



MODERN SCIENCE

Threshold & Philosophical Problems

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The modern scientific revolution: major science areas of the revolution By Obi-Okogbue, J. is licensed under a [Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License](https://creativecommons.org/licenses/by-nc-nd/4.0/).

CHAPTER 8

THE MODERN SCIENTIFIC REVOLUTION: MAJOR SCIENCE AREAS OF THE REVOLUTION

The Renaissance would-be scientists found themselves working with traditional concepts and theories handed down from Aristotle through the scholastics. Most of these concepts and theories were functionlessly outmoded and constituted challenges and oftentimes outright obstacles to the emergence of modern science. These therefore required careful philosophical sifting and excising before science could be established.

By the close of the seventeenth century, it was observed that the scientific revolutionaries have executed some radical shifts in the fundamental categories of scientific explanation. Such that instead of explaining reality in terms of ancient categories such as causality, essence, idea, matter and form, substance and accident, potentiality and actuality, they now explain it in terms of modern categories such as force, energy, motion, laws, changes of mass in space and time, electricity and so on.

The scientific revolution is a revolution within science and a revolution about science. Excepting Christianity, no other landmark in the history of civilization is comparable to the seventeenth century scientific revolution.¹ Although the scientific revolution is a radical transformation and accelerated progress in several science-fronts, the deeper revolution occurred specifically as radical shifts in certain areas of science such as the method of science and the application of science. It is worthy of note that it was only when these revolutionary shifts had taken place that modern science properly so called was born.

A New Physical Model of the world: A Physical model of the universe is a coherent picture of everything known about the world. Every people have it. The ancient Egyptians had it. The last popular one in the history of Western civilization was the Medieval Model of the Universe described in the thirteenth century by Alighieri Dante (1265 – 1321). This model was in actual fact ancient Greek model

as formulated by Aristotle, Hipparchus and Ptolemy and Christianized by the theologians of the Church in the twelfth century.

The universe according to this model consisted of a stationary globe-like Earth at the centre of nine translucent and revolving spheres. The eighth of these spheres carry the Sun, Moon, five planets and the fixed stars. The ninth, the *premium mobil*, drives the whole thing round. Outside the ninth sphere is the tenth, Heaven, the eternal and infinite abode of God, which cannot be described in simple terms of space and time.

An outstanding feature of this Physical model is the distinction between the terrestrial and celestial realms. The radical break between the two realms occurred at the Moon. Beneath the Moon is the realm of imperfection, corruption and generation. Everything here is composed of the four elements of ordinary matter: earth, water, air and fire. None of these elements are found in pure state. All bodies are a composition of the four, but earth is the dominant element in solids, and water in liquids. The elements themselves are determined by two sets of more fundamental qualities. The first set comprises four qualities of hot, cold, wet and dry. The other sets of qualities are heaviness and lightness.

From the Moon outwards, the celestial or heavenly realm, is a plenum of a more quintessential or perfect type of matter, a fifth element, the *aether*. The plenum of this realm carry a number of spherical shells and by their nature (composed of *aether*), they move in uniform circular motion and with some fixed stars and planets. The motion here was not completely self-caused; ultimately Aristotle's First Cause or God moved the spheres, and sometimes Aristotle posited the existence of Resident Intelligences as movers of individual spheres.

Integral components of this model of the universe are the doctrines of natural places and motion. Terrestrial matter and celestial matter behave radically differently. Terrestrial matter is always seeking its proper (natural) place in the Universe: earth, the most humble element, seeks to be at rest in the lowest place possible, the centre of the Earth; water seeks to be above earth; air to be above water and fire above air. Earthy bodies such as stones, trees and apples have a tendency to fall towards the centre of the Earth; whereas fiery bodies tend to rise. If a body is not at its natural place than unimpeded it will move towards it. Horizontal (rectilinear) motions on Earth, as a matter of fact, are always as a result of applied force. In the fourteenth century, the theory of impetus was introduced to account for the continued horizontal movement of bodies like projectiles without anything pushing them. Impetus acting as internal force, according to the theory,

was implanted on the bodies when it was set in motion until resistance dissipates it. A cart, for instance, only moves if it is pushed or pulled and its speed is proportional to the applied force and to the resistance it encounters. When the force is removed the cart stops.

The four basic elements uninterrupted would sort themselves out into four concentric spheres like the spheres of heaven. But in reality they never do this because they are constantly being disturbed at the boundary of the two realms. As the sphere of the moon rotates it churns the outer layer of terrestrial matter and this prevents terrestrial matter from ever settling down. It follows that all motion on earth are due to the heavens.

Celestial matter, on the other hand, is not subject to change or decay and obeys a radically different law of motion. Being in its proper place, it has no tendency either to rise or to fall out of the sky, it moves sideways in perfect circles around the centre of the Earth. In this way the nine celestial spheres, carrying everything we see in the sky rotate about the Earth, each at its own speed. Each sphere is in the care of a resident intelligence, a sort of angel; and is driven by the love of God or in a later development of the theory, by impetus imparted by God. For many centuries this model answered almost all the questions which people asked or could care to ask about the origin, structure, and purpose of the world. As science advanced, however, it stopped to adequately address many of the questions raised by the budding scientists of the sixteenth and seventeenth centuries who eventually finally destroyed it.

The change from geocentric to heliocentric physical model was initially proposed by Aristarchus of Samos in the third century B. C. Aristarchus opined that this model simplifies the apparent motions of all bodies. One problem, however, remained intractable: "If the heliocentric model was true then the earth like the other planets, must rotate in a circle with the sun at the centre. At the end of a six-month period, the earth must be on the far side of its orbit about the sun relative to its starting position."²

The major attack on the Ptolemaic geocentric physical model was launched in 1543 by a canon of the Roman Church, Nicholas Copernicus. In his book *De Revolutionibus*, Copernicus revised Ptolemy's mathematical model by eliminating equant points and by taking the sun to be the centre of planetary motions. Copernicus' theory was a mathematical demonstration that heliocentrism was in principle a simpler and workable model than the Ptolemaic one.

Fully developed, however, Copernicus' model was as complicated as the Ptolemaic one, it also failed to predict the positions of the sun, moon and planets with any greater accuracy. The main reason for this failure was that Copernicus had retained the ancients' idea that celestial bodies must move in perfect circles at uniform speed. Because of its technicality, Copernicus' theory was regarded for over fifty years as a mere convenient computational device to save the appearance (calculate planetary positions). That notwithstanding, his book survived because of the simplicity of his model.

The astronomical revolution started by Copernicus raised three questions that must be successfully answered before his model or any other new model could stand. These questions are:

- If the planets are not really carried round the Earth by transparent spheres driven by the love of God or by impetus, then what makes them move?
- If they are not held in place by transparent spheres or guided by resident Intelligences then what holds them in their orbit?
- If as Aristotle taught, a heavy body falls to the Earth because it is seeking its proper place near the center of the Universe, how are we to explain its behavior if the center of the Earth – and therefore the center of the Universe – is moving?

The next assault on the credibility of the Ptolemaic model was rendered by Tycho Brahe of Copenhagen (1546 – 1601). He collected much data through a great deal of astronomical observation. In a little book *De Stella Nova*, he carefully recorded the sudden appearance of a bright star in the constellation of Cassiopeia in 1572. For a short time it shown as brightly as Venus and yet by the year 1574 it had disappeared. This apparently meant that something was wrong with the idea that celestial bodies are incorruptible and unchanging. Still a few years later, Tycho Brahe showed that the great comet of 1577 was at least three times as far away as the moon and as such was far beyond the terrestrial realm of change and decay, and well into the supposedly unchanging celestial realm. The comet raised two disconcerting questions:

- How was change possible in celestial realm?
- How did the comet travel through the solid translucent sphere?

The distinguished and enthusiastic mathematician Johnnes Kepler (1571 – 1630) struck the next devastating blow on the Ptolemaic model. In his book *Commentaries on the Motion of Mars* (1609), he analyzed the enormous and accurate observations of Mars bequeathed to him by Tycho Brahe. Kepler's work

is an induction and verification of three statements or laws, which formed the foundation of Newton's astronomy. Kepler's three laws are summarized as follows:

- 1 - The planets travel paths which are ellipses with the Sun in one focus.
- 2 - The area swept out in any orbit by the straight line joining the centres of the Sun and a planet are proportional to the time.
- 3 - The squares of the periodic times which the different planets take to describe their orbits are proportional to the cubes of their mean distances from the Sun.

In these short statements are encapsulated enormous knowledge about planetary motions of Kepler's time and earlier times. Kepler's first law implies that it is impossible to represent the motion of a planet by a circle or combination of circles because its orbit is an ellipse. This is a reversal of the ancient notion that celestial bodies move in perfect circles. Kepler also strongly advocated, having read William Gilbert's work on electrostatic attraction and magnetic effects: that in order for a body to behave as the planets apparently behaved in space there must be some kind of force to hold them in their curved paths. This implies discarding the translucent or the plenum spheres of ancient model.

Kepler believed that God created the world in accordance with the principles of perfect numbers, which express and govern the motion and structure of the heavens. So this underlying mathematical harmony, the music of the spheres, is the real and discoverable cause of planetary motions. Searching for the underlying mathematical harmony is the true inspiring force in Kepler's laborious life.

Kepler's law of planetary motion marks the decisive break with the tradition of speculative astronomy and the birth of a new physio-mathematical field – celestial mechanics, finally and firmly established by Isaac Newton.

Galilei Galileo (1564 – 1642) gave the most 'popular' polemics ever against the Ptolemaic model. In his book *The Two Chief World Systems* (1632); written in Italian for the purpose of popularizing the issue, he presented arguments that ostensibly favoured the Copernican system against the Ptolemaic model. He showed that the Copernican system was not a mere computational device to save the appearance. He advanced proofs for the physical truth of the Copernican system. With his telescope turned to the sky, he showed anyone that cared to look that there were mountains on the moon and spots on the sun which change from day to day. He also showed that there were moons which circle about Jupiter and not about the centre of the earth.

Galileo's book infuriated the Church, which had invested so much of her authority on the christianized Ptolemaic system. To suppress its spread, the Church put Copernicus' book in the Index in 1616 and put Galileo under arrest in 1633. But this was too late because the medieval model was crumbling irretrievably.

