BLOCK 1

Today science is considered as one of the best sources of reliable knowledge, especially for providing the knowledge of the reality around us. But today's science and philosophy has its basis in the mythology of the past. The ancient people were in search of an explanation of the nature that was externally obvious to them, yet the origin, nature and structure was too transcendent to their limited minds. This is the reason they took refuge in the myths. Although these myths were not so clear and satisfactory, these gave them the momentum to go ahead and search for more convincing answers. This is the story of the development and growth of science. Today's science was the myth of the past. Both strive to explain the reality; both have the same goal; but the methods followed are different. Myths when elaborated and rationalized become philosophy. Also philosophy becomes a reflection on the data furnished by science which will help in furthering human knowledge. Philosophy and science are the two sides of the same coin i.e. knowledge. Even this discipline of knowledge has its foundation laid down long ago by the Greek thinkers, by 6th century BC.

This block consists of four units introducing us to the philosophy of science and the Greek roots from which it developed.

Unit 1 will introduce the course that we will study: Introduction to Philosophy of Science and Cosmology. It gives the various stages of how the so called contemporary science has developed. Beginning with an analysis of myths, it will show the relationship that exists between philosophy and science, philosophical cosmology and what we understand by philosophy of science.

Unit 2 familiarizes us with the contributions of Pre-Socratic thinkers. The entire academic edifice of the western world is founded on firm foundation laid down by the Greeks. The major schools during this period were the Ionian school, the Pythagorean brotherhood, the Eleatic, and the Atomists schools. All their thinking revolved around two questions: What is the basic stuff of everything? How can we explain the process of change?

Unit 3 deals with the Socratic thinkers and their contribution. This unit carries with it two of the most important foundation stones of the western thinking: Plato and Aristotle. They have elaborated on topics like universe, its origin, teleology, structure, development and matter and motion. Animism is a common feature in both the accounts.

Unit 4 highlights the growth of philosophy of science and cosmology in the Middle Ages. This unit gives us an immediate account of what happened in Europe after Aristotle. There was interplay of three movements: Aristotelianism, scholasticism and Arabic science. Ptolemy's system is one of the important achievements of this period. Roger Bacon tried his best to introduce his experimental science.

The whole of western tradition has its basis in the Greek thought. The whole of western tradition carries forward the torch of knowledge lit by the Greeks. The great thinkers such as Socrates, Plato and Aristotle were the main contributors.

BPY 012- PHILOSOPHY OF SCIENCE AND COSMOLOGY (4 credits)

COURSE INTRODUCTION

Philosophical cosmology is a discipline within philosophy that deals with questions concerning the origin, structure and nature of the universe. The study of the Universe has a long history involving science, philosophy, esotericism, and religion, but the name cosmology was first used only in the later 18th century. Philosophy began with wonder at the reality that was obvious to human eyes, yet its origin, makeup and growing up during the times gone by has surprised most of the thinkers. It is different from the science as well as myth. The goal of all the three is to explain the reality, but the methods and course that they hold on to are quite different. There is a slow development from myth to philosophy and then to science. Myths are not existentially true and meaningful; philosophy tries to be factually true and meaningful by rational investigation. Science attempts to be factually true and does not directly influence the existential meaning. Myths provide us with intuitive and existential meaning. Philosophy gives us rational meaning. Science shows us empirical facts.

This block contains four blocks, each of the block having four units.

Block 1 is on Pre-Copernican Philosophy of Science and Cosmology and introduces to us the study of cosmology, pre-Socratic, Socratic, and middle age thinkers.

Block 2 introduces Mechanical philosophy of nature as contributed by Copernicus, Newton and other schools and its implications.

Block 3 studies the contributions of the contemporary philosophy of science with special reference to logical positivism, historicism and historical realism

Block 4 deals with the contributions of the contemporary philosophy of nature and the various movements that emerged during this time.

This course consisting of 16 units as a whole will enlighten us on the subject of cosmology and philosophy of science.

