by Newton. Again Galileo's dialogues would have made Newton realise that quoting authority (as Simplicio quotes Aristotle) is not the best way to do science. Descartes was more mathematician and philosopher than experimental scientist, whereas Galileo was an experimental scientist. Like Galileo, Newton made gadgets and he conducted experiments in Optics and made observations in Astronomy and Mechanics.

It is also true that towards the end of Galileo's *Dialogues Concerning Two New Sciences*, some statements close to the First and Second Laws of Motion occur. For on the fourth day of the dialogue, in discussing the motion of projectiles, the following statements, which have been interpreted as being close to the First and Second Laws respectively, occur :

1. Imagine a particle projected along a horizontal plane without friction, then we know, . . . that this particle will move along this same plane with a motion which is uniform . . .[10]
2. . . . the vertical motion continues to be accelerated downwards in proportion to the square of time . . .[11]

In late medieval science, the impetus theory had been advanced, particularly to solve the problem of the "violent" motion of the projectile. In Aristotelian physics, a stone thrown should reach this Earth directly in a straight line, but it is observed that the projectile does not follow that path. Aristotle thought that this was due to the fact that disturbed air pushes the particles after contact with the projector was broken. Those medievals who rejected Aristotle thought that the observed motion of the projectile is due to the fact that the projector impresses a certain impetus or motive force into the moving body as the projector loses contact with it. This impetus theory gave Galileo his principle of inertia that a body in motion will move with constant speed, but unlike Descartes, Galileo thought that inertial motion was in a circle. This was the state of affairs when Newton engaged himself in these problems.

Again, the idea of gravitation was in the air for quite some time, and although Newton had got on to the correct theory of gravitation in 1666, it was Robert Hooke who first published a qualitative account of gravity together with the law of inertia in 1674, where he said :

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[9] Cohen, *op. cit.* p. 139.

[10] Galileo Galilei - *Dialogues Concerning Two New Sciences.* trans. Crew, A., and Salvio, A. de, New York, Dover, p. 244.

[11] *op. cit.* p. 250.

i. "all celestial bodies whatsoever have an attraction or gravitating power towards their own centres, whereby they attract not only there own parts, and keep them from flying from them, as we may observe the Earth to do but that they also attract all the other celestial bodies that are within the sphere of their activity . . . "

ii. "all bodies whatsoever that are put into a direct and simple motion, will so continue to move forward in a straight line . . . "

iii. "these attractive forces are so much the more powerful in operating, by how much nearer the body wrought upon is to their own centres. Now what these several degrees are I have not yet experimentally verified."[12]

This is not all. The inverse square law for gravitation had been suggested as far back as 1645 by Boulliau, and Kepler's third law as well as the law (known even to Kepler) that light diminishes its intensity with the square of distance from the source could have suggested it.[13] Newton himself seems to have thought that Pythagoras had anticipated him in discovering that the force of gravity varied inversely with the square of distance.[14]

Of course, as mentioned earlier, none of these reduce Newton's claim to greatness. Newton asked the correct questions and accepted the correct ideas whether it be of Galileo, Descartes, Kepler or any others in achieving his great synthesis, rejecting the wrong ideas of the same people with great physical intuition. Let us put ourselves for a moment in the position of Newton of 1666.

Aristotelianism was in shambles but a way to unify the celestial and terrestrial motions with the same laws applicable everywhere in the universe had to be envisaged. It would have been clear to Newton that the main attack should be directed to the task of bringing together Kepler, who gave the celestial laws, and Galileo who had given the terrestrial laws. But how ? The two pieces did not appear to fit together.

One could not see how Kepler's and Galileo's laws could be linked but, the confusion was confounded by the fact that the views of "the giants" were contradictory. Kepler had shown that the planets move in ellipses, but Galileo thought they moved in circles. Kepler thought the planets were driven along by the "lines of force" issuing from the Sun, Galileo that they were not driven at all, as circular motion was, as inertial motion, self-perpetuating. Kepler thought that inertia of the planets made them lag behind, while Galileo thought inertia was the very thing that made planets continue to go round in circles. These contradictions were further enhanced by Descartes' position that inertia made bodies persist, not in circular motion but in motion in straight lines - a suggestion which looked quite wild - as it was very clear that the heavenly bodies, while they could be moving in circular or elliptical orbits, certainly did not move in straight lines.