Added bits of attacks were coming from more scientists. Rene Descartes (1596 – 1630) forwarded the idea that a body will continue in a straight line unless it collides with another body. Robert Hooke (1635 – 1703) suggested that there must be a force of attraction between all bodies which holds the planets in their orbits and causes things to fall to earth. But no one could show how powerful this force on the planets would have to be, or how it would vary with distance in order that they would move in Kepler's ellipses.

Sir Isaac Newton (1642 – 1727) solved the puzzles and his solutions are contained in his great book *The Mathematical Principles of Natural Philosophy* (1687) known for short as *The Principia*. In part III of the book titled the System of the World, Newton completed the Copernican revolution and thus gave the world a new working model of the solar system. He showed mathematically how the motions of everything we see in the sky – stars, sun, moon, planets and comets – can be explained and predicted by three simple laws of motion and one law of universal gravitation. He also showed that these same laws govern the motions we see on earth, from the rise and fall of the ocean tides to the behavior of projectiles and the fall of apples. Thus Newton's system of the world answered the key questions.

The first question "what makes the planets move?" was answered by Newton's first law of motion. It states: every body preserves in its state of rest or of uniform motion in a straight line, except in so far as it is compelled to change that state by impressed forces. The other two questions were answered by Newton's second law of motion [change of motion (i.e. the rate of change momentum = mx) is proportional to the moving force impressed, and takes place in the direction of the straight line in which such force is impressed], and by his law of universal gravitation. This law holds that the planets and the moon are held in their orbits by the force of gravity. To account for this and for the acceleration of falling bodies on earth, Newton showed that there must be a force of attraction between two bodies proportional to the product of their masses and inversely proportional to their distances apart. He also demonstrated mathematically that the force of attraction exerted by a large body, like the earth, acts as though all of its

mass is concentrated at its centre. A falling apple is really attracted to the centre of the moving earth.

Newton's system of the world broke the ancient barrier between the divine and incorruptible heavenly sphere of Aristotle and the imperfect and changing terrestrial sphere; and in so doing unified terrestrial and celestial mechanics.

Newton's system of the world is a radical change from the geocentric plenum model of Aristotle, with its homocentric implications to heliocentrism, which sends man and his earth to the periphery. In heliocentrism, the earth like other bodies was spinning on its axis and orbiting about the sun. And man becomes a mere rid or speck in the general scheme of things.

A NEW CONCEPTION OF *PHYSIS*: The modern scientific revolution was grounded in a new conception of nature. By the seventeenth century, it was widely appreciated that a radical transformation was taking place in the way nature was being conceived.

The fundamental issues of natural philosophy which primarily concerned leading thinkers in the first quarter of the seventeenth century was the problem of what nature was; that is, what was that which naturally existed? What was that existent which constituted nature? Still put in another way, what was the primary physical existent? In this question, the term physical is synonymous with natural. Another formulation of the question is, what is the nature of that existent with which the science of physics is primarily concerned?

This new conception of nature in philosophy reflects in books published from about 1620 by such thinkers like Galileo in Italy and Francis Bacon in England. This new conception was fully developed by the Frenchman Sebastian Basso in his *Philosophia Naturalis* (1621). This new conception of nature was further fully elaborated during the seventeenth century by thinkers such as Descartes in his *Principles of Philosophy* (1644); Gassendi, in a number of books, worked out the theory of material atomism; Thomas Hobbes in his *De Corpora*; Leibniz in a series of monographs, articles, and letters; Newton in his *Philosophiæ Naturalis Principia Mathematica* (1686).

The answer of the seventeenth century to this question of the physical existent, the answer which determined subsequent development of the science of physics, the science of nature, and also many others, down into this century, this answer was that the physical existent was matter.

Antecedent thought, that is, ancient, traditional, Aristotelian thought, held that any individual thing was composed of matter and form. Example: marble matter could be shaped into the form of a bust of Socrates. But things change, seeds grow into trees, and the bust of Socrates loses an ear. Some changes are accidental in the sense that they involve no substantial change. Something, however, had remained constant throughout these changes, and it was this, which was seen as the substantial form. There was clearly something which made a dog a dog, a cat a cat, and Socrates Socrates, despite changes in his appearance – this was the substantial form.

Characteristically, the ancients used the concept of the substantial form to explain virtually every natural phenomenon. Puteanus, for instance, explained the attraction of the lodestone in terms of its substantial form. Thus modern thinkers became suspicious of the concept and criticized it. Robert Boyle, for instance, complained in his *Origin and Form of Qualities* (1666):

For if it be demanded why jet attracts straw, Hubbard purges choler, snow dazzles the eyes rather than grass, etc., to say, that these and the like effects are performed by the substantial forms of the respective bodies, is at best to tell what is the agent, not how the effect is wrought.³

Other thinkers joined in denigrating the concept of substantial form. John Locke retorts that besides the figure, size and posture of the solid parts of bodies, he knew not what forms are. Descartes argued that it is quite unintelligible to suppose that these qualities or forms could have the power subsequently to produce local motion in other bodies.

The seventeenth century new conception of nature as matter radically diverged from antecedent thought in a number of respects. In the first place, antecedent thought takes the concept of matter to be merely a principle, a correlative of form, as that which was formed, as that which takes form. Matter was not something capable of separate existence. It could only exist as formed. In itself, matter lacked definiteness. All definiteness was due to form. In the seventeenth century, the revolutionary step was taken of conceiving matter as the independent physical existent, as the actual existence, as the self-subsistent stuff (capable of existing separately). Matter is fully 'being', that is, it is not subject to 'becoming'; matter always *is* and always is *what it is*; That is, matter is completely without any capability of internal change, either by itself or of being

changed by anything else. Matter in itself is entirely unchangeable. As Newton says, matter is movable but it cannot move itself.

Thus, in the seventeenth century as in antecedent thought, matter retained its passivity but diverged from antecedent thought in its relation to the concept of motion. For Aristotle, *Kinesis* (motion) was the internal process of change involved in becoming in the process of actualization of potentiality. That is, in Aristotelian thought, change is either qualitative alteration, quantitative alteration or *phora* 'change of place'. In the new conception, because matter is fully actual, passive, just what it is, not involved in any process of internal change, only *phora* 'change of place' or *locomotion* is the possible motion for it. Thus in the new conception of motion becomes synonymous with locomotion.

With the new conception of motion came a new conception of physics (as the science or knowledge of nature). In modern conception as in Aristotle, physics is grounded in *Kinesis* (motion). But while in Aristotle *kinesis* (motion) pertains to the physical as inner process of change, of becoming, to know the physical was to understand its inner process of becoming or actualization. And this means that for Aristotle physics was inseparable from metaphysics. For the seventeenth century scientific revolutionaries, *Kinesis* (motion) pertains to the physical existent only as a change of place. Thus the science of physics is in terms of the motion, the change of place, of bodies. In the seventeenth century, the science of physics is thus a pure kinetics or *phoronomy*. This still entails, as Descartes observes, a connection between physics and metaphysics; but it does not make the science of physics dependent upon metaphysics as *Aristotlelians* made it. But metaphysics is not irrelevant to physics, any thinker concerned with the subject of physics is explicitly or implicitly led to metaphysics.

The seventeenth century new conception of matter as substance led to an inescapable metaphysical dualism systematically developed by Descartes and generally accepted thenceforth. The universe was divided into two: one part was *res extensa*, matter (nature); the other part was *res cogitans*, mind or spirit. The field of enquiry was divided accordingly: natural science studies the realm of nature, with its implications of corporeality, extensivity, geometricization or mathematicization; and philosophy studies the realm of the mind. Thus from the seventeenth century these two, science and philosophy, started the steps to go their separate ways. In the new scheme of things matter became the principal object of scientific investigation and there was no place for the philosophy of nature; its subject having been taken over by natural science. What remained for philosophy

to investigate were only the epistemological and logical enquiries, which have natural science but not nature as its object – this is today usually called the philosophy of science. Philosophy of nature as a field of enquiry virtually ceased to exist.

A NEW CONCEPTION OF PHYSICS: Physics is an account of natural phenomena. It is the investigation of the visible world of things; an account of the material world. It implies the knowledge of the basic constitution and operation of physical events and processes.

Plato's physics or theory of nature is found mainly in his *Timaeus*. Plato recorded that Socrates desired to understand physics but was disillusioned by the conflicting theories put forward by earlier philosopher-scientists: Anaximander, Anaximenes, Leucippus and Democritus. Plato shared Socrates' disillusionment because as his investigations show, the theories of physics could never be more than "a likely story", being an account aimed at making *phenomena (appearance)* intelligible.

Plato's theory of *Forms* all the more renders physics as an exact, accurate, scientific knowledge impossible. The real world, according to Plato, is the world of Forms; whereas the visible world is full of change and imperfections. Yet it is the visible world of things, with all its change and imperfections, that physics is concerned to give account.

Although Plato concluded that physics can only be "a likely story" or probable knowledge, he was determined to make sure that he said things about the visible world that was as accurate as the vagaries of the subject-matter allowed. Plato believed that although the visible world is full of change and imperfections, it still exhibits order and purpose. In this way, he rejects the Epicurean-inherited Democritean account that things came into being through the accidental collision of atoms.

To Epicurus, the origin of everything is explained by the notion that there is no beginning to the atoms. Atoms have always existed in space. Like raindrops they were at a time separately vertically falling in space without resistance and of the same distance apart from each other. As they dropped, one atom gradually and slightly tended to the side in a lateral 'swerve'. Eventually, this atom moved into the path of another one, and the resulting impact forced both of these atoms into the paths of others thereby setting in motion a whole series of collisions until all atoms have been formed into clusters. These clusters or arrangements of atoms are

the things we see now. Consequently, nothing, including Gods and humans, is the product of creation or purpose, but rather the accidental product of the collision of atoms.

Plato rejects this accidental account of things. He believes that although this world is full of change and imperfection, it nevertheless exhibits order and purpose. The orbits of the planets, he observes, are arranged according to a precise series of geometrical intervals, which, when appropriately calculated, produced the basis for the harmonic scale. Plato made much of the Pythagorean use of mathematics in describing the world, though instead of saying like the Pythagoreans did, that things are numbers; he said that things participate in numbers, that they are capable of mathematical explanation. This mathematical characteristic of things suggested to Plato that behind things there must be not merely chance and subsequent mechanism but rather thought and purpose. The cosmos must therefore be the work of *intelligence*, since it is the mind that orders all things. Man and the world strike a likeness to each other for both have first an intelligible and eternal element, and second a sensible and perishing element. In man you have the dualism of the union of body and soul. In the world you have world as a soul in which things are arranged.