UNIT 1 INTRODUCTION TO PHILOSOPHY OF SCIENCE AND COSMOLOGY

Contents

1.0 OBJECTIVES

The main objective of this Unit is to give a pre-taste of philosophy of science and philosophical cosmology without going into details. Although the details of the 'how' of philosophizing are not considered in this unit, it is a very important Unit as it is the basis for all that will follow during this course. In this unit we shall try to give a definition of philosophy, both etymological and real; and then we shall show as to how philosophy is to be differentiated from or related to 'philosophizing'. But the notion of *wisdom* will be clarified in greater depth and width in relation to 'philosophy' and in contrast to 'knowledge'. Philosophy is not just one of the disciplines of knowledge, as any other one. Hence clarification of its all-comprehensive character by referring to its scope is yet another objective of this unit of study. Finally the importance of philosophy is also to be paid attention to.

Thus by the end of this Unit you should be able:

- to have a general understanding of philosophy of science;

- to appreciate some features of cosmology
- to articulate differences between myth, science and philosophy
- to realize the need for cosmology serving as the data for philosophising
- to appreciate some of the wider and deeper philosophical questions arising from science and cosmology.

1. 1 INTRODUCTION

OLBER'S PARADOX

Let us start with a contemporary story. During a warm summer evening, some friends were sitting at Varanasi on the banks of river Ganges and conversing. At first it was just chit-chatting. Then when they saw the sun-set, the mood become more serious and appreciative of nature. So the conversation turned to serious issues like the origin and effect of the sun on river, ecological problems of today and the human role in it.

As evening proceeded, the group of friends get into much more involved discussion. Gradually, a myriad of stars began to materialize above our dark-adapted eyes, while a voluptuous Milky Way unquestionably assumed the leading role of such great spectacle. Less than ten minutes later everyone had become completely engrossed by the marvellous scene over our heads.

Still out of the blue, one young and educated man asked: "Please, tell me, if there are almost infinite suns as you say, doesn't the night have to be pretty much lighted?" Apparently simple and naive, he had posed a very hard question. Were the Universe filled with infinitely many stars for an also infinite time, it sounded reasonable that no night could exist, as heavens would be bright by other stars even when our Sun disappeared into horizon.

The question about the night's darkness involves not only a difficult topic by itself, but a truly essential one, as it is intimately connected with the structure and evolution of the universe as a whole. Assuming an infinite old universe with stars scattered more or less randomly throughout infinite space -the usual model since the end of medieval times- the night sky should not be dark as it obviously has ever been.

This evident contradiction between theory and reality became generically known as "Olbers' paradox", after the German amateur astronomer who wrote about it in 1823.

Newton thought that the universe had to be a static, infinitely old, unlimited expanse of stars homogeneously distributed. This model effectively resolved the otherwise problematic appearance of a privilege centre of gravity -in a non homogenous universe large gravitational forces would not be compensated at all- but failed to solve the riddle of the sky darkness.

We now know that space and time are no longer independent entities as previously thought, but integrate a single reality called spacetime. According to Einstein's Theory of General Relativity, spacetime has the property to grip mass, telling it how to move, while at the same time mass grips spacetime, telling it how to curve. This helps us today to understand the problem of the night sky.

By joining together theoretical solutions derived from General Relativity, with practical compelling evidence obtained from our best observational instruments, most cosmologists agree that our universe (that is, all the space, matter, time, and energy) was "created" in a singular episode called the Big Bang, some 13.7 billion years ago, and it has been expanding ever since.

Basing ourselves on this widely accepted model, Olbers' paradox has now become resolved. However, the long and winding road actually travelled towards its definite solution is still worthily to be known, not only for being very instructive by itself, but at least as a deserved tribute to all other unreferenced road-makers.

SCIENTIFIC APPROACH

Since first serious attempts to explain the cause of the night darkness, elaborated more than 400 years ago, many alternative solutions have been proposed to justify why the sky is not seen as fully covered by stars. Most of them have proved to be wrong, as they were based on incorrect models about the universe's structure and/or its evolution.

As it may be imagined, just a few proposed solutions to Olbers' paradox are compatible with our current cosmological model derived from General Relativity' solutions and its description of the evolution of the universe from its main flagship: the Big Bang.

"Cosmic age too short": Originally proposed by American poet Edgar Allan Poe in 1848, and by German astronomer Johann Mädler in 1861. The basic idea was simply that light from distant stars still hasn't reached us, since light has a finite speed, and the universe a finite age. In 1901, the Scottish mathematician and physicist Lord Kelvin analysed quantitatively the connection between the sky-cover fraction by stars and its relative brightness, concluding that in order to obtain a sky continuously bright as the Sun's surface, it would be necessary to include all starlight up to a distance of 3,000 trillion light years. As we can not receive any light that has travelled from longer than 13.7 billion years (the present *cosmic particle horizon*), this proposed solution is really on the right track.

