STUDY SESSION 13

THE HISTORY AND METHOD OF SCIENCE

13.1 Introduction

This study session will take you on a journey ride through the history of science. Along the way, you will be exposed to how different philosophers and scientists from antiquity to the present age contribute immensely to the growth of science. You will also learn about the impact of Christian and Islamic cultures on scientific development. You will further be enlightened on some of the essential features of scientific research and some selected methodological perspectives that have emerged from philosophical disquisitions on the subject, especially since the twentieth century.

13.1.1 Learning Outcomes for Study Session 13

At the end of this session you should be able to:

1. Name the different epochs of the history of science;
2. Identify key philosophers and scientists of each epoch;
3. State the contributions of the identified philosophers and scientists to the development of science;
4. State the contributions of religion to scientific growth; and

5. Outline the procedure of scientific method.

13.2 Science in Ancient Greek Civilization (600-320 B.C.)

The humble beginnings of Western science have traditionally been located among the philosophers of Greek city-states on the coast and island of the Eastern Mediterranean, in 6th and 5th centuries B.C.[1] Their works are known only through fragments, references and brief quotations made by authors who came later, perhaps by hundreds of years. You already know from the previous sessions that the early Greek philosophers were cosmologists who speculated freely about the ultimate constituent or substratum of the cosmos. For Thales of Miletus, the earliest Greek philosopher in recorded history, "All is water", whilst for Empedocles (500-440 B.C.) another of these ancient thinkers the ultimate principles of the universe are "love and strife". In this way, the Greeks moved away from the mythological explanations of their own cultures and of the ancient civilizations from which they sprang and from which they borrowed much of their detailed knowledge. The Greeks were the great adumbrators of the modern European scientific attitude. One very important tradition, Pythagoreanism (founded by the mystical mathematician and philosopher, Pythagoras c. 530 B.C.) was explicitly religious. Pythagoras wanted to discover the master-key to universal harmony, both natural and social, and the personality of members, which he construed as an ordered array of dots, was for the tradition he founded an important clue.

Somewhat later appeared the Eleatic Zeno (c. 490) and Parmenides (c.500) who employed sophisticated arguments to support the philosophical position that asserted the unchanging unity of all things. In addition, Zeno's paradoxes of motion presents a challenge that has lingered even into contemporary times.

[1] B. Russell, *History of Western Philosophy.* (London: Routledge, 1961) parts 1 & 2

Certainly, by the 5th century B.C., these inquiries became quite sophisticated in argumentation. But they were more speculative than empirical; they pertained more to speculative explanations of empirical; they pertained more to speculative explanations of commonsense phenomena rather than highly technical arguments about controlled artificial experiments; the later emerged with Aristotle.

Plato (429-347 B.C.) was a great metaphysician, mathematician, astrophysicist and political theorist. He loved mathematics and saw in it the key to a rational method of scientific inquiry. In his *magnum opus*, the *Republic*, he argues that geometry prepares the mind for the discourse of dialectics about the real ideas, of which perceptible things are but images, leading ultimately to wisdom and illumination. For Plato, genuine scientific knowledge is possible through the intellectual apprehension of the ideal entities in the world of forms.

Aristotle (384-322 B.C.) the greatest student of Plato, was one of the world's first, and greatest, scholars. An ex-student of Plato's Academy (a school devoted to learning), Aristotle eventually set up his own school, the Lyceum. His interests straddled the entire natural and human world of his day, including metaphysics and ethics. Through painstaking observation and disciplined theorizing he created a biological science and a taxonomy similar to those used today. Aristotle also made important contributions to logic, physics and political theory. He was also a master of the scholarly method of investigation. He would define the subject area and its problems, dialogue critically with his predecessors (sometimes showing that they were naïve or incorrect in some important respects) and then proceeded by reason and experience to develop his own argument. Indeed, we owe to him the basic divisions of learning and also the articulation and elaboration of the principles of method and of the different sorts of knowledge attainable by the use of reason. In the late 4th century B.C. Alexander the Great, an ex-student of Aristotle, annexed most of Asia Minor and inaugurated a vast empire. Greek culture flowered and the great cities competed for famous scholars and classical texts. The greatest of these centres of learning was the city of Alexandria in Egypt. It had a great library and was the equivalent of a modern university. Largely independent of religious trappings, the library of Alexandria housed thousands of classical texts and many erudite and eminent scholars of that period flocked to it. Although this Hellenistic Age (roughly from 323-30 B.C.) did not quite achieve the genius of the Greek era, it produced, especially in the Alexandrian School, some notable mathematicians namely Euclid (330-275 B.C.), Archimedes (287-212 B.C.), and Apollonius (260-200) and astronomers, for example, Hipparchus (190-120 B.C.). Studies in medicine and philosophy flourished also, and during this period, the seeds of alchemy were developed by Egyptian alchemists attempting to rationalize chemical change with Aristotelian theories.

The demise of the Alexandrian School occurred in 624 when the Muslims, under Caliph Omar, conquered Alexandria and destroyed the library. The Caliph is said to have justified his brazen act of vandalism on the ground that "if these teachings agree with the book of God (the *Koran*) they are useless, and need not be preserved; if they disagree, they are pernicious, and ought to be destroyed".[2] Thus science suffered a terrible, though temporary, set-back.

13.2.1 In-Text Questions (ITQs)

The setback suffered by science in the ancient period was caused by the destruction of which library?

13.2.2 In-Text Answers (ITAs)

[2] J. Jeans, *The Growth of Physical Science*. (New York: Fawcett Publications, 1961) p. 97

The library of Alexandria

13.13 Science in Rome

Towards the close of the pre-Christian epoch (around the second century B.C.) the Roman Empire achieved dominance over the Mediterranean world. Rome presented a paradox to scholars. The Roman civilization, so sophisticated and apparently quite modern in its personalities and politics, very solid in the learned discipline of jurisprudence and law, very progressive in the state of technologies of warfare and public hygiene, with direct access to the corpus of Greek science, nevertheless failed to produce a scientist of note. Two able scientists that worked during the reign of Emperor Marcus Aurelius in the second century A.D. were both Greeks: Galen of Pergamon, who synthesized and advanced the study of medicine, anatomy, and physiology, and Ptolemy of Alexandria, who brought mathematical astronomy close to a classic perfection and attempted to bring the mathematical cum scientific method to the earliest empirical social science-astrological prediction.

Generally speaking, the Romans considered science as fit only for casual speculation, on the one hand, and practical techniques, on the other. They discussed scientific matters seriously only in connection with philosophies that were basically ethical. Stoicism and Epicureanism were especially dominant at that time. The messages offered by them to the wise were dignified resignation and the pursuit of happiness respectively. Nevertheless, one of the leading Epicureans, Lucretius, authored a master piece of speculative science entitled *On the Nature of Things*. The central argument of his atheistic and atomistic explanation of phenomena was that the gods and other deities in current mythological explanations of the universe were fictions calculated to instill fear and obedience among the gullible people.

Some scholars have advanced reasons for the failure of ancient Rome to contribute significantly to some dispute of its technological, socio-political and judicial achievements.