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12. Kuhn. Thomas - *The Copernican Revolution*, Cambridge, Harvard University Press (1957) p. 254.
13. cf. Koestler, Arthur - *The Sleepwalkers*, London Hutchinson (1957) p. 502.
14. See Kearney, Hugh - *Science and Change 1500-1700*. London, World University Library (1971) pp. 190-91.

How, it may be asked, did Newton become "the conductor who pulled the orchestra together and made a harmony out of the caterwauling discords."[15] In the answer to this I am now suggesting an idea which, if it has been presented before, has as least not been presented positively and with emphasis. The foundation of Newton's work was laid in the two or three years from 1664 to 1667. The contemporary Newtonian scholar at Cambridge, D. T. Whiteside, who edited Newton's papers, writes that from the beginnings in 1664, "Newton over the next two years was to develop a series of researches formidable in technical content and effervescent with still untested creative thought . . . Their detailed systematization, carried through by typically stubborn perseverance and massive power of mental concentration was to take most of the rest of his life".[16]

Almost all Newtonian scholars agree on this fact. But what is its significance? I am suggesting that Newton knew very early that to get away from Aristotelianism he had had to have a *full* philosophy. Aristotelianism was a full philosophy and it could not be overthrown by tinkering here and there. I believe that Newton saw this clearly. He had to decide what his world is going to be – or what he thought the world actually was. Aristotelianism was dying . . . He turned to the main contender to replace it, Cartesianism. He felt that the mechanical world-view of Descartes was correct. The world is like an intricate, impersonal, inert machine. He agreed that matter was divisible and the motion of, and interaction between, particles produced the phenomena, but unlike Descartes he did not want infinite divisibility of matter. He agreed with and borrowed Descartes' first two laws of material things, which he immediately took as his first principle – the Law of Inertia or the First Law of Motion.

Here again Newton did not go all the way with Descartes. He knew that Descartes' theory of vortices was unsatisfactory. It was mentioned earlier that Newton read Pierre Gassendi, himself a mathematican and an arch-critic of Cartesianism. Gassendi was reviving atomism. The trouble with Descartes was that he thought that matter was infinitely divisible - the division did not stop at any level. For Descartes, as for Aristotle, a vaccum is an impossibility. Ancient Greek atomists like Democritus had made the existence of atoms the basis for the possibility of vaccua. Newton tilted towards Gassendi's atomism. Newton's corpuscular theory of light shows that he accepted corpuscularism. He probably knew the work of Galileo (1564-1642) and Torricelli (1608-1647) on vaccua. He wrote that Aristotle was still his friend. Aristotle had said, "If there were a vaccum any body would continue its motion at uniform velocity in a straight line - which is absurd; therefore there cannot be a vaccum." Newton by his First Law accepted that inertial motion was in straight lines, so the possibility of vaccua then follows even on the Aristotelian conception. Newton drew from Aristotle, Kepler, Galileo, Descartes and Gassendi and corrected them and formed the principles of his philosophy : a mechanical view of nature, with the possibility of atoms and vaccua, and perhaps most important of all - the principle of intertia borrowed from Descartes; but based on his own reasons and conceptions.

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[15] Koestler, *op. cit.* p. 496.

[16] Cohen, *op. cit.* pp. 139-40.

We must raise a question of some importance before we proceed. Descartes had considered extension as the essential characteristic of matter. This made space and matter coalesce, leaving no room for vaccua. Newton gave up this idea, separated space from matter - and was it this that led him to posit an absolute space and, together with it, an absolute time? Or was this conception a later development? This is a difficult area but we shall touch upon this again later in this essay.

Newton was at home in Woolsthrope in 1666 as the Cambridge University was closed during this time due to the Great Plague. The story that the fall of an apple from a tree in his home garden gave him insight into the work of gravitation might well be literally true. But it was certainly metaphorically true. For the problem of unifying celestial and terrestial force was linked up with heaviness or weight of bodies which make them fall to the ground.