"Too little energy": Originally proposed by American cosmologist Edward Harrison in 1964. It was derived after computing the amount of energy required to create a bright sky, and finding out that it implies an overwhelming large number: the observable universe would need 10 trillion times more energy than it currently shows. This means that even if all matter in the universe were transformed into energy according to Einstein's famous formula, the night sky would be barely brighter than it really is. This argument is truly one of the few heavy weight solutions to the riddle.

This definite beginning imposes a finite age for the universe. If it is 13.7 billion years old, then light from stars further away than 13.7 billion light years just has not had enough time to get here. This is true even if the universe is infinite. And we did not even consider the fact that the luminous age of stars is certainly limited, which actually makes "things even worse".

The scarcity of the contained energy and matter in the whole universe also becomes an independent valid reason to justify its darkness. As the contained amount of energy and matter are intimately related to the way that the universe has actually evolved according to General Relativity (Freedman & Turner 2003), it is the particular developed evolution of the universe which synthesizes at last the final explanation for the Olbers' paradox.

The darkness effect attributed to the cosmological redshift has been quantitative compared to the darkness effect just originated by the finiteness of the age of the universe in the aforementioned cosmological context (Wesson 1989), resulting that the latter argument is far more important. However, not all scientists agree with that model, and the redshift solution is still the accepted one for those defenders of the "expanding steady- state" theory (Vicino 2003).

Thus we can safely affirm that subject of the night darkness is essentially a cosmological question, as it is intimately related to the actual architecture of the universe. In fact, the "easy" model of an endless spatial and perpetual universe immediately becomes controversial with our real night.

Many solutions have been proposed to solve the so called Olbers's paradox, almost each one based on a different explanation for the whole universe. The majority of those models have been proved to be wrong, as they collide to our current cosmological believes.

Nowadays we confidently can assure that there are just two principal factors that separately concur to produce a dark night sky: the universe is too young, and it also contains far less energy than it would be required to.

1. 2 THE MYTHS OF YESTERDAY

THE EMERGENCE OF MYTHS

As already indicated we humans have a cosmic tradition going back to about 13.7 billion years, when the Big Bang gave rise to the known universe of today! About 4.5 billion years ago the solar system was formed. Further, 4.5 million years ago humans (*Homo sapiens*) evolved. About 20,000 years ago Neanderthals would sit around the fire at night watching starry sky and listening to the sounds from far. They were trying to understand the world around them. They were trying to make sense of life, but more importantly, of death. How did dead people show up in their sleep, in their dreams? What could be made of their own impending deaths? In order to honor the dead person, Neanderthals buried their dead with flowers and beads. They also took care of the sick and elderly. In trying to understand death through ritual and ceremony, Neanderthals gave us their greatest gift: mythology. This endures till today though in different forms!

At first primitive humans thought very little about anything but immediate things. They were preoccupied thinking such things as: "Here is a bear; what shall I do?" Or "There is a squirrel; how can I get it?" Until language had developed to some extent there could have been little thinking beyond the range of actual experience, for language is the instrument of thought as bookkeeping is the instrument of business. It records and fixes and enables thought to get on to more and more complex ideas. Primordial man, before he could talk, probably saw very vividly, mimicked very cleverly, gestured, laughed, danced, and lived, without much speculation about whence he came or why he lived. He feared the dark, no doubt, and thunderstorms and big animals and queer things and whatever he dreamt about, and no doubt he did things to propitiate what he feared or to change his luck and please the imaginary powers in rock and beast and river. He made no clear distinction between animate and inanimate things; if a stick hurt him, he kicked it; if the river foamed and flooded, he thought it was hostile. His thought was probably very much at the level of a bright little contemporary boy of four or five. But since he had little or no speech he would do little to pass on the fancies fantasies that came to him, and develop any tradition or concerted acts about them.