Although Plato says the mind orders everything, he bypasses the doctrine of *creatio ex nihilo* in his explanation of the origin of the visible world. And although Plato holds that "that which becomes must necessarily become through the agency of some cause", and this agent he calls the Divine Craftsman or Demiurge, yet it does not bring new things into being but rather orders what already exists in chaotic form. Thus in explaining the generation of things in the visible world, Plato assumes the existence of the ingredients of things; namely, that out of which things are made: the *Demiurge* who is the craftsman, and the ideas or forms or patterns after which things are made.

Plato departed from the materialists who taught that all things derived from original kind of matter whether in the form of earth, air, fire or water. Matter, according to Plato, could not be the basic reality, a more refined thing other than matter must explain reality. Matter whether in the form of earth, air or water is a reflection of Idea or Form, and this Form is expressed through a medium, the receptacle, considered the "nurse of all becoming". The receptacle is a matrix or a medium that has no structure but is capable of receiving the imposition of structure by the *Demiurge*. Plato also calls the receptacle space – that which "is everlasting, not admitting destruction, providing a situation for all things that come into being,

but itself apprehended without the senses by a sort of bastard reasoning and hardly an object of belief.” There is no explanation of the origin of the receptacle, for in Plato’s thought, it is underived, as are the forms and the *Demiurge*. The receptacle is where things appear and perish. Plato wishes to assert that matter is the appearance of something more basic. The world of things is the world of phenomena – appearance. Things are analyzable into geometrical surfaces. These surfaces are primary and irreducible and are found as raw materials in the receptacle and requires some organizing agency to arrange them into triangles and then into phenomena. All this is achieved by the World Soul, which is eternal and the world of appearance, is full of change.

Aristotle’s physics found mainly in his book, *On the Heavens (De Caelo)*, begins with the notion of *prime matter*. Aristotle rejects the position that either pure form or pure matter could exist separately. There is no primary matter existing by itself anywhere. By prime matter Aristotle means the substratum in things that is capable of changing, of becoming other substances or things, of assuming novel forms. The processes of nature, therefore, involve the continuous transformation of matter from one form to another. According to Aristotle, the matter out of which everything on earth is composed are earth, water, air and fire; but the heavenly bodies consist of a quite different element, a fifth element, the *aither*. Aristotle also has the notion of four causes: efficient cause, material cause, formal cause, and final cause. The final cause means the natural end or natural purpose of natural events and processes. Aristotle applies a combination of the elements and the final cause to explain motion; and to account for the whole process of generation and corruption. The elements have naturally within them the “principles of motion and rest”. It is the final cause or natural end of fire and air or things of these natures to rise rectilinearly up. It is the final cause or natural end of earth and water or things of these natures to fall rectilinearly down towards the centre of the earth at the centre of the universe. Aristotle asserts that the rate of fall is directly proportional to the object’s weight; that is, a 10-pound body would fall ten times as fast as a 1-pound body. He also asserts the retarding influence of a viscous medium like water upon the natural falling body. He asserts that the denser the medium, the slower the motion of a body. Thus he declares that speed is inversely proportional to the density of the medium. Therefore in a vacuum where no medium exists, the speed of a falling body would be infinite.

The motions of the heavenly bodies are different. The heavenly bodies make regular, eternal, circular motion. This is because they are constituted of *aither*, and

it is the natural end of *either* to so move. Circular motions are by Aristotle considered the most perfect motion.

Besides the rectilinear and circular natural motions, there can of course be motion in other directions as when a heavy object such as a stone, an arrow or a projectile is thrown into the air. Such a motion is not natural but enforced or imparted for Aristotle as for Descartes later. In *De Caelo* Aristotle declares: "Nature is a cause of movement in the thing itself, force a cause in something else..." Things move and change and become according to their own nature. This is the root meaning of *Nature*. Natural Science (Physics) therefore, is the study of the potentialities and behavior of things. The unnatural is imposed and generally destructive.

Doubts over Aristotle's accounts of motion started mainly with his account of enforced, unnatural or violent motion. Aristotle had explained that a projectile needed not only a mover but also a conjoined mover that continues to provide force. In the case of the projectile, Aristotle relies on the medium. After the projectile is shot out from the projector, it pushes the air aside and the air streams and circles behind the projectile to continue to give it further push – this streaming of air behind prevents a vacuum. According to Aristotle, a vacuum could not exist, as space must be filled with matter to transmit physical effect by direct contact. So the atomists were wrong about atom and void as the only existents. The impetus theory account of motion prior to the seventeenth century scientific revolution was self-evident, philosophical and qualitative explanation. Being so, little progress could be made in understanding and accounting for motion until Aristotle's misconception about motion were cleared: that is, until it was shown that motion could be analyzed independent of medium; and bodies could move without a conjoined mover. Criticisms started from the sixth century. John Philopones in his sixth century commentary on Aristotle's *Physics* accepted the outlines of Aristotle's impetus theory: the doctrine of natural motion and the incompatibility of mixed motion but objected that the arrow's motion depended on the medium. He remarks: if the arrow's motion depended on the medium, then the bow itself could be ignored. He asked, why not place the arrow in the tip of a stick and without touching it, attempt to move it by directing large amount of air behind it? He answers: even if we use all possible force in this way, "the projectile would still not move as much as a single cubit." It is instead more reasonable to "suppose that some incorporeal power is transferred from the projector to the projectile, and that the air set in motion contributes either nothing at all or else very little to the

projectile's motion."⁴ And as the moving force is removed, impressed force or impetus gradually wears out. When it is finally worn out, gravity, which was initially inoperative takes effect and the projectile dropped under natural motion; thus maintaining the incompatibility of mixed motion. But the old idea that speed increases as goal is approached is dispensed with. Impressed force also helped to regard speed as the quality of the moving body. The impetus theory reached its height of sophistication in the fourteenth century when it was used to explain even celestial motion.

The use of final cause to account for the physics of motion was also severely criticized. The place of purpose in biology is reasonable, for instance, one could reasonably talk of the purpose of gills in fish; but the use of purpose as explanation in the physics of motion, the purpose of the fall of an apple, for instance, was perceived as over-generous (really explaining nothing). And so Descartes sought to expel it from science completely. In the *Principles of Philosophy*, he says: "*it is not the final but the efficient causes of created things that we must enquire into.*" To do otherwise would be to assume that "*we can share in God's plans.*" And on his own part, Boyle shunned all arguments, which suppose "in nature and bodies inanimate, designs and passions proper to living and perhaps peculiar to intelligent beings."⁵

Galileo in the late sixteenth century, in his work *On Motion (De Motu)*, began to quantify or mathematicize motion by concentrating on distance, rate and time of motion ignoring medium and weight of falling body as of no value. Galileo's efforts belonged to the general tradition of Tartaglia, G. B. Benedetti and Bonamico (Galileo's Pisan teacher). These tried to mathematicize the impetus theory of dynamics. This sixteenth century attempt failed because impetus was a qualitative not quantitative force. But this failure made Galileo realize the necessity for a new dynamics that should satisfy both the Archimedean demands for an expression appropriate to abstract magnitude moving through geometrical space and the exigencies of real bodies rolling down physical inclined planes.

In the first chapter of *De Motu*, Galileo broke with Aristotle by denying the existence of light bodies. Lightness, he says, is relative. Apparently light bodies move upwards because heavy ones fall down below them, but in reality all bodies are more or less heavy. This perhaps was derived from Archimedes's hydrostatics. He is concerned with the rise of light bodies in water as with the fall of heavy ones in air, and so he regards the resistance of the medium (air or water) as a kind of buoyancy which supports less dense bodies more effectively than it does more

dense ones. In summary, he is saying that bodies fall at speeds proportional to their densities (not their weights as Aristotle holds) less the density of the medium. Or, as he says, speed will be “measured by the difference between the weight of a volume of the medium equal to the volume of the body, and the weight of the body itself.” Thus, in air, for instance, objects made of the same material, having the same density, would fall at the same speed, irrespective of their weights. If one has two objects of the same weight, however, the denser would fall faster. If the density or buoyancy of the medium were to be progressively decreased, then the objects would fall progressively faster until in the limit (i.e. in a vacuum) their speeds would be proportional to their densities. Thus motion in a vacuum is possible, Aristotle’s claim to the contrary notwithstanding.

From thence, Galileo derived peculiar notions about acceleration in free fall. According to him, a falling body has first to overcome the force, which placed it in position, so its initial motion is accelerated motion. Once its characteristic speed of fall is attained, there is no further acceleration; there indeed cannot be any because, a constant force must produce a constant speed. Since heavy bodies have a greater force to overcome, they attain their characteristic speed more slowly than light ones. By this reasoning Galileo was able to deny Aristotle’s contention that unopposed natural motion would be infinitely swift, as in a vacuum, and thus opened the way for later consideration of the speed of bodies falling with no resisting medium. From a consideration of inclined planes, he later reversed himself and asserted that inertial motion was possible. And following-up Johnnes Kepler’s three laws of planetary motion and his assertion that the planets require some force (Kepler has in mind intelligence) to push them, to keep them moving in their orbits; Galileo suggested that every body, even one as huge as a planet, tends to move in a straight line (because of inertia) but since the paths of a planet in the heavens was actually an ellipse, one had to account also for the modification of this natural tendency – by a force. Strangely, Galileo failed to discover this force even as he has discovered that gravity pulls a projectile when impressed force wears out.

Rene Descartes (1596 – 1650) is a younger contemporary of Galileo. He invented new mathematical methods useful in physical science. He asserts that to be a body is to be extended. And extension means being filled with matter. Extension devoid of matter is a contradiction. Therefore, no vacuum can exist in nature. And there is one kind of matter in the universe, and that all the properties of matter which we perceive can be explained in terms of its division into parts

and the motion of these parts. The only events which physics has to consider are the transfers of motion between particles and the changes in the direction of their motion.