For instance, it has been argued that slavery, by stifling the motivation for industrial innovation, was the cause. But this explanation is too simplistic for slavery, as a n institution, did not actually disappear in Europe until the 19th century, by which time science was very much on course. Furthermore, it has been speculated that, perhaps, the social structure of Rome did not allow for the social mobility necessary for scientific progress, and that its long attachment to gross forms of magic left no room for the appreciation of the unique commitment to the hard and hazardous road to knowledge and wisdom through disciplined inquiry into isolated aspects of the objective world. Be that as it may, when one ponders over how few have been the cultures in which science has flourished, one may reverse the question and consider Rome as the normal, and classical Greece as the surprising phenomenon to be explained.

13.3.1 In-Text Questions (ITQs)

Name the two able scientists that worked during the reign of Emperor Marcus Aurelius in the second century A.D.

13.3.2 In-Text Answers (ITAs)

Galen of Pergamon and Ptolemy of Alexandria

13.4 Science in the Dark and Middle Ages (642-1453)

Historically considered, the Greco-Roman civilization went through its full cycle in about 1000 A.D. It is often referred to as the Dark Ages. At that time, literate culture in the Rome-dominated Western Europe was barely kept alive in the monasteries. In contrast, the Eastern empire under the hegemony of Constantinople, hosted a civilized society. Nevertheless, in its 1000 years history, the Eastern empire of Byzantium did not produce much new science.

In the early part of the 11th century A.D., most learned men knew and understood a little tattered fragment of ancient science, but thereafter something like progress was noticeable. The 12th century witnessed some semblance of renaissance for science in Europe due partly to her contact with the superior Islamic civilization in Spain and Palestine, and partly to the development of towns with literate upper classes. It was in this period that the first speculative treatises on natural philosophy were produced. The 13th century witnessed the founding of great monasteries, universities and the great age of scholastic learning. St. Thomas Aquinas (1226-1274), the theologian and Aristotelian, together with the experimentally-minded Franciscan friar Roger Bacon (1214-1294) who worked mainly on optics belong to this period. At the period in question, learning was centred in the monasteries not in the universities, and religion tended to obstruct the road to scientific progress whereas philosophy served as its handmaiden.

In the 1350s, Europe witnessed traumatic economic and social disasters in the forms of general financial collapse and the Black Death (Bubonic Plague). Although philosophical debates (including interesting mathematical speculations) still took place, in terms of science the medieval epoch was generally sterile. During the period natural philosophy and particular facts were studied mainly in connection with problems relating to religion either for the elucidation of biblical texts or for the debate with the adherents of pagan philosophies. Aristotelianism was the dominant *Weltanschauung*, although Platonism and neo-Platonism were visible. Little attention was paid to experimentation, and authorities were cited instead of scientific investigations that could have revealed interesting facts about the natural world.

However, although earlier historians of science unanimously depicted the medieval period as one of unbridled dogmatism and superstition, it is becoming increasingly accepted now, with more scholarship in the history of science, that some essential facts and principles of modern science owed greatly to the medieval period. The issue becomes clearer when it is realized that learned men of that epoch were not all trying to do scientific research as it is now understood. At that time the distinction between techniques, theoretical science and popular magic was not at all clear to anyone: science was just embryonic then. Thus in Europe, in the formative period of the present civilization, there was something that could be called science which still required more anthropological imagination to be clearly understood.

Before we continue our historical narrative concerning the evolution of Western science, it is well for us to digress somewhat and consider, albeit briefly, the contributions of some other civilizations to the development of science. As we noted at the very beginning of our discussion, science as we know it now is the totality of contributions from different civilizations at different periods of history.

13.4.1 In-Text Questions (ITQs)

1. Name the dominant philosophical theme used in propagating scientific and religious ideals in the Dark and Middle ages.
2. The experimentally-minded Franciscan friar Roger Bacon researched mainly on what?

13.4.2 In-Text Answers (ITAs)

1. Aristotelianism

2. Optics

13.5 The Contributions of Islamic Civilization to Science

Here, we are going to take a brief look at Islamic culture. Islamic culture is very relevant to European science.[3] Not only is its religion related to Judaism and Christianity, there was, in addition, active cultural intermingling between Arabic speaking countries and Latin Europe at crucial periods. In this regard, the literate language of nations that straddle the distance from Persia to Spain is particularly relevant. The conquerors, followers of Prophet Mohammed, settled in those lands and brought peace and prosperity where they settled. For instance, the library at Cordoba in Spain was a great centre of learning and research. Drawing from the traditions of Greek science through Christian scholars at Syria, the early Arab leaders of Baghdad in the 9th century had the bulk of the corpus of Greek science translated, and, soon after, their own scholars advanced further, especially in mathematics, astronomy, optics, chemistry and medicine.

In chemistry and optics, Islamic scholars made some notable contributions. Jabir ibn Hayyan, who seems to have flourished in the latter half of the 8th century A.D., explained how to prepare arsenic and antimony, how to refine metals, and how to dye cloth and leather, and made other contributions besides.[4] He was the first adumbrator of the phlogiston theory in chemistry.

Geber, who probably worked around the 9th century, has been regarded as the father of Arabian alchemy, and it is instructive to note that modern chemistry evolved from alchemy. Arabic alchemy, like the earlier alchemy of Alexandria, differed from modern chemistry in its aims rather than in its methods, restricting its researches to the aim of changing base

[3] Encyclopaedia Britannica (1975) pp. 360-375

[4] J. Jeans, *The Growth of Physical Science*. (New York: Fewectt Publications, 1961) p. 101

metals and other sources into gold or silver. In this connection, we find Geber investigating and improving the standard methods of evaporation, filtration, sublimation, melting, distillation and crystallization, as well as preparing many new chemical substances such as the oxides of sulphide and mercury. He was knowledgeable on how to prepare tetraoxosulphate (VI) and trioxonitrate (IV) acids.

In optics, Al-Kindi of Basra and Baghdad (800-873) worked especially on refraction of light. A century and half later, Ibn-al-Hazen (965-1038) gave correct explanation of the act of vision, saying that ocular vision is achieved by something passing from the object into the eye. He also worked on the problems of finding the true relation between the positions of a source of light and its image formed by a lens. Al Khawarizmi wrote a treatise on algebra which contributed much to introduce our present numerical notation into Western Europe.

The 12th century witnessed a heavy programme of translation of works from Arabic into Latin, at first in astrology and magic, then in medicine, and finally in philosophy and science. Arabic medicine overtook that of Europe, and medieval Islamic scholars such as Avicenna (980-1037) and Averroes (1126-1198) speculated on metaphysics, logic, and science within the context of Platonism and Aristotelianism respectively.

Later, Islamic civilization was under pressure from external forces and so declined. But, we can say that in addition to its enormous service to Western civilization in terms of preserving and translating the Greek heritage, Arabic numerals are now used in mathematical calculations, and that the Arabic language has contributed to modern science a number of the words (mainly of plants and foods). In fact the words “alcohol” and “algebra” are of Arabic origin.

13.5.1 In-Text Questions (ITQs)

1. Which Islamic Scientist gave a correct explanation of the act of vision with the claim that ocular vision is achieved by something passing from the object into the eye?
2. The words “alcohol” and “algebra” are of which cultural origin?