It was seen that in the Aristotelian system bodies fell to Earth as Earth was the centre of the Universe, and thus Earth was the natural place of heavy bodies. But as Earth, after Copernicus, Kepler and Galileo was no longer the centre of the Universe, why did bodies continue to fall to the Earth any more? This fall of bodies was also associated with heaviness or weight. What then is weight? Moreover, if the Moon and planets are similar to Earth and bodies on Earth, then these celestial bodies must have weight. But what is the meaning of the weight of a planet and where does a planet fall due to its weight?

Galileo thought that weight was an absolute quality of matter which requires no cause, and associated it with inertia. And for him inertia made the planets continue to move in their circular orbits. Here again it was Kepler who had the right insight. For he was the first to explain weight as the mutual attraction between two bodies. He also attributed the tides to the attraction of the Sun and the Moon. I have not tried to detail how much Kepler's ideas would have helped Newton, but Newton's indebtedness to Kepler's findings as well as his ideas probably surpasses what he owes to any other single person. Thus, for example, Kearney says, "... if such a distinction is possible Newton built upon the work of Kepler." [17]

There was a further element which added to the confusion. This was the association of gravity with magnetism. William Gilbert (1540 - 1603) had propounded the view that the Earth was a massive loadstone, and magnetism was the only phenomenon which exhibited directly the tendency of one body to attract another. One could observe that it also acted at a distance, without any perceivable medium or mechanism. It was not surprising that even the great Kepler was deceived into thinking that the attraction that the Sun exerts on planets was magnetic.

But once Newton had accepted the First Law of Motion the rest of the riddle begins to fall into place. Kepler says that planets move in ellipses. What force drags them away from their natural motion—motion in a straight line? Newton's note books for 1664-1666 show that he had formulated the law of centrifugal force (as the force when a body moves uniformly along a circle is at once directly proportional to

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17. *op. cit.*

the square of speed and inversely proportional to radius) before Huygens, to whom the credit for the discovery of this law is given.[18] Equating the centripetal force that should balance the centrifugal force so that the planets do move as they do, Newton probably realized that on the basis of Kepler's third law the centripetal force needed to hold the planets will be a single force emanating from the Sun and varying inversely with the square of the distance.

There is evidence that Newton believed, even during these formative years, that the gravity of the Earth extends up to the Moon. This probably originated in him due to the work on the path of projectiles that Galileo had studied earlier. The way Newton combined the centripetal force, gravity and the motion of the Moon is seen in Definition 5 of the *Principia.*

Definition 5 :

> "A centripetal force is that by which bodies are drawn or impelled or any way tend towards a centre. Of this sort is gravity by which bodies tend to the centre of earth's magnetism, by which iron tends to the loadstone; and that force, whatever it is, by which planets are perpetually drawn aside from the rectilinear motions, which otherwise they would pursue . . . "[19]

That Newton's unification of the celestial and the terrestrial motion was achieved by extending the terrestrial projectiles to the celestial Moon's orbit is seen from his writings. In Definition 5 itself we read,

> "If a leaden ball projected from the top of a mountain by the force of gun powder with a given velocity, and in a direction parallel to the horizon, is carried in a curved line to the distance of two miles before it falls to the ground, the same, if the resistance of the air were taken away, with a double or decuple velocity, would fly twice or ten times as far. And by increasing the velocity, we may at pleasure increase the distance to which it might be projected and diminish the curvature of the line, which it might describe, till at least it should fall at the distance of 10, 30 or 90 degrees, or even might go quite round the whole earth before it falls; or lastly, so that it might never fall to the earth, but go forward into the celestial space, and proceed in its motion in *infinitum.* And after the same manner that a projectile, by the force of gravity may be made to revolve in an orbit, and go round the whole earth, the moon also. either by the force of gravity, if it is endured with gravity, or by any other force that impels it towards the earth, may be perpetually drawn aside towards the earth, out of the rectilinear way, which by its innate force it would pursue, and would be made to revolve in the orbit which it now describes; nor could the moon, without some such force, be retained in its orbit. If this force was too small, it would not sufficiently turn the moon out of a rectilinear course; if it was too great,

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18. Kearney, *op. cit.* p. 194.
19. See Hurd, D. L. and Kipling. J. J. ed. - *The Origins and Growth of Physical Science,* Penguin Vol. I., p. 181.