In these questions of primitive thought, we must remember that the so called "lowly and savage" people of today probably throw very little light on the mental state of men before the days of fully developed language. Primordial man could have had little or no tradition before the development of speech. All primitive people of today, on the contrary, are soaked in tradition - the tradition of thousands of generations. They may have weapons like their remote ancestors and methods like them, but what were slight and shallow impressions on the minds of their predecessors are now deep and intricate grooves worn throughout the intervening centuries generation by generation. Thus the language enabled them to create myths and thus perceive meaning in their own lives.

The word "mythos" is related to the Greek meaning "to be spoken with the mouth". All myths are fundamentally, if not historically, true and lead to the highest of truths. The myths and their many facets have given birth to religion, mysticism, spirituality, philosophy or in short, to the different articulations of human quest for meaning. Myth is humankind's basic method of communicating our meaning of the cosmos and answering the why and how regarding birth, life, death of humans and the rhythms of nature.

Mythology lives and breathes in us. In other words, we live and breathe our myths. Myth constitutes our very existence. We have been imprinted with certain fears and faiths that have dwelt in our collective unconscious for thousands of years. Mythology is the language of the universe of rituals, ceremonies and symbols. They are the enactments of our desire to have mystical experience, communion with reality. With and through myths we bathe ourselves in the Mystery.

THE MYTH: A SPIRITUAL METAPHOR

The crucial fact about mythology is that it is a spiritual metaphor. Myth is a guidepost to a higher truth or understanding, which if taken literally destroys its original function and meaning. For example, the myth of Adam and Eve, is a myth describing how humans became conscious and further, conscious of evil. The story is that Eve convinced Adam to eat the apple and we were thrown out of paradise. A literal interpretation of this myth has led generations of people to believe women to be the cause for evil in humanity and think of their suffering in childbirth as a just punishment. By analyzing this myth exegetically and interpreting it, we learn that the serpent in the story in all cultures, with the exception of the Old Testament, represents wisdom, the feminine goddess, power and rebirth because it sheds its skin. The tree is the Tree of Life and the World Tree found in almost every culture and is understood as the link between the conscious and unconscious, the under-world and upper-world. By eating the apple, Eve made the humans almost godlike. This myth might imply that the Divine is within us. This understanding of myth as elaborated by Carl Jung , Joseph Campbell or Paul Ricoeur, goes against the anti-historical or rational interpretations of myths, that was fashionable few decades ago. As opposed to this view we know today that we make myths and myths make us.

Campbell and Jung suggest that we create new myths because the creative act allows us to delve into and become aware of the unconscious which initially created symbols that have lasted a millennium and have bound us physically and psychically. As Campbell holds the mythical image "lies at the depth of the unconscious where man is no longer a distinct individual, but his mind widens out and merges into the mind of mankind, not the conscious mind, but the unconscious mind of mankind, where we are all the same."

The Purpose: Meaning-Making

Emile Durkheim, noted sociologist and mythologist, explained that myth exists as a social institution that orders rituals, economy, history and meaning structures of the society. He described it as the unconscious of the society. In other words, myth is a global way of thinking through which all social agendas emerge. Joseph Campbell said that we are all living (or enacting) a myth and that we must figure out what our myth is, so that we are not forced to live it against our will. He also warns that a society that takes its myth literally is suffocating itself. Studying mythical symbols is one form of bringing back the wonderfully divine, if not mystical, experience of realizing that all life is connected, at the very least, on an unconscious level.

Joseph Campbell gives four purposes to myth: 1.To awaken wonder by putting us back in touch with the child within. 2.To fill all corners or niches of an image with the Mystery. 3.To validate social order. 4.To teach us how to conduct ourselves during the stages of our lives. We can further add: 5. Myths enable us to live the reality of contradictions meaningfully by giving us ideals to live by!

In short, through myths we make sense of our reality. It provides us with meanings, enables us to organize even the contradictory experiences of our lives. It makes our lives bearable. It explains to ourselves our own experiences. It justifies our actions to ourselves and explains our failures and tragedies. Thus it has basically mediating and a motivating functions. Myths also mediate the infinite through the finite. It situates us in the vast cosmic and divine background, wherein we can find the significance of our own selves. The puny, little human actions are magnified and enriched because of the cosmic and divine significance attached to it. They also motivate our actions. They enable us to live a meaningful life within a wider horizon of significance. It is in such a horizon that we are encouraged to act. Every action, originating from a mythical experience, becomes unique and infinitely more meaningful at least for the actor of the myth.