13.5.2 In-Text Answers (ITAs)

1. Ibn-al-Hazen
2. Arabic

13.6 Contributions of Ancient India, China and Japan

The Indian civilization is about the oldest still alive and it achieved a high level of technology at an early stage. It does appear that Indian mathematics, with its highly developed system of numeration and reckoning, influenced Arabic algebra; it also provided the principal Arabic numerals (i.e. the nine digits in a place-value system). But the distinctive characteristic of Indian civilization is that of higher consciousness through religion. In this, European thought has been somewhat deficient to the extent that it becomes aware of its lack once in a while. It then logically follows that the achievement of Europe and India cannot be gauged on equal terms, but must be recognized as complementary in view of the different (though interrelated) paradigms on which they were built.

The ancient Chinese and Japanese civilization also made important contributions to the growth of Western science. The dominant worldview of China then was this-worldly, although it was anchored on interpersonal relationship rather than on abstract regularities.

Chinese technology, until the Renaissance, was consistently more advanced than the European. As a matter of fact, the three important inventions that scholars such as Francis Bacon saw as crucial for the transformation of European society came from China: magnetic compass, gunpowder and the printing press. At any rate – and this is lamentable anyway – Europe tends not to recognize its debt to China.

There are some reasons why China did not achieve the breakthrough in modern science as Europe did.[5] First, the Chinese philosophy of nature was based on organic analogies and relations of harmony and, in addition, did not produce abstract logic and mathematics that could function as the language of science. Second, China paid too much attention to stability and bureaucracy; she distrusted the merchant class, and a clumsy bureaucracy made innovations quite difficult. Thus, the Chinese society failed to provide the necessary soil for the healthy growth of science. Europe overtook her, and the situation has remained so ever since.

Japan's case is somewhat fascinating. For centuries a colony of China, it had a brief exposure to Western science and religion before her leaders decided, in the early years of the 17th century, to shut the door against such "dangerous influences". In the later part of the 19th century, however, the Japanese decided to assimilate with vengeance much of what was formerly regarded as "dangerous influences", notably, Western culture and science. Today Japan is a very sophisticated and highly industrialized society. Indeed, Japanese native religion was sufficiently elastic to accommodate new ideas from foreign culture, and the ordinary Japanese can now cope with living partly in a hyper-modern world and partly still in one of ancient rigid social tradition.

[5] S. F. Mason, *A History of the Sciences*. (New York: Macmillan, 1962) pp. 73-88

13.6.1 In-Text Questions (ITQs)

List the three important Chinese original inventions that scholars such as Francis Bacon saw as crucial for the transformation of European society.

13.6.2 In-Text Answers (ITAs)

Magnetic compass, gunpowder and the printing press

13.7 The Rebirth of Science in the Renaissance (1452-1600)

For all its contributions to science, the medieval era was a period of "go-slow" for science. Every inquiry then was construed as a handmaid of theology, and the Church fathers and Islamic philosophers used Platonism and Aristotelianism to justify their theological positions.[6]

Now the word "science" is protean and in the period under consideration (the renaissance), it was restricted to fields providing knowledge: theology and philosophy. For other disciplines, the word "art" or "technique" were used to characterize them: some arts were also characterized "liberal" and they were taught in Latin in schools and universities. These disciplines included logic, rhetoric, mathematics and the learned or professional arts of medicine and law. The other arts subjects were more mechanical and generally involved low pay.

[6] J. Jeans, *The Growth of Physical Science.* (New York: Fewectt Publications, 1961) pp. 106-113

The Renaissance saw the movement of learning and scholarship back to the universities from the monasteries and men of wide culture were able to demonstrate their talents within and without the university tradition.

Certain factors contributed to the rebirth of science in the 15th century. To begin with, Europe began to expand territorially in 1413, and in that year some of her sea-farers raided the African coast. But the early 15th century was one of cultural stagnation in Europe, the universities were in decay, the church was disintegrating, and the economy still smarted from the effects of the Black Death.

However, the light of science flickered. It received a fillip from three sources: (a) the discovery of man and nature, especially in Italy: (b) growth in mining, metallurgy, and trade in certain cities in Germany, coupled with the invention of the printing press by Gutenberg, and (c) trans-oceanic explorations pioneered by Spain and Portugal that engendered new demands on astronomy and on mathematical techniques and instruments.

13.7.1 In-Text Questions (ITQs)

1. Which era was a period of "go-slow" for science?
2. Which period saw the movement of learning and scholarship back to the universities from the monasteries?

13.7.2 In-Text Answers (ITAs)

1. The medieval era
2. The Renaissance

13.8 Science in the 17th and 18th Centuries

The scientific feat of the Renaissance was furthered by men like Galileo and Newton in the 17th century.[7] But before Galileo and Newton, Copernicus (1473-1543), a Polish ecclesiastic, inaugurated what is generally regarded as the Copernican Revolution. Copernicus devoted his leisure to astronomy. He believed that the sun is the centre of the universe, and that the earth rotated on its axis and revolved around the sun. In his major work *De Revolutionibus Orbium Coelestrum* (1543), Copernicus accomplished the revolution that bears his name by removing the earth from the centre of the universe and reduced it to the status of a mere body that moves around the sun. Before him, almost everybody took it for granted that the earth was the centre of the universe (geocentric theory) and this was in agreement with the teaching of the Church. But with the dethronement of the earth, it became difficult, in the long run, to give man the pre-eminence he had enjoyed in Christian theology. For us today, it requires an active imagination to grasp the revolutionary import of Copernicus heliocentric theory.

Galileo Galilei (1564-1641) was one of the greatest scientists of the 17th century. An astronomer of no mean achievement, Galileo is usually taken to be the founder of the science of dynamics. He was one of the 17th century revolutionaries who criticized the schoolmen for their neglect of experimental science. Galileo was the first to establish the law of falling bodies. Until his time, it had been supposed that heavy objects fall quicker than light objects. Legend has it that Galileo showed for the first time that there was no measurable difference between the rate of fall of objects in a vacuum at the Learning Tower of Pisa. Thus, the acceleration (that is, the rate at which velocity increases) of falling bodies is always the same. Aristotelian theory of falling bodies became discredited.

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[7] I. B. Cohen, *Revolution in Source*.(Cambridge, Massa: Harvard University Press, 1985) pp. 105-175

Galileo also studied projectiles and showed that they too behave in accordance with the law of falling bodies. He demonstrated that projectiles described a parabola (curve) because of the law of inertia and that of falling bodies. Galileo also accepted the heliocentric theory of Copernicus, studied the sky with his telescope only to discover heavenly bodies hitherto unknown. This discovery irked the traditionalists and the clergy, and they maintained that the telescope revealed only delusions. He was persecuted by the Inquisition in 1616 and 1633, and the story of Galileo's battle with pigheaded orthodoxy more than anything else told the tale of the various battles which scientific innovators had to fight in order to establish genuine scientific knowledge.[8]

Galileo also made important contributions to the study of pendulum. He discovered the law governing its behaviour, and another scientist, Huygens (1629-1695) perfected the pendulum to make a clock. Isaac Newton (1642-1727) is taken to be one of the greatest scientists of all times – and rightly so. Indeed, he achieved the acme of scientific feat for which Copernicus, Kepler (1571-1630), who made immense contributions in astronomy) and Galileo had paved the way. It is said that Newton discovered the law of gravitation when he noticed an apple fall in a garden. He then asked himself why it was that the apple fell at all. Starting from his three laws of motion, Newton deduced the gravitation law to the effect that every planet, at every moment, has an acceleration toward the sun which varies inversely with the square of the distance from the sun. He showed that this law of gravitation explains tidal phenomena, the motion of the planets and their satellites, the orbits of comets and, virtually everything in planetary theory of his day. The law of universal gravitation asserts that everybody attracts every other body with a force directly proportional to their masses and inversely proportional to the square of the distances between them.