Descartes thus affirms the atomist ideal of accounting for qualitative changes at the macroscopic level in terms of quantitative changes at the submicroscopic level. He restricted the subject-matter of science to those qualities that may be expressed in mathematical forms and compared in ratios. Hence, he called for a universal mathematics to unlock the secrets of the universe. He also holds the view that all motion are transmitted by physical contact; therefore he espouses a mechanical philosophy.

Isaac Newton (1642 – 1727) is usually given credit for being the first to state explicitly the three laws of motion. But Kepler had formulated the three laws of planetary motion and Galileo clearly understood the principles of inertia. Newton in real terms was just building on the foundation laid by these science-giants. His three laws of motion, which in harmonizing celestial and terrestrial physics of motion summarizes his description of the universe, are as follows:

Law 1: A body continues at rest or uniform motion unless affected by force imposed on it. This is the law stipulating the principles of inertia (the natural tendency to resist change); and it says in effect that every body which is at rest tends to remain at rest; every body which is in motion tends to remain in uniform motion in a straight line. To put a body into motion force is needed. To stop a body in motion force is needed. Therefore forces are changers of motion. Uniform motion means that a body traverses equal distances in equal time interval. The usual motion of an automobile, 40 mi/hr, for instance, is not uniform but average speed though in solving algebraic problems, it is often treated as uniform speed. The concept of uniform motion is an idealization.

Law 2: The change of motion is proportional to the motive force applied, and is in the direction of that force.

Just as lengths of objects are measured in feet or meters, and masses in pounds or kilogrammes, forces are expressed in units called dynes, newtons or poundels. Newton's second law tells us how to relate these units of forces to other properties. The mathematical expression for this law is:

$$\mathbf{F} = m\mathbf{a}$$

Where **F** is the force, **m** is the mass, and **a** is the acceleration.

This is a novel concept. Acceleration as the term is usually employed is more correctly identified with uniform acceleration. Uniform velocity means traversing equal distances in equal time intervals; uniform acceleration means equal velocity changes in equal time intervals. Uniform acceleration results from the action of a constant force. If the applied force increases or decreases, so will the acceleration. Newton's second law $F = ma$ may also be written in the form:

$$W = m \cdot g$$

Weight = Mass. Gravitational acceleration

Law 3: To every action there is always opposed an equal reaction. These accounts of motion are counter-intuitive, and they differ greatly from the Aristotelian account accepted without question till the fourteenth century when it started to be seriously challenged. The idea of instantaneous velocity, which to us now is very obvious, was a stumbling block. A greater stumbling block was the new idea of steady motion without a cause. It was previously assumed that for continuous motion there must be continuous force. But this only holds where there is friction which is absent in the heavens. Before this was realized, it was assumed that planets were pushed round by intelligent angels.

Newton also espouses a mechanical philosophy for he writes in his *System of the World*:

I am induced by many reasons to suspect that all the phenomena of nature may depend upon certain forces by which the particles bodies, by some causes hitherto unknown, are either naturally impelled towards each other, and cohere in regular figures, or are repelled and recede from each other The whole programme of science is, from the phenomena of motions, to investigate the forces of nature and from these forces to demonstrate the other phenomena.⁶

Even though Newton is here applying the force of gravity, which apparently operates without physical contact, his philosophy with that of Descartes is nonetheless together classed as mechanical philosophy. He hopes that mechanical explanation of gravity would eventually be discovered but until then he was prepared to make use of the idea without such an explanation yet.

The new mechanical approach to science worked best with the science dealing with matter in its most abstract and general form, amenable to mathematical descriptions, simple observations and experiments: such sciences as mathematics itself, astronomy, mechanics (statics, dynamics, hydraulics) and

optics. These were brought to a new excellence during the seventeenth century. Thus in the seventeenth century, the pride of place given by the scholastics to the Aristotelian substance and quality was transferred to matter.

Seventeenth century mechanical philosophy especially Newton's removed cause and with cause intelligence from the planetary system. It is curious that for Plato, highly regular motions were a sign of intelligence, while by the seventeenth century, the complex motions of the planets implicate the absence of cosmic intelligence.

How does the new mechanical philosophy excise intelligence from nature when ancient mechanical philosophy, like Ptolemy's epicycles and mathematically expressed laws, failed to do so? In the first place, the new mechanical philosophy, following Descartes, applied only to matter, which was regarded as absolutely separate from spirit. Secondly, Newton's *Principia* (1687) shows that no external controlling forces nor their maintenance, are needed in the scheme of things; because a frictionless mechanism would continue forever. It is the development of nearly frictionless clockwork in the sixteenth and seventeenth centuries that may have led to the concept of self-maintaining mechanism having no frictional losses. This, at one stroke, removed the need for a Machine-Minder for the heavens; or the need of falling objects to aspire to reach their proper (natural) places in the scheme of things. The new symbols now are measurable quantities such as mass, force and velocity, the algebraic symbols of Newton's laws of motion.

A NEW CONCEPTION OF GRAVITY:

One of the most important seventeenth century transformations in science occurred in the conception of gravity. The seventeenth century conception of gravity is quite different from the ancients. The seventeenth-century scientific innovators conceived gravity as the attraction between two bodies depending on the amount of matter which those bodies contain, and on the distance which separates them, the force being reciprocal. For the ancients, and this includes the Middle Ages, the force of attraction is considered to be more the property of geometrical point (positions) rather than of an aggregate of matter.

In Aristotle's system of the world, everything had its naturally appointed place, and they were attracted to return to it if they were displaced. Stones, for instance, fell towards the Earth because they were seeking to return to their natural place at the centre of the Earth, which is at the centre of the universe. Airy and fiery things were attracted to a station below the orbit of the moon because that

was their natural place. So among the ancients, nothing attracted but natural positions.

Such a conception of gravity met with difficulties in the Copernican system. Copernicus theory demonstrates that the Earth could not be the centre or at the centre of the universe, yet earthly and watery things continue to fall towards it. Thus, he conceived gravity as the tendency of aggregates of matter to congregate together in the form of a sphere anywhere they might be, not necessarily at the centre of the Earth. In such a conception, each body: the earth, sun, moon and planets, had its system of gravity so that a stone in space would fall towards the nearest heavenly body. But he still thought of geometrical points as being the foci of gravity. Copernicus did not believe that the bodies of the solar system exerted an influence upon each other by virtue of their own private systems of gravity. For him the arrangements and motions of the heavenly bodies were natural and not determined by gravity or any other mechanical scheme.

Copernicus did not categorically say what the matter of interplanetary space was, but he was said by Kepler after him to believe that heavenly bodies were imbedded in solid crystalline shells which rotated one inside the other and carried the heavenly bodies on their courses.

Such a view of the arrangement and motion of the heavenly bodies had to be abandoned when Tycho Brahe and others in 1577 observed the orbit of a comet across the skies, and noted that it moved through the solar system, cutting across the supposed solid crystalline shells. Consequently, if the solid crystalline-shells theory is disproved, the question "what preserves the arrangements and causes the motion of the heavenly bodies?" re-appears. And there had always been the possibility that the heavenly bodies moved of their own accord independently of each other and had no regular order.

Early modern scientists, however, strongly believed that the sun, moon, earth, and planets, together constitute a system, with a common centre, and united by a single principle upon which all the diverse regular movements of the heavenly bodies are based. In 1600 William Gilbert suggested that the principle holding together the solar system was magnetism. Gilbert did experiments with spherical loadstones and showed that lodestones exerted influence upon objects at a distance. He took the earth to be a giant lodestone with rocks and soil as superficial covering. So as the lodestones exerted magnetic influence upon objects at a distance, so the earth exerted gravitational influence upon surrounding objects;

and that gravity extended throughout the solar system, acting as an integument of the system.

In one of his experiments, Gilbert showed that the magnetic force exerted by a lodestone upon a given piece of iron increased with its size. The greater the mass of the lodestones, the greater its attraction for the piece of iron, the action being reciprocal, that is, the lodestone attracted the iron as much as the iron attracted the lodestone. Thus the properties of magnetic force as investigated by Gilbert became the model for the modern conception of gravitational force: concrete masses of matter rather than geometrical points were the foci of gravity; the force increasing with the amount of matter.

Gilbert, much like Tycho Brahe, however, believed that the planets moved round the sun, while the sun and planets as a whole moved round the earth at the centre of the world. But he is different from Tycho Brahe and agreed with Copernicus that the fixed stars are stationary and that the earth rotates on its axis daily. Gilbert holds that all the bodies in the solar system mutually influence each other's movement through the interaction of their magnetic forces: there was no Prime Mover controlling their movement from outside.

Gilbert's theories were temporarily very influential and they were applied by Johannes Kepler to explain why the planets moved in elliptical orbits. Kepler also developed Gilbert's conception of gravity believing it to be "a mutual affection between cognate bodies tending towards union or conjunction, similar in kind to magnetism" such a force of gravity between two bodies was dependent upon their masses. The earth was fifty three times as large as the size of the moon. Kepler incidentally did not have the concept of inertia, so he believed it was 'animal force or some equivalent' that kept the bodies of the solar system moving. Like Gilbert, Kepler accepted the cosmic values of Copernicus: the earth was much the same as the other planets whilst the sun ruled the universe, possessing a special sort of magnetism (magnetic effluvia) which impelled the planets round their courses, and distorted their orbits from circles into ellipses. So while Kepler accepted the old mechanical notion that a moving body required a constant application of an impelling force to keep it moving, Galileo stuck to the old astronomical view that the motions of the planets were circular and uniform. His principle of inertia laid it down that natural motion was circular and uniform. Thus both failed to assimilate each other's work and so while each of them could have brought together astronomy and mechanics neither of them did.

Descartes, like Galileo, believed that the planets moved in circular orbits with uniform speeds and not in elliptical orbits with varying speeds as Kepler had discovered. Descartes too rejected the idea that there was such a thing as a force of gravity operating between aggregates of matter across empty space. Hence he criticized Galileo for determining the laws of the free fall of bodies without first ascertaining whether the fall of bodies could be free. Descartes held that matter and extension were co-terminus and so space was filled up with matter and therefore nothing could fall freely. The fall of stone to the earth, for instance, was due to the suction effect of the vortex of matter, which surrounds the earth. In the same vein, the circular orbits of the planets were due to the suction effects of the vortex matter surrounding the sun, which distorted the natural straight line motions under inertia into circle.