> it would turn it too much and draw down the moon from its orbit towards the earth. It is necessary that the force be of a just quantity and it belongs to the mathematicians to find the force that may serve exactly to retain a body in a given orbit, with a given velocity; and *vice versa*, to determine the curvilinear way into which a body projected from a given place, with a given velocity, may be made to deviate from its natural rectilinear way, by means of a given force." [20]

It was this artificial satellite, created by thought experiment, that gave direction to Newton's reasoning. And, to believe Newton, he seems to have calculated he centripetal force that could keep the Moon in its orbit by balancing the centripetal force with the centrifugal force so that the resultant is the Moon's orbit. But not quite satisfied with the values that he obtained in 1666, he did not publish his work. That is partly why the charge of plagiarism levelled at Newton by Hooke, mentioned in the opening paragraph of this essay, is not justifiable.

These are some of the sources, the origins, of Newton's vision. Before moving on to look at his vision from a different angle, however, there is need to indicate the magnitude of Newton's achievement.

The unique genius of Newton was the combination of intuitive physicial thought with great mathematical talent. It was significantly the *Mathematical* Principles of Natural Philosophy which he presented. The great individual achievement of Newton was in synthesising the laws of terrestrial and celestial motion, giving the mathematical or quantitative precision, thereby also giving definite meaning to the interrelated set of concepts and relating the grand system to observable facts, making it testable. It was the culmination of the conceptual revolution triggered off by Copernicus. Within the short space of the three years between 1684 and 1687, during which time he finally put the *Principia* system into shape, Newton struck off the finite two-sphere universe of the Aristotelian middle ages and spread it over infinite space and infinite time; he split up the Aristotelian plenum, adopted the corpuscular view of the universe, and installed the possibility of empty space or vaccua in the universe; he created one universe, where the same laws of physics applied universally, and dropped any significant sense attributable to the distinction between the "heavens" and the Earth–for he made all bodies to be in motion, pulling and pushing each other, in an endless universe with no centre; he installed gravity to account for the fall of bodies near Earth and got rid of the conception of "natural" motion of bodies; he showed how gravity makes planets move round the Sun; he distinguished between gravity and magnetism with his Second Law of Motion, he dropped the impetus theory of the "medievals" and stipulated that a force is not that which changes the position but that which changes the motion of a body; he introduced the idea of action at a distance to account for the pull of gravity acting between distant bodies, although he himself could not believe in it. The universe was earlier a compressed globe, with man at the bottom. The new universe was a great clockwork, the mechanism

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[20] *op. cit.*, p. 182.

infinitely spread with Earth and man exhilaratingly free yet spellbound with wonder and awe. In short, in one great stroke of genius he removed Western man from the Aristotelian universe, where he had lived for two millenia, and put him in a new universe, thoroughly different from the old.

Philosophical and Methodological Issues.

Let us now take a look at some of the more interesting philosophical and methodological aspects of Newton's work. This could also throw more light on the epistemological origins of his vision. Newton's new universe was not entirely acceptable at the beginning to many including Newton himself. The reason was that Newton had incorporated a ghost into his system - action at a distance. How could the massive forces of gravity required to hold the Moon or the planets act through empty space ? it was an enormous, bold step that he took, but Newton was unhappy that he had to take it. The situation was not thought realistic or even conceivable at the time, in spite of the observed magnetic attraction without immediate contact. Newton himself wrote,

> "It is inconceivable that inanimate brute matter should, without the mediation of something else, which is not material, operate upon and affect other matter without mutual contact . . . That gravity should be innate, . . . so that one body may act upon another, at a distance through a vaccum, . . . is to me so great an absurdity, that I believe no man who has in philosophical matters a competent faculty of thinking, can ever fall in to it . . ."[21]

This shows the great conceptual leap which Newton had to take; it also indicates how the limitations of the era weighed heavily on a giant innovator. Seeing no other way out he reluctantly freed himself from the bondage of the era, but as the above passage shows, he often returned to the ways of the times, looking for the transmitter of gravity- Copernicus did not publish his revolutionary work until he was pressurized by many a sympathiser and admirer, and when he published it, it was as good as a posthumous publication. Darwin was delaying pulblication until Wallace jumped the gun. Newton, even though he had his supreme insights far back in 1666, and even when, as we saw, Hooke came out with both the first law of motion and the idea of gravitation in 1674, never published his discoveries until he was coaxed into it by young Edmund Halley, who also bore the cost of the publication of the *Principia*. Men of original ideas, men who bring about coneeptual revolutions, face such difficulties, as much innovation has to be made to jump from one world-view to another, at times at great personal risk.