[8] B. Russell, Op. cit. pp. 517-520

His major work: *The Mathematical Principles of Natural Philosophy* contains the theoretical principles of Newtonian physics, a paradigm of scientific research for two centuries.[9] Newton made notable contributions in optical theory also. He analyzed the components of white light, studied the spectrum of colours, reflection and refraction of light, as well as other optical phenomena besides. His contributions to science are so solid that it was only in this century that the hard-core of his theoretical system, his conceptions of space and time, have been superseded.

Science received a boost towards the end of the eighteenth century from the industrial revolution that began from Britain around 1760. Indeed, the 18th century was a period of revolution in different aspects of European life: the revolution from Aristotelian cosmology to the Newtonian, the industrial revolution, and the French revolution of 1789. The industrial revolution transformed the very fabric of European life. Europe metamorphosed from an agrarian society to the urban; human labour was gradually replaced by mechanical labour, and lopsided trade with Africa especially provided cheap labour and raw materials to oil the wheel of the revolution. At any rate, the contribution of the industrial revolution to science was indirect at the outset. Though virtually all the problems that resulted from industrial practice were beyond the capacity of existing scientific techniques and theories of the time, there is little doubt that attempts to solve them acted as a catalyst for scientific research and provided audience for further investigation. Industrial chemistry, thermodynamics and engineering greatly benefited from the industrial revolution.

After the French revolution, France dominated the scientific field. She produced great mathematicians (Laplace and Lagrange), the eminent chemist, Antonie Lavoisier (who inaugurated the chemical revolution by replacing the phlogiston theory with the oxygen

[9] I. B. Cohen, Op. cit. pp. 161-175

theory), and Sadi Carnot (the renowned engineer). A state supported system of education was introduced, rewards and scholarship were given to deserving inventors and students, and the Ecole Polytechnique was founded. By the time of Napoleon Bonaparte, Paris became the Mecca of the scientific world.[10]

13.8.1 In-Text Questions (ITQs)

1. Which law asserts that everybody attracts every other body with a force directly proportional to their masses and inversely proportional to the square of the distances between them?
2. Name the theory that considers the earth to be the centre of the universe.
3. Whose theory of falling bodies discredited that of Aristotle?

13.8.2 In-Text Answers (ITAs)

1. The law of universal gravitation
2. Geocentric theory
3. Galileo Galilei

13.9 Science in the 19th Century

With the advantage of hindsight, the 19th century appears as a golden age for science. Science at that time expanded its tentacles to new areas of inquiry. Mathematics and experiment were combined in physics, and controlled experimentation in biology received a

[10] T. S. Kuhn, *The Essential Tension*.(Chicago: The University of Chicago Press, 1977) p. 63

new lease of life. In addition, new and reformed universities were founded where research was fostered, as well as teaching, and communication through specialized journals and societies. Science became professionalized heavily, and Newtonian physics bestrode the intellectual world like a colossus.

In physics, different research areas were successfully uplifted by the concept of energy defined as the ability to do work. Eminent 19th century physicists include Hans Christian Oersted (1777-1851), Michael Faraday (1791-1879), Hermann von Helmholtz (1821-1894) and James Clerk Maxwell (1831-1979). These men, in their various ways, contributed to the theory of energy conversion and conservation. But they generally worked within the context of Newtonian theory, although development in the electromagnetic theory was beginning to question the validity of Newtonian physics, especially during the last quarter of the 19th century.

In chemistry, chemists built on the foundation of the nomenclature of chemical substances founded by Lavoisier. Charles Dalton's atomic theory (the theory that all material objects are made up of small indivisible and indestructible particles called atoms) was further elaborated. Dimitri Mendeleev (1834-1907) a Russian invented the modern Periodic Table of elements. Scientists in this area work assiduously in classifying substances into elements and compounds. By this time, the underlying theory of alchemy, that a way could be found for transmuting all base metals into gold, was dropped, and investigators spent more energy in discovering and predicting the properties of hitherto unknown elements.

As chemistry continued to make progress, chemists were able to uncover the true structure of organic (or carbon-based) substances. Thereafter, chemistry moved closer to unity with physics, and achieved an increased power in industrial application.

The fundamental discoveries in biology were those of the cellular structure of organisms by Theodore Schwann, the microbiological origin of disease by Louis Pasteur (1882-1895), and natural selection by Charles Darwin (1809-1882).

Darwin's theory of evolution (1859) unified the disciplines of biology, philosophy and geology. But it clashed with theology because it tended to jettison the "divine plan" as a causative agent in the evolutionary process. In philosophy it provided the basic principles for the metaphysical theories of Herbert Spencer, Henri Bergson and Telhi deChardin.[11]

Another noteworthy discovery in biology was made by the Austrian-German monk, Gregor Mendel (1822-1884) in the area of inheritance of characteristics by filial generations of species and varieties. Today the disciplines of genetic engineering attest to the invaluable contributions of Mendel.

The major theme of 19th century Europe was progress and science justifiably received credit for much of it. It also shared in the general optimism of the time. Three basic factors are decipherable in this general praise of science. First, we have the ancient tradition of respect for learning as a contribution to civilization independently of its application. Second, there was the discovery that science could be fruitfully applied in industry. A third factor, intermittent in its appearance, was the conception of natural science as a weapon against religious dogma and popular superstition. In the 19th century the memory of the trials of Galileo stayed fresh in popular stories of science, such that the debate and argument over Darwinism in England gave a new impetus to the ideological struggle in which liberal minded Christians allied with agnostics against the orthodox. These three factors, taken together, served as a *Weltonschaury* to many an intellectual, and remained a strong inspiration for science until contemporary times. In point of fact, they no longer have the

[11] J. I. Omoregbe, *A Simplified History of Western Philosophy.*(Lagos: Joja Educational and Publishers Ltd, 1991) pp. 18-28

same force today as they had in the 19th century, although they present some serious problems for the future of science.

13.9.1 In-Text Question (ITQs)

1. Who invented the modern Periodic Table of elements?
2. The theory of natural selection is scribed to whom?

13.9.2 In-Text Answers (ITAs)

1. Dimitri Mendeleev
2. Charles Darwin

13.10 Macro and Micro Science in the Twentieth Century: The Two Great Revolutions in Physics

Certain tendencies in the womb of the 19th century science blossomed in the 20th century. Science became highly professional in its social organization, reductionist in style (that is, investigations were concentrated on the artificially pure, stable and controllable processes set up in the laboratory), and positive in outlook.