The views of Descartes were very influential and so served to divert attention from the unfolding problems of gravitational force. Even, one of the followers of Descartes, Christian Huygens (1629 – 95) performed experiments that apparently supported the vortex views of Descartes. Huygens' more important contribution is in circular motion. He discovered that a centripetal force was required to keep a body on circular motion and he determined the law governing such a force. But in the case of the planets he failed (perhaps owing to his adherence to Descartes) to see that this force was provided by gravitation.

Kepler's theories were revived in 1666 by Alphonse Borelli (1608 – 78). He suggested that a balance of two opposing forces caused the elliptical orbit of planets. In the first place, there is the force of gravity attracting the planets to the sun; and secondly, there is a centrifugal force tending to move the planet away from the sun – similar to the force exerted on a stone when it is whirled in a string. However, Borelli stuck to the impetus theory of mechanics and so like Kepler, he supposed that the planets were impelled round their courses by rays of force radiating from the sun and rotating with the sun like the spokes of a wheel. He was of the view that bodies tended to be naturally in a straight line, not in a circle as Kepler and Galileo had believed, so that a force of gravity from the sun was necessary to constrain the planets to move in closed orbits. Borelli, however, was unable to find exactly how great a force of gravity was required to bend the natural straight-line motions of the planets into the ellipses observed; hence his theory of planetary motion remained a conjecture.

With Galileo's modern conception of the principle of inertia neatly in place – i.e. that unimpeded the motion of a body is in a uniform speed in a straight line.

The problem of accounting for the motions of the heavenly bodies in mechanical terms resolved into two main sub-questions: First: the question of determining the law governing the centripetal force necessary to bend such linear motions under inertia into circular or elliptical motions. Second: the question of demonstrating that gravity could provide the centripetal force constraining the planets to move in closed orbits. This required deriving the law governing the variation of gravitational force with the distance between the gravitational bodies.

In 1685 under the prompting of Halley, Isaac Newton proved that a sphere of gravitating matter, such as the earth or the sun, attracts bodies outside it as though all its mass is concentrated at the centre. This demonstration justified the simplification by which the sun, the planets, the earth and the moon were taken as massive points, and raised conjectures or rough approximate calculations into proofs of great accuracy. J.W.L. Glaisher underscores the significance of this landmark demonstration in the following lines:

No sooner had Newton proved this superb theorem – and we know from his own words that he has no expectation of so beautiful a result till it emerged from his mathematical investigation – than all the mechanism of the Universe at once lay spread before him.... It was now in his power to apply mathematical analysis with absolute precision to the actual problem of astronomy.⁷

This successful demonstration, and the then available Picart's new accurate measurement of the earth, etc, cleared the way for the old question of gravity and other questions. Newton could then prove that the earth's force of gravity provided exactly the centripetal force required to keep the moon in its observed orbit. In the same vein, he showed that the gravitational field of the sun accounted for the observed motions of the planets according to Kepler's laws, and that comets moved in approximately parabolic paths round the sun. Newton also showed that the tides were as a result of differential gravitational effects of the sun and the moon upon the oceans. He showed that very high tides occurred at new and full moons when the gravitational pulls of the sun and the moon act together whilst low tides occurred at the quarters when the pulls tend to neutralize one another. In short the whole intricate movement of the solar system could then be deduced from the one assumption that each particle of matter behaved as though it attracted every other particle with a force proportional to the product of the mass and inversely proportional to the square of the distance between them. The

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movements so deduced were found to agree accurately with those observed for two centuries. Newton's demonstrations were later incorporated in the *Principia Mathematica* which was completed by late 1686 but published in 1687.

REVOLUTION IN THE METHOD OF SCIENCE: The expression "scientific method" evokes a belief in a "...binding, unchanging, exceptionless algorithmic rules"; a pervasive, all-powerful, universal, straight-jacket procedure that once discovered was there to be mechanically applied and scientific breakthrough will result. This kind of belief has always been there in the history of western thought. In the thirteenth century, the *Ars Magna* of Ramon Lull had such a universal pretension. Later, *Monas Hieroglyphica* of John Dee and *De Arte Combinatoria* of Leibniz all had such universal pretension. Today such a belief exists about scientific method. Pervasive though it is, such a belief is naïve for as Harry Girvet and co say: "The scientific method does not constitute a master plan or a single model and if the phrase does indeed suggest such a plan or model, then it can lead only to over simplification."⁸

The scientific method does not in actual fact possess such universal claims, as many are wont to believe. Just as discoveries are always made in other aspects of science, so it is made in the area of methodology. The procedures of science continue to be reformulated in the course of investigation, and as the subject-matter changes. Consequently, scientists themselves scorn methods that make universal pretension.

Sure, science has many techniques but only one method. As a rational activity, argument and the presentation of evidence advance science. And since the time of Aristotle, the nature and classification of argument have been a central concern of philosophy. The nature of scientific argument – scientific method – has been the concern of philosophy from the earliest time.

Aristotle's book outlining the scientific method is called the *Organon* (Latin for Instrument or tool). Bacon's book analyzing the scientific method is called the *Novum Organon - the new Instrument*. Bacon used the term "new" consciously to underscore the revolutionary nature of the transformation he was instigating in the method of doing science in the seventeenth century. The development and application of the new scientific method is a central feature of the seventeenth century scientific revolution.

The ancient method, otherwise also variously referred to as antecedent method, the Aristotelian method, the Euclidean, Archimedean, Medieval, Neo-

Platonist or scholastic ideal of method, was a deductive procedure. For the ancients, the structure of a completed science ought to be a deductive system of statements.

In his formal work on methodology, the *Posterior Analytics*, the second part of the *Organon*, Aristotle stresses that the method of investigation in natural science is a procedure of deduction of conclusions from principle. This he called *a-Podeixis*, *demonstration or deduction*. He holds that demonstration is deduction because like Plato he believes that knowledge strictly speaking is irrefutable; and deduction is the procedure that warrants its conclusion. Demonstration means, according to Aristotle, to go from something in some sense better known to something less known. That is, to go from something which is self-evident because it carried its own warrant intrinsically, such as a first principle, a philosophical principle or Euclidean axiom, to something which received its scientific warrant from its being derived from the first principle (or definition). A first principle (or definition) is self-evident because its truth is clearly, distinctly and immediately present to the mind. Its self-evidence is independent of any limiting condition. One apprehends directly the reasons for its self-evidence. Aristotle so much favoured deduction that he suggested that induction might be reduced to a mode of deduction.

Many writers in late antiquity believed that the ideal of deductive systematization had been realized in the geometry of Euclid and the statics of Archimedes. Euclid and Archimedes had separately formulated systems of statements comprising axioms, definitions and theorems ordered in such a way that the truth of the theorems follows from the assumed or self-evident truth of the axioms. For instance, Euclid proved that the sum of the angles of a triangle is equal to two right angles. And Archimedes proved from his axioms on the lever that two unequal weights balance at distances from the fulcrum that are inversely proportional to their weights.

The three highlights of the ideal of deductive systematization are:

1. The axioms and the theorems are deductively related.
2. The axioms themselves are self-evident truths
3. The theorems agree with observations.

The deductive ideal meant that without reference to observation (held by the ancients to be merely heuristic) or experimentation (scorned because it is an imposed non-natural contraption or contrivance interfering with natural order); the ancients propounded theories based on propositions derived from intuitive insights

and then elaborated by deductive reasoning. The internal consistency of a deduction – a magnificent edifice to behold – was esteemed more highly than probability. This underpins the high value placed on reason by the ancients. And this appeal to reason as sole arbiter constitutes the sharpest distinction between antecedent method and the new method of the seventeenth century. In other words, deduction in the hands of the ancients implies that facts were deduced from and obliged to conform to an authoritative and rational synthesis. That is, deduction being *a-priori* attached little or no significance to observation and experimentation.

Scholasticism idealized Aristotle and held anything said by him to be sacrosanct. This attitude of slavish attachment to authority put in check for centuries any possible effort to improve the synthesis, which Aristotle bequeathed.

Antecedent method celebrated its consistency more than any other thing; hence learning during the medieval period in Europe became overpoweringly bookish. Scholars spent so much of their time interpreting and comparing texts in old books. There was no reference to observation or experiment. There was no contact between ideas and reality. An investigation in natural science started with a belief based on an authority (especially Aristotle) rather than on an observed fact. And also outside Alchemy – with its specter of magic – there was little practical work. So to most medieval scholars, natural science was not really an investigation of the unknown but a search in the library for something which was already known and written down in the past. The implication of all these was that learning became dogmatic and stagnant.

THE NEW METHOD: At the beginning of the seventeenth century, three main persons were consciously working to revolutionize the method of doing science. They are Galilei Galileo, Francis Bacon and Rene Descartes. Of these theoreticians of the new method of science, Bacon was the *primus inter pares*. Asserting this fact, the first members of the Royal Society wrote: "If we must select some one philosopher as the hero of the revolution in scientific method, beyond all doubt Francis Bacon must occupy the place of honor."⁹

His new method of science is presented in the *Novum Organum – New Instrument or New Method* (1620). *Novum Organum* is a conscious allusion to the *Organon* – a *corpus* of Aristotle's logical treatises especially the *Posterior Analytics* dealing on method which Bacon intended to supersede.

Bacon started by generally accepting the main outlines of Aristotle's inductive-deductive theory of scientific procedure: the progression from observation to general principles and back to observations. But he was critical the way both procedures had been carried out. He was, however, especially more critical of the deductive procedure. He favoured inductive procedure as a method of natural science, though he still assigned important role to deduction in the confirmation of inductive generalizations.

To the inductive stage, Bacon rendered a three-part indictment:

1. He criticized Aristotle and his followers for doing a haphazard, uncritical collection of data. To correct this Bacon called for a thoroughgoing implementation of Roger Bacon's second prerogative of experiment, that is, the use of systematic experimentation to gain new knowledge of nature. In this connection, Bacon stressed the value of scientific instruments in the collection of data.
2. Bacon criticized the Aristotelians for generalizing too hastily. Given few observations, the Aristotelians leap directly to the most general principles and then use these principles to deduce generalizations of lesser scope.
3. Aristotle and his followers, Bacon criticized, relied on induction by simple enumeration of instances. In this, correlations of properties found to hold for several individuals of a given type are affirmed to hold for all individuals of that type. But the application of this kind of "puerile" inductive technique often leads to "mere conjecture" (or false conclusion because negative instances are not taken into account). Bacon quoted 1 Sam 16: 1-13 to demonstrate the weakness of induction upon simple enumeration. According to the passage, seven sons were rejected and if Samuel has reasoned inductively, so too should have been the eighth son, who happened to be David.