Since Newton communicated his discoveries in optics to the Royal Society almost from the beginning, it is certain that although the coneeption of his brain-child took place in 1666, Newton had a number of misgivings about his world-view and hesitated to give it out. Action at a distance was not the only one of them. Another was the question why it was the case that a universe filled with gravity did

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[21] See e.g. Koestler, *op. cit.* p. 503.

not collapse and Newton, himself a great dabbler in theology, had to assign to God the function of counteracting gravity to keep the universe going. That was not all. While Newton could never overcome the problems of action at a distance and why the universe did not collapse due to gravity, he would have been emboldened to publish his theory later on by certain other difficulties which he was able to overcome with the mathematics that he developed.

· The following is a striking example of a difficulty that he did overcome. Newton was unhappy with the details of his conception that the fall of objects near the surface of the Earth and the "fall" of the Moon towards the Earth are related. For, if gravity belonged to different particles (corpuscles) on the surface of the Earth, the object falling near the surface of the Earth will be pulled in different directions as these particles will act separately from their own locations on Earth. Therefore it is not possible to consider gravity as a force acting from the centre of the Earth, although that conception could be a good approximation for action on the distant Moon. Newton overcame this difficulty when he was able to show mathematically that the sum total of the gravitating forces of the particles acting from a (spherical) body have their resultant acting at the centre of the body. Again, through his mathematics Newton was also able to relate his theory to observation. Thus, for example, he could use his mathematics to show that Keplerian elliptical orbits of the planets were mathematically deducible from the conception of a force whose strength varies inversely as the distance from the Sun placed at one of the foci of the ellipse. He could also derive Kepler's third law, which equated the square of the ratio of the orbital periods of two planets to the cube of the ratio of the average distances of the two planets from the Sun, which again linked his theory of gravitation with data based on observation. In fact this would have suggested the inverse square law, as we indicated.

Much of the problems that Newton's gravitation faced emerged from the corpuscular conception of nature, which was the outlook of the times. As we saw, Descartes was partly originator of this conception and corpuscularianism led to Mechanism. The mechanistic view of nature conceived the transference of force to be by contact, and Mechanism was aimed at getting rid of ghosts like action at a distance. Newton himself believed in the corpuscular view. Thus his corpuscular theory of light, and his work in colour spectra is in the mechanistic tradition But as notions of action at a distance and God's hand in preventing the collapse of the world entered his view, he failed to be a full fledged mechanist, for Mechanism entertained Deism, which believes that God has no hand in the management of the world after its creation.

Descartes, who undertook to reconstruct the universe, beginning only with matter and motion, created a universe filled with infinitely divided particles, all in contact and with no vaccum We saw that, in his view, matter produced whirlpools in the skies, and the heavenly bodies move because they are carried in these different whirlpools. Gravity itself was due to these whirlpools sucking things down towards their centre. The immense influence that this Cartesian thought had at the time is unbelievable today. Descartes was dead by 1687, but his follower, Christian Huygens, although a friend of Newton who admired the mathematical beauty of the *Principia* systems, rejected it as untenable as it was non-mechanistic. Leibniz, who saw the *world* as full of monads – a sort of universe of corpuscules somewhat similar to the *Jaina* souls, attacked the *Principia* saying, "what has happened in poetry happens also in the philosophical world. People have gone weary of rational romances, . . and they are become fond again of the tales of fairies." Perhaps the fact that Newton, although he wanted to fall in line with the mechanists of his time, and was to that extent a product of his times, had a mystical, Pythagorean or Neoplatonist streak in him, as did Kepler before him, was fortunate for science.[22]

God and action at a distance were not the only controversial issues for Newton. The assumption of an absolute space and an absolute time, both infinitely stretching, was as controversial. It is true that matter has to be atomistic and space has to be distinct from matter, for inertial motion to be possible in nature. But the absolute conceptions of space and time came under the immediate attack of the monadist Leibniz, and much later of Ernst Mach (1838–1916).