The scientific achievements of this century are too numerous to be catalogued. We shall consider just two: the revolution in macro (big) science via the theory of relativity and that in micro (small) science accomplished through the indeterminacy principle.[12]

[12] L. Randall, *Warped Passages: Unravelling the Mysteries of the Universe's Hidden Dimensions* (New York: Harper Perennial, 2005)

The special theory of relativity (1905) and the General theory of relativity (1916) were posited by Albert Einstein (1879-1955) to resolve certain theoretical and experimental anomalies in Newtonian physics. As we noted earlier, Newton's theory was the paradigm of research in physics (and related scientific fields) for two centuries, and it assumed the existence of a universal coordinate system or frame of reference for measurement in space and time. One of the cardinal implications of Newtonian theory is that ether-shift (that is, measurable shift in position of the invisible, super-elastic substance called ether that supposedly pervades the whole universe) should be observed in terrestrial measurements with reference to the earth. Two physicists, Michelson and Morley performed the relevant experiments in 1886.[13] Further experiments were carried out until 1904 but in all of them no ether-shift was observed. This anomaly prompted a lot of critical discussion of Newtonian theory amongst theoretical physicists. Einstein, in 1905, brought a new twist in the whole debate. He found the trouble with Newton's theory of gravitation by looking into its very heart - an attribute of scientific genius of which Einstein was a master.

What did Einstein find? He found the assumption that time and space are given absolutely and are alike for all observers. But further analysis of the steps by which different observers can actually compare their time in space revealed to him that something must be wrong with this assumption. He discovered that we cannot compare the time in two different places without sending a signal from one to the other which, logically, demands the passage of time. Consequently, Einstein showed that there is not universal "now", there is only "here and now" for each observer, so that space and time are inextricably interwoven, and are species of a single reality.

[13] J. Jeans Op. cit. pp. 260-267

In Einstein's theory of relativity, time is not a strict succession of universal before and after. Closely spaced occurrences which appear in one sequence to A, say, may appear in the opposite sequence to B. Thus, the traditional notion of time sequence was discredited, and the ideas of simultaneity fell into oblivion. Moreover, the structure of space became entangled with the matter which is embedded in it, and the Euclidean theory of space had to be adjusted. With the relativity theory and developments in non-Euclidean geometry, it is now possible to talk intelligibly about the sum of the three angles of a triangle being more or less than 180^0. Einstein also introduced the fourth dimension (space-time) into the traditional three dimensions of length, width and height.

He also established one of the basic equations that made it possible to know scientifically the great amount of energy latent in matter and which makes the exploitation of nuclear energy possible. The equation brought together energy (e), mass (m) and the velocity of light (c). It is written in its standard form thus: $E=mc^2$.

Another significant revolution, as we stated before, is quantum mechanics. It is a revolution in micro (small) physics and Einstein too contributed immensely to it (He received the 1921 Nobel Prize in Physics for his contribution to the understanding of photoelectric effect, a phenomenon explained by quantum theory). The story of the steps leading to this revolution, like those leading to relativity theory, is interesting and illuminating for it throws some light on the nature of the scientific endeavour, an endeavour that is largely geared towards the solution of problems.[14] Only a very brief sketch can be given here. In 1900, it was discovered by Max Planck (1850-1947) that matter gives out energy not n a continuous stream, as was previously supposed, but in discrete packets of quanta of definite sizes. Prior to that time, there was a deadlock as to the explanation of the radiation (giving-off) of energy from a red-

[14] K. R. Popper, *Conjectures and Refutations*. (London & New York: Routledge, 2002) p. 172-173

hot black body according to the continuous-flow theory based on Newtonian principles. Planck investigated the phenomena of radiation very closely. He imagined that all matter consists of "vibrators", each having its own particular frequency of vibration, the frequency of vibration being the number of vibrations of a unit matter per second. He described the units of vibration as "quanta" and argued that the amount of energy in any unit of energy is equal to the frequency of the vibrations times a constant h, (which is generally stated as Planck's constant).

But problems still remained, for physicists realized there was no way of describing scientifically the present and future states of subatomic particles and events in completely deterministic fashion. By 1926 this anomaly had reached a head because it was becoming increasingly impossible to predict the behaviour of the electron within the context of the classical pattern of causality. Werner Heisenberg (1901-1976), a German physicist, articulated this in a formal principle in 1927 and gave it the sensible name of the principle of uncertainty or indeterminacy. It asserts that: it is impossible, in principle to measure with complete precision the position and velocity of a subatomic particle simultaneously.[15]

Through this principle, Heisenberg demonstrated that every description of nature contains some basic and irremovable uncertainty. For instance, the more accurately we measure the position of an electron, say, the less certain we will be of its velocity. The more accurate we measure the velocity, the more uncertain we will be of its precise position. It follows then that we can never predict the future of a subatomic particle with complete certainty since, as a matter of fact, we cannot be completely certain of its presence.

[15]T. Hey,&P. Watters,*The New Quantum Universe*.(Cambridge: Cambridge University Press, 2003)p. 21-24

The physical fact about sub-atomic or micro phenomena as described by quantum mechanics is not really in question. Their future cannot be predicted with complete accuracy. In short, the future, from the point of view of the present, is problematic.

Another consequence of the uncertainty principle is that in investigations of micro phenomena, the observer, together with instruments he uses in observations must also be taken into account when interpreting the results of experiments. For in such experiments highly sophisticated equipment that could influence – and in fact do influence – their outcomes are indispensable.

In addition, quantum mechanics has shown that the traditional concepts of physics fit nature inaccurately, that deep-going conceptual reconstructions are desiderata in science, and that the language of ordinary day-to-day life are quite unsuitable in high-level scientific work.

Again, it has increased the use of probability calculi or statistical techniques in micro physics since, as it were, the atoms or elementary particles form a world of potentialities or probabilities rather than one of things or facts.

On the whole, the theory of relativity and the uncertainty principle have led to a radical revision in the basic concepts of classical or Newtonian physics. For instance, concepts such as mass, energy, etc. all underwent significant changes as a result of the relativity theory. As we noted already, the uncertainty principle has increased the application of statistical method in micro physics.

The two theories demand, at the societal level, that all of us ought to jettison dogmatism, fanaticism, and intolerance and embrace open-mindedness, the desire to listen to others, and the recognition that our most cherished beliefs may be shown to be erroneous in future.

13.10.1 In-Text Questions (ITQs)

Who propounded the theory of relativity?