To overcome the weakness of induction by simple enumeration, Bacon introduced the refinement he called eliminative induction. This new technique "separate nature by proper rejection and exclusion" thereby eliminating all false hypotheses leaving clearly exhibited and in isolation the one remaining true claim.

To the deductive stage, Bacon rendered two principal criticisms:

1. The Aristotelians had failed to define adequately such important predicates thereby rendering useless those syllogistic arguments in which these predicates occur. According to Bacon, syllogistic demonstrations are effective only if the terms of the syllogisms are well defined.

2. Bacon criticized Aristotle and his followers for reducing science to deductive logic by over emphasizing the deduction of consequences from first principles. He argued that deductive arguments have scientific value only if their premises have inductive support.

Having vigorously criticized ancient method, one would have expected a clear-cut presentation of the new method; but going through the *Novum Organum*, unfortunately, one fails to glean what this new method amounts to. Even, comparing the main scientific revolutionaries of the seventeenth century, one fails to see a common pattern. For instance, while "Descartes agreed with Bacon that the highest achievement of science is a pyramid of propositions, with the most general principles at the apex; but whereas Bacon sought to discover general laws by progressive inductive ascent from less general relations, Descartes sought to begin at the apex and work as far downwards as possible by a deductive procedure."¹⁰ Bacon's new method however, is essentially inductive for he writes in the *Novum Organum*, Book 1, Aphorism 19:

There are and can be only two ways of searching into and discovering truth. The one flies from the sense and particular to the most general axioms, and from these principles, the truth of which it takes for settled and immovable, proceeds to judgement and to the discovery of middle axioms. And this way is now in fashion. The other derives axioms from the senses and particulars, rising by a gradual and unbroken ascent, so that it arrives at the most general axioms last of all. This is the true way, but as yet untried.¹¹

Bacon visualized teams of people carrying out a multitude of planned experiment as against antecedent method so he proposed the planning of experiments. He urges: "Why sit around waiting for the chance happening of phenomena? Speed up the process by creating the situation you wish to investigate! In this way nature can be coaxed into divulging her secrets at a more rapid rate."¹²

Bacon believed that making all possible observations and performing all feasible experiments, collecting and tabulating the results would yield a great mass of facts from which new more general laws of nature would almost automatically be extracted by a process of induction. Thus for Bacon, a pyramid of scientific theory would be built up inductively, solidly based on an encyclopedia of factual information. The theories, axioms, hypotheses so obtained would at each stage be tested experimentally and applied to human use if suitable.

This method of induction he exemplified in his science fiction *The New Atlantis* (1627). In this utopian society in a remote island, there was a large establishment called Salomon's House. This establishment devoted to experiment in applied science describes in detail how research is staffed and organized. Here too science is applied methodically to the welfare of society.

One sure way to understand and reconstruct the new method is to assess the productive and practical scientific activities of a modern practicing scientist like Galileo or Newton.

In matters of method, Galileo is known to be very critical of Aristotle of the *Posterior Analytic* but not the Aristotle of the biological investigation. Galileo's method must be regarded as empiricist in comparison with either Cartesian or Aristotle of the *Posterior Analytics*, earlier Aristotle. He applied the telescope to the study of astronomy. And with its aid he demonstrated the importance of observation. With it also he brought Copernicus astronomy based on the *a-priori* principle of mathematical simplicity to practical test. But he went further than that, he showed how in the science of mechanics, especially on accelerated motion, one must start by looking for quantities that can be measured and then try to establish the relation between them. Thus he restated the concern of physical science; physical science is concerned not with *why* but *how* bodies fall. Before Galileo it was assumed that every motion needed a continual force to maintain it. The planets had to be kept in motion by Aristotle's Unmoved Mover or by Kepler's action of the sun exerted through the aether. With Galileo's investigation it became clear that it was not motion, but the creation or destruction of motion, or a change in its direction, which required external force. When matter was endowed with inertia and the planetary system was set in motion it needed no force to keep the planets moving though some cause was required to explain their continued deviation from a straight path as they swing round the sun in their orbits. The problem had not even been properly formulated this way before Galileo.

Isaac Newton was the one who gave the world the most influential and convincing demonstration of the new scientific method. This new method must be regarded as empiricism since it departed from the Aristotelian method of the *Posterior Analytics* and the Cartesian method. This method also carried on in the line of Grosseteste and Roger Bacon in the thirteenth century; and was a completion of the revolution in method initiated by Galileo and Bacon at the beginning of the seventeenth century.

Descartes sought to derive basic physical laws from metaphysical principles; Newton opposed this insisting that the natural philosopher (scientist) bases his generalization on careful examination of phenomena. He observes: "Although the arguing from experiments and observations by induction be no demonstration of general conclusion, yet it is the best way of arguing which the nature of things admit of."¹³ In the new scientific method, according to Newton, observations lead the natural philosopher to the formulation of laws and ultimately theories. The "leading" here is of a highly intuitive and non-formal (not automatic or mechanical) way. That is, the ability to intuitively form laws and then theories from observations depends largely on long familiarity with the matter involved. The laws and theories thus formed are approximative and hypothetical, their warrants come from outside, from the observations from which the 'retroduction' began. The theory can be used to predict in mathematical or logical fashion consequences not yet tested. The verification of the predicted consequences constitutes an additional warrant for the theory. Such a prediction would not be called a 'demonstration' since it does not prove, that is, it does not add to the warrant of its conclusion. It is only when the prediction is verified in terms of canons of observation not themselves part of the deductive structure of the theory that it becomes fully acceptable. Thus it will then be the prediction which helps to verify the theory and not the theory which verifies the prediction.

Newton, therefore, opposed the Cartesian method by affirming later Aristotle's inductive-deductive theory of scientific procedure. Newton calls this the "method of Analysis and synthesis". In this method, as we have observed, he constantly insists on the experimental confirmation of the consequences deduced by synthesis, that is, the dependence of theory for its validation upon the individual facts. Consequently, in Newton, the ancient *a-priori* ideal was given up.

The way Newton applied the new scientific method is presented in his fantastic book the *Principles of Mathematical Philosophy* (1687). In this book Newton shows mathematically how all the motions which we observe in the solar system from the planetary orbits to the ocean tides can be explained and predicted in terms of few simple physical laws. By so doing, he demonstrated how observational data, speculative theory, and mathematical analysis, can be combined to solve an extraordinary difficult problem.

Newton's method is modern, modern in the way he used observational data to verify his theoretical analysis; modern in the way he accepted the mysterious concept of gravity without postulating its final causes, modern in its use of

mathematics. The concepts of gravity and motion could never have been completely explained in words alone without mathematics. Newton proved physical science a distinct discipline by the end of the seventeenth century, with mathematics as its special language, that is, mathematically devising equations to represent scientific situations.

REVOLUTION IN THE APPLICATION OF SCIENCE: If we ask the question: what is the goal of the acquisition of knowledge? What is the motive for which scientific investigation is undertaken? The answers given by the ancients and the moderns would be so radically different that the latter amounts to a revolution.

With the exception of isolated instances, the dominant practice was that the ancients merely aimed to understand nature not to use it or to control it. The ancient philosophers' ideal was a life of leisure spent in contemplation. Those who investigated nature were leading a life of pure research. They preferred a non-utilitarian to utilitarian knowledge. For the ancients, the inquiry concerning nature is its own reward. Knowledge was valued for its own sake. The slogan for the ancients was knowledge for knowledge sake.

This ideal reflects on the ancient's economic life, social structure and religion. In ancient civilization, there was a striking separation of the theoretical and technical traditions. The ancients; Egypt, Mesopotamia and the Greeks were proficient in technology, but the theoretical and the technical scarcely interpenetrated each other. It does not seem like *techné* contributed to *theoria*, nor *theoria* to *techné*. Among the Greeks, though there was some *techné*; *theoria* the unhurried ordering of ideas with a view for man to transcend the material order was the ideal for the leisured, cultivated, and speculative mind. *Theoria* did not involve the grubby manipulation of matter. *Techné* on the other hand, was a skill handed-on in an unwritten, unstudied way from craftsman to apprentice. It aided man to dominate matter in a practical way.

This separation was more pronounced in Physics carried on at such an abstract level that it had no conceivable relevance to the practical problems of engineering and architecture. The Greek architect would never have dreamt of looking up to the first principles of Aristotle's Physics for illumination. And the possibility that the techniques themselves could illuminate the abstract world of ideas and advance the understanding of Physics would scarcely have crossed Aristotle's mind.

A short historical review will reveal the ancient's preference of non-utilitarian end of knowledge. There is the myth of Thales presented as the unworldly philosopher in Plato's *Theaetetus* (174e). He fell down a well while contemplating the heavens. Pythagoras was also attributed to have made distinctions between three lives, the life of contemplation, honour and wealth; and conclude that the best was the first, the life of contemplation. Empedocles (fragment 132) described as fortunate, *olbios*, the man who "has gained the riches of divine intelligence". And in a well known fragment (910) of a lost tragedy, Euripides too used the same word "fortunate" to describe the man who engages in inquiry (*historia*) and who "observes the ageless order of immortal nature".

Plato and Aristotle threw their considerable weight in support of the contemplative motive of knowledge and also gave it a rational justification. For Plato, the study of the changing world of becoming is inferior to the study of the immutable forms, but the former is far from valueless since it reveals the intelligent ordering of the universe. For Aristotle, too, the life of "contemplation" (*theoria*) is the supreme life. The study of biology is vindicated on the ground that 'there is something beautiful' in every species of animal. In his *Metaphysics*, Aristotle presents the comparative worth of utilitarian and non-utilitarian knowledge.

At first he who invented any art whatever that went beyond the common perceptions of man was naturally admired by men, not only because there was something useful in the invention, but because he was thought wise and superior to the rest.