Some of the various definitions of myths are: "Myths are facts of the mind made manifest in a fiction of matter." (Maya Deren) "All variations of a myth are equally true." (Claude Levi Strauss). "Myth is sacred history." (Mircea Eliade). "Myths guide, direct and lead others to the vast, often indecipherable language of the soul." (Dr. Jeffrey Collins). "Mythology is a spiritual hologram. No matter what way a hologram is cut up or in how many pieces, each piece still has the full image. Each myth no matter how small contains the whole." (Dr. Jeffrey Collins). "Myth is a metaphor that is transparent to transcendence." (Emile Durkheim). "Myth is obsessive repetition of a few unconscious representations centred on sexuality." (Dr. Sigmund Freud). "Myth is a symbolic story." (Paul Ricoeur). "Myth is the song of the imagination, infinite and endless." (Joseph Campbell).

1. 3 MYTH, PHILOSOPHY AND SCIENCE

The two narrations above are meant to show the similarity and difference between science and myth. True, for the contemporary persons, science provides us with the best knowledge possible. The primitive people used the best resources they had and came up with answers which did not quiet satisfy them, but still provided them with meaning in life and made them search further. In this process the primitive people gave us the myths, which are truly powerful in shaping our visions. None of us live according to the myths of these people. But we have our own myths: answers we give ourselves collectively and subconsciously when confronted with deep unresolved questions of life, death, reality and destiny.

As such modern humans do have our own shared myths, which most of the time we are not aware of. Only generations later, they will be able to look at us and point out the myths in our collective understanding. We do have our science, which explains to us many of the mysteries of old. Science provides us with the best explanation. But let us not forget that science of today may become the myth of yesterday.

As such myth and science serve the same purpose of explaining the universe to ourselves, but at different levels. The methods they employ are different. The answers they come up with are also diverse. That is because they serve different domains of our enquiry. Science is primarily empirical and provides us with facts, while myths are based on the known facts and provide us with meaning. Such myths, when elaborated and rationalized become philosophy.

Thus there is a movement from myth to philosophy and to science. Myths are mostly factually not true but existentially meaningful. Philosophy tries to be factually true and existentially meaningful. Science attempts to be factually true and does not direct address the existential meaning. Myths provide us with intuitive and existential meaning. Philosophy gives us rational meaning. Science shows us empirical facts.

Check Your Progress 1

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What is a myth?

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2) How is science related to philosophy and myths?

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1. 4 INTRODUCING COSMOLOGY

SCIENTIFIC COSMOLOGY

When people hear the word Cosmology, they fear the worst: relativity, dark matter, galaxy clusters. While these topics are a part of the study of cosmology, they are not the mysterious subjects some make them out to be.

Albert Einstein in 1917 changed the way we look at our Universe. By realizing that time and space are one (space-time, the 4th dimension), we understand gravitational effects from objects like galaxies and dark matter that alter the paths of light. By determining these gravitational effects, we gain insight as to the mass distribution of our Universe and learn how it expands.

We will also take a look at the variety of galaxies in the Universe as well as their distribution in clusters. In addition, we will introduce dark matter - the unknown, highly massive material that is distributed through the halo of galaxies and galaxy clusters that is supposed to be almost 90% of all material in the Universe. We will also introduce the big bang and the Cosmic Background Radiation - the remnants of the big bang.

Most of what we know about cosmology is based on computer simulation and some observational data. What this means is that much of what we know is in flux - that is theoretical with only some observational evidence. However further observation, simulation, and theory refinement is helping to understand the nature of our Universe.

So what do we know so far about our Universe? This brief timeline is based from the big bang (T is time after the big bang) indicate some of the elementary information provided by scientific cosmology.

- 13.6 billion years ago T=0, the Universe began with the big bang
- T = 300,000 years after the big bang, protons and neutrons are formed
- T = 300,000 to 10,000,000 years - recombination, that is hydrogen atoms are formed giving rise to the Cosmic Background Radiation that we still perceive
- T = 10,000,000 to 1,000,000,000 years - clumps of matter combine to form proto-galaxies
- T = 1,000,000,000 to 3,000,000,000 years quasars form

- T = 3,000,000,000 to 8,000,000,000 years, galaxies form
- T = 8,000,000,000 to 12,000,000,000 years, our Solar System and planets
- The Universe is expanding, with the most distant galaxies (quasars) expanding faster than nearby galaxies

Such scientific and astronomical data give us the scientific cosmology. As the Indian cosmologist Jayant Narlikar observes, “In spite of many remarkable advances, cosmology is still very much an open subject.”