13.10.2 In-Text Answers (ITAs)

Albert Einstein

13.11 Procedures of Scientific Research

There is a widespread belief that scientific research starts with observation. This belief is a natural one; after all science, as an empirical discipline, is supposed to explain phenomena occurring all around us. But since Immanuel Kant's *Critique of Pure Reason*, the idea that observation is the starting point of scientific research has increasingly come under critical fire, it is generally recognized now that scientific research cannot commence when scientists merely begin "studying the fact". No scientific inquiry "can even get underway until and unless some difficulty is felt in a practical or theoretical situation".[16] Legend has it, for example, that the noted scientist, Sir Isaac Newton, was motivated to investigate gravitational force by the dropping of an apple from an apple tree. Apples have been falling down ever since that plant evolved, and before Newton was born people had seen them fall without attaching any significance to the occurrence. The ability to perceive problems in the facts of experience, particularly problems whose solutions have a bearing on the solution of other difficulties, is a mark of scientific genius. It is thus understandable that scientific research

[16] M. R. Cohen & E. Nagel, *An Introduction to Logic and Scientific Method*. (London: Routledge and Kegan Paul, 1963), p. 199.

must begin with some problem, and aim at an order that links what may superficially seem to be unrelated facts.[17]

Once the researcher has identified a problem (sometimes such problems may be vaguely felt at the beginning), he would make an educated guess about how to handle it. He would posit a tentative solution of the problem he has identified. This is where familiarity with the subject matter becomes very important. As a matter of fact, a scientist cannot even state the problem unless he is somewhat acquainted with the subject matter he is dealing with. For him to state some obscurely felt difficulty in the form of a determinate problem, he must be able to select, on the basis of his background information, certain elements in his discipline as significant. An example from the history of science could help to clarify this point. In 1895 when the physicist Roentgen interrupted a well-precedented experiment pm cathode-ray phenomenon due to the glow of a barium platinocyanide screen somewhere in the vicinity of his laboratory, he did so not only because he felt that the glow was anomalous but also because he saw it as a significant problem requiring further investigation.[18] Based on his background knowledge about the behaviour of cathode rays, Roentgen entertained the hypothesis that the glow was due to a new form of radiation different from cathode rays. With that preliminary hypothesis, our physicist proceeded to systematically investigate the problem and ended up with the discovery of X-rays.

Not all hypotheses which a researcher can conceive are relevant to a particular problem. Referring back to our example, Roentgen did not consider the shape of the equipment he was using, or the type of shirt he wore at the time of his research etc. as the cause of the radiation he noticed, because no such relation is known to exist between the shape of the equipment used in experiments involving cathode rays etc and the glow of barium platinocyanide screed.

[17] Ibid, p. 200

[18] L. W. Taylor, *Physics, The Pioneer Science*. (Boston Houghton: Miffling Co. 1941), p. 790

Although some philosophers (Bacon and Mill are representative in this respect) have postulated rules for making discoveries, experience has shown that no such rules can be used mechanically to arrive at causal connections between phenomena. If there were rules which, if strictly adhered to can lead to scientific discoveries, then the job of the scientist is made considerably easy. Questions about relevant hypothesis are invariably questions about causal connectedness. In order to "hit upon" relevant hypothesis asserting such connectedness in nature, the scientist, as he observed earlier, must be familiar with the sort of connectedness which the phenomenon under investigation is capable of exhibiting. He would be wasting his time if, he believes that the mechanical application of a set of rules can lead him to the discovery of relevant hypothesis.

Armed with a relevant preliminary hypothesis, the scientist could begin to collect additional facts which, it is hoped, will be a clue to the final solution, because preliminary hypotheses are always based on insufficient data. Thus, it should not be surprising that such a hypothesis may even he very different from the solution to the problem.[19] Basically, scientific research starts with some fact of collections of facts which a scientist considers problematic. Usually these initial facts are too meagre to enable the researcher postulate an adequate explanation for them. Still, they indicate to a competent scientist some preliminary hypothesis that would necessitate the search for additional facts. Referring back to our example once again, Roentgen, having convinced himself that the effect he noticed during the experiment on cathode rays was a new form of radiation similar in certain respects to light, spent more time afterwards to gather additional facts to which the preliminary hypothesis had led.[20]

It must be noted at this point that the postulation of a preliminary hypothesis and the collection of additional facts are practically inseparable because they are interdependent –

[19] I. M. Copi & C. Cohen, *Introduction to Logic.* (New York: Macmillan 1994), p. 543
[20] T. S. Kuhn, *The Essential Tension*. (Chicago: Chicago University Press, 1977), p. 172

there is a dialectical relationship between the two. Serious scientific research requires a preliminary hypothesis to explain the facts, but additional facts may suggest new hypotheses, which may lead to new facts, and these new facts could still suggest other hypotheses, and so on.

The scientist, as his research programme progresses, would eventually come to a stage when he will have the impression that the major facts required for solving the problem he started with are available. In our example, Roentgen, after seven hectic weeks during which he rarely left the laboratory, and before he announced his discovery, felt that he had a hypothesis that explained the data at his disposal. The situation here according to Copi and Nagel[21] is analogous to that of a puzzle solver who has all the pieces of the puzzle but requires to put them together. In formulating a more satisfactory hypothesis or theory that explains the initial problem and additional facts derived from experiments, the scientist has, as it were, to "think things through". The end result of such thinking, if successful, would be a theory that accounts for the available data. The discovery of explanatory theories in science is a creative process which involves both imagination and knowledge always.

Now, scientists are hardly ever satisfied with theories that explain only those facts that were considered initially during the process of research; they usually prefer theories that point beyond the initial data to new ones whose existence in the light of existing knowledge in the field of research would have been unsuspected. This process entails the inference of further consequences through the deductive development of a theory. Scientists and epistemologists put a lot of premium on the predictive or explanatory power of scientific theories, meaning that additional facts must be inferred from a good theory. From his theory that the cause of

[21] Copi, & Cohen, Op.cit. p. 545

the radiation was not the cathode rays but a new radiation similar to light in some essential respects, Roentgen predicted some properties of the new radiation he had already discovered.

But the prediction must be tested to ensure, at least, that the scientist is not on the wrong track. The procedure of deducing testable consequences from a scientific theory (plus initial conditions) is extremely important because it helps scientists to bring to the surface hidden assumptions which can be empirically tested. In our example again, Roentgen spent some time exploring the properties of the X-rays he had predicted in the course of his investigations due to the fact that experiments in science are usually performed to test the consequences of theories in addition to initial conditions. In practice, scientists usually place more emphasize on theories that enable them infer and discover an ever greater variety of true propositions. Since no comprehensive scientific theory can be established as completely true, being at best only highly probable, it follows that theory which predicts more established causal connections between hitherto unconnected phenomena are preferable to ones that predict less of such connections.

All the items of scientific method articulated thus far relate more the theoretical concerns of scientists, that is, to their desire to understand and explain phenomena. But theoretical concerns are intimately connected to practical problems. Consequently when scientists posit theories to explain facts these theories usually have practical applications. Roentgen's discovery of X-ray phenomenon and his subsequent explanations of it have been applied in various ways to address practical problems. In medicine, for example, X-rays have for long been utilized in the diagnosis and treatment of certain ailments. In a large number of cases in science it is from some practical problem that a theoretical development begins, and some theories are consciously developed with a keen eye on the solution of some practical problems.

13.11.1 In-Text Questions (ITQs)

Roentgen's background knowledge about the behaviour of cathode rays led to his discovery of ------

13.11.2 In-Text Answers (ITAs)

X-Rays

13.12 Experimentation and objectivity

Despite the assertion made earlier that scientific research begins with problems, these problems are always connected with some facts which strike the scientist as problematic. Hence, as an empirical activity, scientific research must ultimately make contact with the real world through a network of systematic observations, although as H. I. Brown had indicated,[22] scientific observation is not a straightforward matter. In our daily interactions with the world, our sense organs enable us to perceive things within the backdrop of share linguistically mediated experiences. However, even though ordinary observation and scientific observation are effected through the senses, the later takes the process to the next level that "… allows us to extend the range of observation well beyond the limits of what we can detect with our unaided senses".[23] This has been made possible by the development of new instruments and equipment which have profoundly influenced the nature of scientific experiments.