But as more arts were invented, and some were directed to the necessities of life, others to recreation, the inventors of the latter were naturally always regarded as wiser than the inventors of the former because their branches of knowledge did not aim at utility.¹⁴

In connection with the origin of philosophy, Aristotle also made similar point in praise of non-utilitarian motive of knowledge. He writes:

For it is owing to their wonder that men both now begin and at first began to philosophize...therefore since they philosophized in order to escape from ignorance, it is evident that they were pursuing knowledge in order to know, and not for any utilitarian end. And this is confirmed by the facts; for it was when almost

all the necessities of life and the things that make for comfort and recreation had been secured, that such knowledge began to be sought.¹⁵

For both Plato and Aristotle therefore, the pursuit of knowledge was an end in itself. And knowledge for knowledge sake was the basis of the good life for two reasons. First what marks man out from animals is the possession of reason; thus the cultivation of that faculty is essential for true happiness and excellence. And secondly, the study of nature reveals the beauty and order of the universe, the contemplation of which helps a man to develop an orderly and noble character.

Yet, although the motive of “knowledge for knowledge sake” was generally accepted in different variants by a majority of ancient authors, it will be wrong to assume that the utilitarian ideal of the end of knowledge was non-existent. For example, many ordinary ancient people, the common folks, the non-scientists, valued the practical arts. There were references to agriculture, ship-building, mining, medicine, in passages underscoring man’s indebtedness to Prometheus (the patron of technology). There is the other picture of Thales, the Milesian who applied his astute business acumen to corner the olive presses in Chios and Miletus thereby making a lot of money just to show the world that philosophers could make money if they wished only that their ambition is of another sort.¹⁶ For the Pythagoreans, the doctrine that all things are numbers, abstract as it was, provided the stimulus both for the empirical investigation that they carried out in acoustics and for much fanciful speculation concerning the relation between things and numbers. Plato, though he advocated knowledge for its own sake, was aware that for the generality of ordinary people, what counted was the practical utility of knowledge. When Glaucon was asked in the *Republic* whether astronomy should be included in the education of the guardians, he replied “I certainly agree. Skill in perceiving the seasons, months and years is useful not only to agriculture and navigation, but just as much to the military art.” Socrates replied to him: “I am amused that you seem to be afraid lest the many suppose you to be recommending useless studies.”¹⁷ The important thing in this dialogue is that Plato is aware that “the many” valued the practical utility of any inquiry. The Aristotle of the biological investigation is different from that of the *Posterior Analytics*. In doing biology Aristotle did a lot of dissections. Archimedes the hero of Alexandria achieved a near legendary prowess in the use of science in solving technological problems. Some parts of Greek medicine showed signs of *theoria-techne* overlap. It must be noted, nonetheless, that in spite of these strands of *theoria-techne*

overlap, the ancients in the main were often slow to or entirely failed to, consider whether their theoretical knowledge could be put to practical use.

In the medieval period, the goal of knowledge was salvation not material progress; and science was not only superfluous to that goal but also jeopardized it. St. Augustine set that tone of the motive of knowledge and the medieval people agreed that one: "who can measure the heavens, number the stars and balance the elements" is no more pleasing to God than one who could not. And that scientific knowledge was more likely to encourage pride than to lead people to God.¹⁸ Thus there was at this time no *theoria-techne* overlap, especially in the area of Physics. The reason, in part, derives from the overwhelming influence of Aristotle in matters of method; part of the reason also was the textual nature of university teaching. Then the final appeal was most often to an ancient work. There was no laboratory work in the curricula. There was no direct appeal to observation, consequently the universities lost touch with the progressing arts and crafts.

The arts and crafts, on the other hand and in contrast to the theoretical science, continued to develop fast at this period. And as it developed, it became more complex and more aware of its need for the stimulus of theory. Leonardo Da Vince and people like him were forced to try new theoretical approaches since traditional Physics was not helpful.

Magic, because of its close affinity with art and craft, flourished at this period; and constituted a very dangerous constraint to the development of science. The magi claimed that their pseudo-sciences: astrology, alchemy, and divination could produce prodigious effects with small or negligible physical causes, and so were more effective for the benefit and use of man than the still emerging natural science. And natural science was still at its infancy, nay, not yet even born, and so could not appeal to its practical benefits for justification.

The import of magic could be seen in della Porta's *Natural Magick* (1589). The book distinguished two sorts of magic: sorcery, which deals with "foul spirits" and so, is regarded as "infamous"; and natural magic, accepted by men of learning. According to Porta, natural magic worked "by reason of the hidden and secret properties of things." So he designates it the practical part of natural philosophy. It follows that the world of magic is an enchanted world – in this world, gross effects result from small or insubstantial causes invoked in magic.

Against this backdrop, many authors doubted the value of science. Erasmus in his *Praise of Folly* (1515), accused scientists of seeking to explain inexplicables like thunderbolts, winds, eclipses; and pursuing such madness as measuring the

sun, moon, stars and planets by rule of thumb. The outcome of such follies, Erasmus observed, was endless contentions among scientists on every point. Cornelius Agrippa (1486-1535) in his *De Vanitate Scientiarum* (1530) dismissed the sciences as pointless. He considered Astronomy, for example, as concerned with "vain disputes about Essentricks, Concentricks, Epicycles, Retrogradations, Trepidations, Accessus, Recessus... the works neither of God nor Nature, but the Fiddle-Faddles and Trifles of Mathematics."

There were however, some objections to the claims of magic. Mersenne objected to the bases of the supposed sympathies that hold between things in occult sciences. Gilbert in his *De Magnet* (1600) denied the occult principle that "like attracts like". Also Gilbert dismissed the explanatory language of natural magic as being merely metaphorical. How, for instance, can you talk of the fellow feeling of sympathy in a stone? He asked.

It is worth noting the fact that the occult sciences were aided by Aristotle's account of causation. Aristotle had argued for the presence of four causes in the production of any effect. And the foundation of magic lay in the sheer multiplicity of possible causes. During the sixteenth century, the barrier between the craft and scholarly traditions began to break down though this is not to say that there was *theoria-techné* interpenetrating. Guild secrecy faded out. Craftsmen recording the lore of their tradition started assimilating some scholarly knowledge; while some scholars became interested in the experience and the methods of craftsmen. A proof of this was a work, *On Pyrotechnics*, published in 1540 by an Italian metal worker Biringuccio, who became head of the papal foundry and munitions works. His book described the smelting of metals, the casting of canon and bells, the making of coins, and of gunpowder. A book covering similar ground and methods of mining in addition was produced in 1556 by the scholar George Bauer, a doctor.

THE MODERN IDEAL OF THE MOTIVE KNOWLEDGE: Of the seventeenth century scientific revolutionaries, Francis Bacon was most outstanding in advocating the application of science to the welfare of society. His moral imperative and grand design was to "restore and exalt the power and dominion of man himself, of the human race, over the universe". The power and dominion, which, according to him, man lost during the Fall. Bacon proposed that the truth and value of any system be judged by their works. And the value of work is "for the glory of God and the relief of man's estate". Bacon and Descartes

regarded their work as a call for the redemption of mankind in his material existence.

Bacon derided the science of his day for its wrong method and for being of very little practical use. He says that earlier science was carried on by earlier scientists "seldom sincerely to give a true account of their gift of reason, to the benefit and use of men."¹⁹ He remarked that earlier scholars substituted talk for experiment, and contemplation for action. They were satisfied with purely verbal solutions to real physical problems. They confused science with religion and were always seeking final causes and doctrines, which would explain physical phenomena.

The call by Bacon for the redemption of mankind in his material existence as the motive of knowledge was revolutionary. But more revolutionary was his equating the betterment of mankind with the glory of God; that is, for him, material power is taken as the means to divinely sanctioned end. This markedly contrasts with the ancient's view that the highest motive of knowledge was the cultivation of wisdom, contemplation, or knowledge for its sake, on even a religious experience. This emphasis in the control of natural forces sets Bacon's philosophy in opposition to Aristotelianism, which he severally criticized as Idols of the Theatre and plotted to overthrow. Aristotle's philosophy, he remarked, not only failed to lead to new works to benefit mankind but also thwarted the few attempts that had been made. In contrast Bacon extolled the progress that had been made in the arts and crafts:

Let anyone consider an immense difference there is between man's life in any highly cultivated part of Europe, and in some very wild and barbarous region of the new Indies; and this, not the soil, not the climate, not bodily powers, but the arts provide.²⁰

He cited the following as examples of what can be accomplished by men who are not under the spell of Idols of the Theatre: inventions of printing, gunpowder, mariner's compass, novel techniques as the invention of logarithms, the improvement of scientific instruments which facilitated precise observation and menstruation: the microscope, the thermometer, telescope, barometer and air pump, all of which was developed during the early and mid-seventeenth century. Bacon wished to give further impulse to the developments in the arts and crafts by applying scientific knowledge, derived with his new method, to the development of novel industrial and craft techniques. For this, Bacon was called the *philosopher*

of industry; though his vision of the application of science to industrial processes did not come into effect till the nineteenth century.

For the purpose of advancing and applying science, Bacon proposed the establishment of a scientific academy, a “House of Salomon” in his *New Atlantis* (1627). The academy was to be not just learned society but a research and teaching institute equipped with laboratories, gardens, a library, workshops and powerhouses. The members of the academy were to collect information from foreign lands, from books, from their own experiments and observations. To Bacon, experiment was the only truly necessary ingredient of scientific endeavour; without it, natural philosophy was no better than metaphysical speculation; and the scientist no better than the metaphysician who spun webs of *a-priori* hypotheses out of his own inside. With experiment, the scientist possesses the key to unlock the secrets of nature. According to Bacon, the use of experiment:

is of all others the most radical and fundamental towards natural philosophy; such natural philosophy as shall not vanish in the fume of subtle, sublime or delectable speculation, but such as shall be operative to the endowment and benefit of man's life; for...it will give a more true and real illumination concerning causes and axioms than is hitherto attained. For like as a man's disposition is never well known till he be crossed, nor Proteus ever changed shapes till he was straightened and held fast; so the passages and variations of nature cannot appear so fully in the liberty of nature, as in the trials and vexations of art.²¹

Thus experiments and observations provide information. The information so collected was to be arranged into the form of an encyclopedia from which a new theory or new system of natural philosophy could be derived, a system that would be of great use when applied to the common needs of mankind. In this regard Bacon writes: “The end of our Foundation is the knowledge of causes, and the secret motion of things, and the enlarging of the bounds of the Human Empire, to the effecting of all things possible.”²²

Like most of his projects, Bacon's suggested Foundation did not attract attention in his day. But his views on the advancement of the arts and crafts were popular in the mid-seventeenth century influencing in particular the men who founded the Royal Society. For in addition to the “experiment of light” (the causes of things), they also sought the “experiments of fruits” (the application of knowledge to practical affairs).