Descartes, here again, had argued that all motion is motion of an object relative to others. The search for the 'real motions' thus lacks sense. Newton, on the other hand, argued that it was not senseless but only difficult. Newton's way out of the difficulty was his installation of absolute space, which is at absolute rest. "Absolute space, in its own nature, without relation to anything external, remains always similar and immovable,"[23] he wrote. It is relative to this absolute space that 'real' or 'true' motions get meaning, but since absolute space cannot be observed, it is impossible for us to know the 'real' motion. But Newton himself claimed that there is observational evidence for absolute motion. The famous example that he gave is what is known as 'Newton's bucket experiment'. Newton also claimed that even in an otherwise empty universe we could determine from the shape of (say) a planet whether it was rotating. Ernst Mach, criticizing such experiments, objected to the thought-experiment of the planet's rotation in an empty universe, saying that we have no way of finding out what would happen if the universe was empty – for we have to take the universe as it is. This led to Mach's principle, which states the idea that our theories should deal only with what could be observed, that we observe only with relative motion and that empty space is only nothingness. It was Mach's writings that influenced Einstein in his formative years, although Einstein did not agree with some of Mach's more positivistic ideas later on.

Similar problems were posed by the absolute notion of time. It is of interest here that Newton, probably under the influence of Henry More, thought that absolute spaee and absolute time constitute the Sensorium of God – i.e. the way in which all times and all places are simultaneously present to Him. Immanuel Kant (1724-1804) in an attempt to elaborate and justify the Newtonian system in the transcendental aesthetic of his *Critique of Pure Reason* tried to make space and time *a priori* bases of our experience. Einstein's theories of Relativity make space and time relative to each other, but in spite of their generation being associated with matter

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22 cf. Kearney, *op. cit.* pp. 183-196.

23. Newton, Isaac – 'Absolute Space and Time', Reprinted in *Problems of Space and Times*, Smart J. J. C. ed., New York, The Macmillan Company (1984) p. 81.

itself, it is still an arguable point whether an absolute concept of space-time is not a philosophically necessary conception for the Theory of Relatively.[24]

To turn to the three Laws of Motion – the Laws of Motion are in the corpuscular and mechanistic tradition, but we saw that Newton's conception of real motion was linked with absolute space. These laws have been argued to be a *priori* by Kant, d'Alembert (1717-1783) and James Clerk Maxwell (1831–1879). Some have maintained that the laws are empirical generalizations, but this view faces difficulties. For example, according to Newton's own Theory of Gravitation, the necessary conditions for inertial motion cannot be realized even in principle as all bodies would exert forces on each other. Again, if one uses Mach's definition of mass, which holds that a particle has mass only in so far as it interacts with other particles, an isolated body in motion will have no mass, hence no inertia. Moreover, the criterion that determines for us whether a force is acting on an object is whether that object changes being in uniform motion in a straight line or at rest. But this makes the First Law a tautology; for then it says that 'Every body continues in a state of rest or of uniform motion in a straight line - except when it does not'.

Similar criticism can be made of the other two laws, particularly in eonnection with their testability. This had made some assert that these laws are not mere generalizations, but contain theoretical terms whose meanings go beyond their observational meaning. Thus it is held that these laws are conventional and regulative. Extreme versions of this type of view of all high-level theories, and not only of Newton's laws, are held by the relativist philosophy of science which came into prominence during the second half of this century.

All these, while indicating the basic problems in the revolutionary steps taken by Newton, also raised issues about his methodology. This is particularly so in view of his statement 'hypotheses non fingo', i e. "I feign no hypotheses" in the General Scholium to the *Principia*. This dictum perhaps provided an answer to critics like Leibniz that since the *Principia* offered no explanation (or cause) of gravitation, it was inadequate as a physical theory. But throughout his career Newton insisted on making a sharp distinction between doctrine consisting of those propositions inferred from the phenomena and hypotheses, that is, propositions which had not been so inferred. The possible criticism of his Laws of Motion and the Principle of Gravitation, indicated above, questions whether he could abide by such a distinction and maintain that he was not advancing hypotheses - even in his sense of the latter. It has been pointed out that the problem is not peculiar to Newton, for no general propositions can be inferred from the phenomena.