Scientific observation is done within the context of a theory (or theories) which guides the process in at least three ways: it indicates what kinds of items exist, what kinds of equipment

[22] H. I. Brown, *Observation and Objectivity*. (New York: Oxford University Press, 1987) pp. 48 – 76
[23] Ibid, p. 18

are appropriate for observing them, and how we are to interpret the data from the equipment which aids scientific observation. The discovery of neutrinos, for example, illustrates the intimate connection between scientific observation and theory.[24] It equally underscores the difficulty in maintaining a rigid distinction between observables and unobservable in science. As scientific knowledge grows and better instruments become available, a significant number of so-called unobservable (or theoretical terms) becomes observable. At one stage in the history of science atoms, electrons etc were deemed unobservable; now scientists consider them observable. But how can this change be justified in the light of scientific practice? Ian Hacking provides an interesting perspective on this question when he asserted that:

> … it is not even that scientists use electrons to experiment on something else that makes it impossible to doubt electrons. Understanding some causal properties of electrons, you guess how to build a very ingenious complex device that enables you to line up electrons the way you want, in order to see what will happen to something else.[25]

Hacking's argument should lead us now to a discussion of the role of experiments in science. Being an enterprise whose major objective is to explain the world, science must have a solid footing on experiments, since it is the experimental procedures of research that ensures that scientific theorizing maintains contact with the real world. Scientific experimentation is very tasking; in some cases it takes years of patient observation and computer-assisted analysis of data to come up with tangible results that scientists can use. Experimentation in science is the winnowing process which provides "a reliable way of checking our empirical conjectures

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[24] F. Reines, & C. Cowan, "Detection of the Free Neutrino" in *Physical Review*, Vol., 92, 1953, pp. 830 – 831
[25] I. Hacking, "Experimentation and Scientific Realism". In Tauber, A. (ed). *Science and the Quest for Reality*. (London & Hampshire: Macmillan, 1997), p. 164

about the objective world".[26] The process itself is anchored on measurements. Measurement is a well- ordered procedure for systematic quantification of nature aimed at improving the level of "reasonable agreement" between nature and theory[27]. When the results of measurements conflict with the numbers predicted with the help of theories, the scientist is expected to cross back both the experiment and his theoretical calculation to locate the source of the discrepancy. Scientific research generally can be characterized as a tasking mopping-up activity meant to secure the horizon of objectivity made available by theoretical breakthroughs as well as provide the necessary preparation for future theoretical breakthroughs. Measurement, clearly, is an indispensable tool for such activity.

A much-discussed structural component of scientific method is objectivity. Experimentation and the reproducibility of both the research procedure followed and the phenomenon investigated are key elements in scientific objectivity. Now, there is a widespread misconception about objectivity which derives from the idea that scientific objectivity is a function of the psychological detachment of the scientists from the object of his research. It is tempting to think that the "dryness" and esoteric nature of science makes scientific research objective. However, as Karl Popper[28] observed, neither the dryness nor the remoteness of the problems handled in science could prevent idiosyncratic factors from interfering with the individual scientist's beliefs. Rather, it is the social or public character of science and its institution which imposes a mental discipline on the scientist, and also preserves its objectivity. Objectivity in science is, fundamentally, a complicated trialogue between the scientists, his theory and nature.[29] This implies that the demand for scientific objectivity is more or less a reminder to the scientist that he should implement his research programme in

[26] L. Laudan, "Explaining the Success of Science: Beyond Epistemic Realism and Relativsim". In Cushing C. F. et al (eds) op.cit

[27] Kuhn, op. cit., p. 184

[28] K. R. Popper, *The Poverty of Historicism.* (London: Routledge & Kegan Paul, 1961), p. 155

[29] D. I. O. Anele, "Explanation, Objectivity and Theory Choice in Science", in C. S Momoh, (ed). *The Nigerian Journal of Philosophy, Department of Philosophy, University of Lagos*, Vol. 19, Nos. 1 & 2, 2001, p. 51

consonance with the standard of inter-subjective procedures available for himself and his professional colleagues. It is only in the context of the recognition that objectivity for scientists is always a contextually contingent product of their variable but experimentally justifiable interpretative procedures that the pitfalls of the untenable notion that scientific objectivity rests on the scientist's attitude of detachment from the object of inquiry can be avoided.

13.12.1 In-Text Questions (ITQs)

List three ways in which scientific theory aids the process of scientific observation.

13.12.2 In-Text Answers (ITAs)

(i) It indicates what kinds of items exist, (ii) what kinds of equipment are appropriate for observing them, and (iii) how we are to interpret the data from the equipment which aids scientific observation.

13.13 Philosophical Models of Scientific Method

Emerging from philosophical discussions of science are certain interesting models of scientific method which can enrich one's understanding of the workings of science. The models to be sketched below, albeit briefly, are well known in the philosophy of science.[30]

Because of the undeniable success of science in explaining (and through its application in changing) the world, there is a widespread feeling that there must be something unique and special about science which accounts for its success and which distinguishes it from allegedly

[30] R. H. Newton-Smith, *The Rationality of Science*. (London: Routledge, 1981)

non-scientific disciplines such as astrology, psychoanalysis or even philosophy. Trust philosophers, they have, in most cases tackled the problem of demarcation in a *priorist* or essentialist manner in the quest for an adequate characterization of science that excludes the so- called pseudosciences or metaphysics.

Logical positivism, once an influential school of thought in philosophy, held that scientists try to justify their theories inductively. That is, through the accumulation of confirmatory or verificatory empirical evidence. Continuing accumulation of this sort of evidence implies that science progresses towards truth which can be measured by probability calculus relating the tested predictions of theory to available evidence. Popper disagreed with the inductivist model of science which interprets increasing probability of scientific theories in terms of the accumulation of confirming instances of a theory as a touchstone of scientific progress. The probability of a theory relative to the evidence available at a point in time can never be a guarantee of predictive success, which is something that scientific theories are expected to offer. Thus, Popper prefers falsifiability to verifiability as the demarcating criterion between science and non-science. Popper held that the aim of science is to seek trust, but the scientist cannot be sure he has arrived at the trust. Therefore, scientists have to work from problems and posit theories to solve them, using basic statements such as potential falsifiers of these theories. A theory is scientific if it is testable or refutable in principle, that is, if it can yield a prediction that could contradict experimental findings. Popper claims that the bolder or more improbable (on the basis of existing knowledge) a scientific theory is, the better for scientific progress. The best way to ensure the growth of scientific knowledge is for scientists to stick their necks out and posit bold theories that must be subjected to severe tests. If a theory stands up to severe tests, if it has proved its mettle, then it is corroborated; if otherwise, it is deemed falsified. But the decision that a theory is falsified by a piece of evidence may be mistaken. Hence, the critical attitude is essential all the way in scientific research.