The academy (the House of Salomon) constituted a kind of democratization of knowledge because it lessened the need for high intellectual powers such as were required in reasoning. In this connection Bacon says: "The course I propose for the discovery of sciences is such as leaves but little to the acuteness and strength of wits, but places all wits and understanding nearly on a level."²³

Also revolutionary was Bacon's call for the motive of knowledge to be to give power. Bacon appreciated the overlap between this call and those of the proponents of natural magic. The magi claimed to produce strange and wonderful effects by purely natural (occult) means. Therefore both science and magic seek to better man's life by dominating and improving nature; nevertheless, Bacon was hostile to and disapproved of magic because according to him, it was fraudulent, neither progressive nor cooperative. Science is a social activity and people should work together to achieve a better situation. But magic is a pseudo-science and does not proceed cooperatively.

It follows that Bacon had a *Faustian* belief that knowledge was power. But his exact legal/scientific mind could not equate knowledge with magic. He was not a utilitarian in the base or narrow sense of the word. He, more than any other scientific revolutionary, inveighed against the evils of the purely "luciferous" (money-grubbing) motive of knowledge. He admonished:

Lastly, I would address one general admonition to all; that they consider what are the true ends of knowledge, and that they seek it not either for pleasure of mind, or for contention, or for superiority to others, or for profit, or fame, or power, or any of these inferior things; but for the benefit and use of life; and that they perfect and govern it in charity. For it was from lust of power that the angels fell, from lust of knowledge that men fell; but of charity there can be no excess, neither did angel or man come in danger by it.²⁴

What Bacon sought was "luciferous" (enlightening) knowledge. This he believes gives power; the power to improve the lot of mankind, and to increase the sum total of human happiness. Hence, Bacon was the real progenitor of the eighteenth century enlightenment.

THE FORMALIZATION AND PROFESSIONALIZATION OF SCIENCE:

The aftermath of the radical shifts in different aspects of natural philosophy, as we examined from the beginning of this chapter, was that by the turn of the seventeenth century modern science was born. To shape and give identity to the

emerging new science, to detach it from the constraints of the Church and Scholasticism, and to give direction and focus to the scientific community, scientific societies had to be established. Thus to analyze the formalization and professionalization of science implies analyzing the establishment, objective, structure, funding and membership of the scientific societies and this is what we are concerned to do in this concluding part of this chapter.

The earliest scientific society to appear was the *Academia Secretorum Naturae*. It appeared in Naples in 1560. The name, as one can observe, had an ominous ring of magic; and magic was then being discredited. For this, the society was suppressed and the President was ordered by the Pope to abstain from illicit arts in the future. The next to appear was the *Academia dei Lincei*. It appeared in Italy in 1603. This was more successful than the first. At a time it enlisted Galileo as a Fellow. In 1657, *Academia dei Cimento* was formed in Florence by Leopold de' Medici. This is perhaps the first scientific academy devoted to experimental practices.

A definitional turning-point, however, came in the life of science with the establishment of the Royal Society in 1660. In England in 1645, a group began to meet at Gresham College in London under the name of the *philosophical or Invisible College*. In 1648, most of its members moved to Oxford due to the Civil War. With the restoration of Charles II in 1660, however, London again became the centre of scientific activity and it was felt that an official scientific organization should be founded in England. Consequently, the scientists in London met at Gresham College on 26 November, 1660, and formally proposed the foundation of a "college for the promotion of Physico-Mathematical experimental learning." Two years later, in 1662, Charles II sealed the charter which formally incorporated the institution as the *Royal Society for the Improvement of Natural Knowledge*; called the *Royal Society* for short.

The establishment and operations of the *Royal Society* had direct bearing in promoting, shaping, and defining science. The mere fact of its establishment was considered the best way to move science forward. And the nature of what is meant by science was explicitly stipulated in the statute of the *Royal Society* drawn up by its Curator Robert Hook in 1663. Hook writes that the "business and design" of the society is:

To improve the knowledge of natural things, and all-useful Arts, Manufactures, Mechanic practices, Engynes, and Inventions by Experiments – (not meddling with Divinity, Metaphysics,

Morals, Politicks, Grammar, Rhetorick, or Logick). To attempt the recovery of such allowable arts and inventions as are now lost. To examine all systems, theories, principles, hypotheses, elements, histories and experiments of things natural, mathematical and mechanical, invented, recorded or practiced, by any considerable author, ancient or modern. In order to the compiling of a complete system of solid philosophy for explicating all phenomena produced by nature or art, and recording a rational account of the causes of things.²⁵

There has not been any change in kind between what Hook proposed and what we are doing today.

The establishment and the chartering in 1662 with a replaced charter in 1663, made the *Royal Society* more permanent and formal, making it rank with other chartered corporations. This by implication made science a formal enterprise. In addition, the 1662 Licensing Act conferred permission on the society's officers to license books. This *imprimatur*, hitherto a preserve of Bishops, was crucial in detaching science from value-laden concerns like, religion, metaphysics, morals and so on.

The establishment of scientific societies, especially the *Paris Academy*, furthered the formalization and delimitation of science. The course of the establishment of scientific society in France depended upon state patronage unlike the *Royal Society* where Fellows had to pay a subscription. Again, while the *Royal Society* was in London, in France scientific institutions were less concentrated in the metropolis.

Convinced that the advancement of science would benefit France economically, and that the application of science would further his policy of expanding the industry and commerce of the country, and convinced that every aspect of French intellectual and artistic life should be brought under the state control in order to bring ever more honour and glory to his royal master; Jean-Baptiste Colbert (1619-83), Chief Minister to Louise XIV, decided to set up a new scientific society rather than patronize any of the existing ones struggling to survive. In 1666 the *Academia Royal des Sciences*, otherwise popularly called the *Paris Royal Academy of Sciences*, was founded by Louis XIV. This was a small-incorporated society of experimental philosophers with about twenty to thirty members. The society was subsidized and equipped by government fund; hence the Fellows, all government appointees, were obliged by the state, to direct their

efforts to useful cooperative projects such as discovering a way to measure longitude at sea.

With the creation of the *Academia*, experimental philosophy (science) gained the endorsement of the French absolute state. And the government aimed to make the Academy (France) the centre of the experimental philosophy in Europe. Hence it enlisted such most active and original minds of the century. Such minds were lured by the promises of a handsome pension and proper research facilities.

The centralization of French science resulted in the re-establishment of consensus among the experimental community as the fundamental principle in doing natural philosophy. Before the middle decades of the seventeenth century, experimental philosophers in France were ideologically heterogeneous, having a variety of physical philosophies, and even divided as to the purpose and form of experimental activity. By the turn of the century, the experimental community shared a homogenous ideology with matter in motion (not matter and form) as the underpinning principle. There was the general agreement that natural philosophy remained a causal science and that the activity of observing and measuring natural phenomena was ultimately intended to aid the construction of an apodictic physics. There was now the consensus among the community that the only plausible natural philosophy was one founded on mechanistic principles not Aristotelian qualities. By early eighteenth century, the mechanistic view was shared by both laymen and clerics alike, and even by experimental philosophers passionately affiliated to Aristotle. And mathematical physics – eventually dynamics – was the leading model of human knowledge. So much so that when Napoleon Bonapart asked Laplace why God was not mentioned in his monumental work *Mecanique Celeste* (1799); Laplace replied: “Sir, I have no need of that philosophy in interpreting the world”.

The early societies gave the emerging new science an identity, gave the scientific community a focus, and put those who are interested in science in touch with those interested in applying it. These they did by securing adequate discussions during their meetings, by focusing scientific opinion, by exchanging information, and by publishing scientific journals. *The Journal des Savants*, the first of its kind, established by Sallo, first as a periodical, appeared in France (first in Paris) in January 1665. Two months later the *Philosophical Transactions* of the *Royal Society* was published by the secretary Henry Oldenburg initially as a private venture. The *Philosophical Transactions* was the first scientific journal to

appear with scientific papers signed by their authors. The cumulative and public features of modern science derive largely from these journals.

The early scientific societies, the *Royal Society* of London and the *Parisian Academia des Sciences* also helped in establishing science as a recognized profession. This they did by being models to the "specialized" scientific societies that proliferated in the nineteenth century. In the eighteenth century, scientific societies were specialized only in the sense that they belonged to a particular place. In the nineteenth century, they became specialized in the topics they discussed. In great Britain, between 1800 and 1900, societies were founded for surgery, geology, astronomy, zoology, geography, entomology, botany, microscopy, pharmacy, there was the *Societe Chimique de Paris* (1857) and there was the *Societe Physique de Paris* (1873). These provided, so to speak, "the social services of science:" they arranged meetings, conferences, publications, and they fostered professional standards by arbitrating in scientific matters. It was against this backdrop that in 1840 William Whewell invented the word "scientist" thereby completing the professionalization of science. Whewell wrote: "We need very much a name to describe a cultivator of science in general. I should incline to call him a scientist. Thus we might say that an artist is a Musician, Painter or Poet, a Scientist is a Mathematician, Physicist or Naturalist."²⁶

Before this date, the word "science" invited confusion and was used only for conveniences and to avoid constant recourse to the more cumbersome expressions like "natural philosophy" and "experimental philosophy" both of which have authentic ring of the new learning of the seventeenth century.

The scientific societies articulated the new rhetoric that praised the usefulness of science, its putative contribution to social and material progress, and its detachment from the value-laden realms of politics and religion. And they provided the standard of what could go by science. All these derived mainly from the writings of Bacon. But the contributions of science to technology and economic development remained minimal till the nineteenth century. And although the new rhetoric about science embodied objectivity and value-neutrality, science played a significant role in shaping the eighteenth century Enlightenment, and in precipitating liberal and revolutionary social and political courses during the next two centuries.

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