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[24] See e.g Grunbaum, Adolf - The Philosophical Retention of Absotute Space and Einstein's General Theory of Relativity, *The Philosophical Review.* Vol. LXVI (1957), pp. 525–534, reprinted in part in Smart, *op. cit.* pp. 313-17.

It can be seen that even in the case of Newton's work on light the same problems rise. For example, Newton, in his *Optics* "proved by experiments" the propositions that 'The Light of the Sun consists of Rays differently Refrangible'. But the underlying assumptions and definitions made these inferences rest on extra-empirical bases. The proof here rests on a definition of Rays of Light, which I quote.

Definition 1.

> "*By the Rays of Light I understand its least Parts, and those as well Successive in the same lines, as Contemporary in several lines.* For it is manifest that Light consists of Parts, both Successive and Contemporary : because in the same place you may stop that which comes one moment, and let pass that which comes presently after; and in the same time you may stop it in any one place and let it pass in any other. For that part of Light which is stopp'd cannot be the same with that which is let pass. The least Light or part of Light, which may be stopp'd alone without the rest of light, or propagated alone, or to do so suffer anything alone, which the rest of Light both not or suffers not, I call a Ray of Light." [25]

We see here a great attempt to "experimentalize" a Ray of Light, which concept is really an abstraction. This makes Newton make *substantive assumptions* about light and its nature. Newton's method, however much he tries to be inductivist (i e. generalize from empirical facts), it more akin to deductivism (i e theory predicting the empirical facts). Indeed, the *Principia* is written in the pattern of Êuclid's *Elements*, that is, in the form of a deductive system, but with less vigour. All the same when he lays claim only to propound mathematical principles which "co-ordinate" empirical data, one sees that an element of the present day positivist is also not lacking in him.

We could see that, to bring about the conceptual revolution which established the new world -view, Newton had either consciouly or intuitively but unwittingly made a large number of assumptions - or conceptual innovations. In him seem to be the mechanistic and the metaphysical, the inductive and the deductive, interwoven. Critics found the Newtonian system metaphysical first, but men forgot its mystical elements later on and Newton's *Principia* came to be regarded as the basis of the new mechanistic view of the universe. For the system therein worked, it led to new discoveries like that of Neptune. Not only in mechanics, even in the other branches of Physics like heat and thermodynamics, the mechanistic model reigned supreme. The eighteenth and much of the nineteenth century saw the world as a machine - a great clock work - whose blue-print as well as the handbook was the *Principia*.

Conclusion

That science has been, in general, a collective enterprise, this paper would have indicated. It has not remained static on one conception, however successful that

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[25] I reproduce this from the abstracts of a paper read by John Worrall on 'Newton and Hypotheses' at the History and Philosophy of Science Seminar in Cambridge University, 1983.

concepton might have been. Falsifiability is a characteristic feature of science. Newton's work was, as we saw, not readily accepted, Then it became, as it happened only for the second time in the history of the West, the paradigm of knowledge. But already minor dark clouds were gathering. There was no planet Vulcan to account for the perturbations of the orbit of Mercury. Some scientists like Kelvin (1824-1907) were thinking of returning to the earlier mechanistic view of the universe again with no action at a distance. But more importantly, field theories in physics were catching up to the second part of the nineteenth century, particularly after Clerk Maxwell (1831-1879). It was then that the irresistible Ernest Mach criticized the basic notions of the Newtonian system, in his *Science of Mechanics.*

Young Einstein, who was already contemplating on the foundational problems in Physics, had read Kant without being impressed, but Mach's *Science of Mechanics* fired his imagination. In two strokes of genius which spread a little over a decade - the Special ande General Relativity - Einstein rid physics of the mechanical model, absolute space and absolute time, and the action at a distance, which last, as we saw, Newton had tried unsuccessfully to evade.

With what better thought, then could one end this essay than Einstein's own salute to his great predecessor, written when Einstein was reaching seventy, in a piece which he himself called *his* 'obituary'.

> "Newton forgive me; you found the only way which, in your age, was just about possible for a man of highest thought and creative power. The concepts, which you created, are even today still guiding our thinking in physics, although we now know that they will have to be replaced by others further removed from immediate experience, if we aim at a profounder understanding of the relationships." [26]

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[26] Schipp, P A. - *Albert Einstein, Philosopher Scientist,* Vol I., New York, Harper Torchbooks (1959) pp. 31-32.