Popper's falsificationist model has some merits. One, it presents a more modest idea of scientific achievement by construing scientific progress in terms of increasing verisimilitude rather than in terms of attainment of certainty. Two, it puts science on a firmer logical ground than does the verificationist or inductivist model. Three, falsifiability is a tidy way of handling the demarcation problem.

One of the major criticisms of Popper's methodology is its inability to provide an unambiguous answer to the question: when is a scientific claim successfully corroborated, or falsified?[31] Basing their argument on the phenomenon of experiment's regress, some scholars maintain correctly that there is no univocal and theory-independent algorithm for deciding on the issues involved. The decision that a theory is corroborated or falsified, as the case may be, is hinged on whether the outcome of the experiments was consistent with the theoretical assumptions of observations (or language of pure observation for describing them), scientists are bound to disagree legitimately as to when a particular experimental finding constitutes corroboration or falsification of a particular theory. Popper was wrong in thinking that the logical neatness of falsifiability also applies to the practical problem of falsification.

The problems of the falsificationist model have led to a more historical turn in the philosophy of science. Thomas Kuhn's theory is a typical example in this respect. Kuhn argues that before a major scientific discipline evolves, there existed a number of conflicting explanations of the natural phenomenon (or phenomena) from which that discipline emerges eventually. This period of theoretical anarchy is brought to a close when one of the competing explanations either solves a difficult problem which its competitors could not solve or explains a much wider range of natural phenomena. When such an explanation becomes available and there is some kind of consensus about legitimate problems and problem-solutions in that particular domain, normal science has begun. Normal science is

[31] T. F. Grieryn, "Boundaries of Science," in *Tanber*, op. cit, pp. 297-298

research firmly based on one or more past scientific achievements, achievements which members of a scientific community acknowledge for some time as supplying the foundation for future practices.[32] The principal focus of normal scientific activity is the disciplinary matrix (paradigm) whose basic cognitive components are: (a) symbolic generalizations, such as f=ma, e=mc^2 etc, (b) models, such as the depiction of an atom as a miniature solar system, and (c) exemplars, which are concrete problem-solutions accepted by scientists in a particular domain as providing the template for solving other related problems.

Normal science proceeds by finer and finer refinements of the problems and problems-solutions achieved within the context of a disciplinary matrix (theory). According to Kuhn, normal science is a puzzle-solving activity in which the disciplinary matrix or theory functions as the framework for puzzle solving. Sometimes, however, a problem degenerates into an anomaly, and later into a crisis. But then, scientists never abandon a theory unless another one is available. In deciding between competing theories, logical and empirical considerations, though difficult to apply in practice, are relevant but not determinative, for they are complemented by the psychology of perception and the sociology of commitment and consensus.

Kuhn's-theory demonstrates clearly the insights into scientific methodology which can be arrived at by taking the history of science very serious in dealing with methodological issues. It also explains the high degree of research consensus in the developed sciences, particularly physics. But critics of Kuhn have argued that it is rare to see in the history of science the level of consensus which he attributes to scientists during normal science. Some philosophers also accuse Kuhn of erroneously downplaying the role of logical and empirical factors in the choice of theories amongst competing alternatives in science. They insist, correctly, that even though the application of logical and empirical criteria in theory choice are problematic, as

[32] T. S. Kuhn, *The Structure of Scientific Revolutions.* (Chicago: The University of Chicago Press, 1970), p. 10

Kuhn suggested, scientists have learnt to cope with such difficulties, without jettisoning these criteria completely, and successfully reach agreement as to when experimental findings justify the modification of particular theories, or their outright abandonment.

Lack of agreement amongst philosophers of science on the essence of scientific method has encouraged some scholars to posit anarchist views on methodology. Paul Feyerabend, for instance, has propounded such a view. Feyerabend was critical of Popper and Kuhn.[33] He says that Popper's methodological prescriptions, if applied resolutely, would eliminate science without replacing it with anything comparable. As for Kuhn, he says that Kuhn's ideas, though interesting, are too vague to give rise to anything substantial in methodology. Feyerabend disclaims the need for methodology. He argues that methodology is like a chain tied to science, impeding and stifling its growth. He reminds us that various non-western cultures of the world had made some progress in the areas of medicine and excellence of western science (and its seeming superiority over other approaches) is not just a reflection of its superior methodology, rather it is due to "ideological pressures identical with those which today make us listen to science to the exclusion of everything else."[34] Instead of the principle of tenacity which Kuhn prescribes during normal science, Feyerabend urges the principle of proliferation of scientific theories as the only way to ensure scientific progress. More precisely, he argues that the principles of tenacity and proliferation are always co-present in the history of science, and the interplay between them amounts to the continuation, on a new level, of the biological development of the species.

Feyerabend has succeeded in drawing attention to the problems attendant with taking methodological prescriptions for science too seriously. His liberal perspective on science as a

[33] P. K. Feyerabend, "Consolations for the Specialists". In Imre Lakatos Alan Musgrave (eds). *Criticism and the Growth of Knowledge*. (Cambridge: Cambridge University Press), 1970, pp. 197 – 230

[34] P. K. Fayerabend, "How to Defend Society Against Science". In Ian Hacking (ed), *Scientific Revolutions,* (Oxford: Oxford University Press, 1989), p. 161.

whole is a helpful attitude to the overweening influence of "experts" on people's lives which, according to Gernot Bohme,[35] has disabled the average contemporary man from being the master of his life. However, Feyerabend went too far by putting outmoded superstitions or magical practices on the same level with modern science. It is simply false to say, as Feyerabend did, that the excellence of science over other approaches is due to ideological pressures that favour science: the fact of the matter is that science has enormously increased our knowledge of the knowable world in the last three centuries and through its application in technology, altered the very texture of our practical dealings with it to an extent unmatched by pre-scientific approaches. The methodological entailments of science in terms of verification coherence and predictability are intimately connected with the relative success of science in increasing our knowledge of the world. Any theory, such as Feyerabend\s, which discountenances this fact is simply wrong. Further, his theory of "anything goes" does not hold water. For if we accept that idea then nothing can ever be ruled out in science. A scientist wishing to study the behaviour of thunder, for instance, could as well carry out some rituals in the shrine of *Amadioha*, the god of thunder. An astronomer interested in detailed investigation of the solar system need not go beyond the first chapter of the book of Genesis. It is obvious from these examples that success in science entails that some approaches are more appropriate than others in carrying out the tasks which scientists engage in as scientists, although they cannot guarantee certainly or truth.

13.13.1 In-Text Questions (ITQs)

Which philosopher of science prefers falsifiability to verifiability?

[35] G. Bohme, *Coping with Science.* (Boulder, Colorado: Westview Press, 1992)

13.13.2 In-Text Answers (ITAs)

Karl Popper

13.14 Summary of Study Session 13

Indeed, our journey in this study session has been a long and arduous one. Nevertheless your knowledge vault must have been enriched. You can now discuss meaningfully about the systematic development of science across human, cultural and religious history stating clearly the sense in which each impacted on the growth of science. Our knowledge bank is further enriched by our discussion on the method of science involving systematic steps. Of critical importance is also our discussion on the models of scientific method.

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