PHILOSOPHICAL COSMOLOGY

Confronted with the majesty and paradox of the universe, humans have a natural tendency to post questions: about themselves and the world around them. Every question implies partial knowledge and partial ignorance. Thus the search for deeper answers go on. The answers provided by scientific cosmology is further reflected on philosophically. Then we have the philosophical discipline of cosmology as such.
Etymologically “cosmos” means order and is against chaos. Cosmology therefore means methodological study of order (in the universe). However the most popular meaning of cosmos is the universe considered as an orderly system. So cosmology is a reflective study of the cosmos – from the electron to the galaxies.

So Foley defines cosmology as “the pursuit of the ultimate principles of the material universe .” The Free Dictionary understands cosmology as “The study of the physical universe considered as a totality of phenomena in time and space.” Renoirte understood it as “The study of the problem of the ultimate constitutive causes of the material world.” Further, K Dougherty “ a science which considers the first principles and causes of mobile beings in general.”

Van Fraassen, in his “The Scientific Image,” says that “Science aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true.”

From the above definitions it is clear that cosmology is the philosophical reflection on material reality. To be more precise, it is a reflection on the knowledge of the universe furnished by science. Since it is a reflection in search of the ultimate principles, it is philosophical. Since the data on which reflection is made are supplied by science, it is scientific.

Why cosmology

It may be argued that science, especially modern science, can meet the needs of modern men and women and so cosmology is a meaningless luxury. This argument, usually comes from a rather confused understanding of the role of science and philosophy. The role of science in the realm of knowledge can be reduced to three basic operations:

a. The search for numerical relations between measurements and properties.
b. The synthesis of these laws in theories from which they are deductible as logically implied consequences.
c. The expression of these relations under the form of general laws.

There is in the humans a deeper quest to go beyond these three operations and ask deeper questions. Delving deep into the ultimate reasons, they want to ask the questions: From where did the universe emerge? Where does it evolve? What is the ultimate nature of the universe? How come there is something rather than nothing? How do we explain the number of galaxies? They lead us to the philosophical issues arising from scientific cosmology.

Of course, modern science seems to do much more than these above operations. Here we should remember that in modern times, much more than in the ancient days, there is a remarkable interaction between science and philosophy and so often the one trespasses into the territory of the other. Albert Einstein and Stephen Hawkings are examples of great scientists who have attempted to cross the border between science and philosophy.

Human beings in their never ending search is not satisfied with the bare particulars and details of things, however systematic and accurate they may be. They want to know the implications or the presuppositions of the theories . They want to appreciate the experiences they have and from theoretical perspectives. The answers to these basic human questions can only be partially provided by science. It can furnish some data and provide some pointers. It is here that philosophy will have to come and carry on the search. Thus cosmology understood as a reflection on the data furnished by the science has a definite role in furthering human knowledge, which science alone cannot adequately perform.

Purpose of cosmology

- To acquaint the students with the developments in science and some of their important implications.
- To present a scientific view of the world and thereby instill into them a "scientific spirit" - a sense of objectivity, quest for search and attitude of open-mindedness.
- To instill in the students an awareness of the importance of science and scientific developments taking place around us and the tremendous challenges that humans face as a result of them.

Method employed for this purpose is based on science. We study the some of the important theories and data given by science. Thus we will try to highlight the most important theories of modern science, regarding the origin and destiny of the world. Then we reflect on them in order to find out their deeper philosophical implications.

Perhaps in no other place does human identity as a seeker become more manifest and the complementary nature of science and philosophy becomes more striking than in cosmology. Both its nature and methodology bring out this fact.

Check Your Progress 2

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What philosophical cosmology?

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2) What are some of the basic questions in cosmology?

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1. 5 INTRODUCING PHILOSOPHY OF SCIENCE

Humans have a natural tendency to post questions: about themselves and the world around them. Every question implies partial knowledge and partial ignorance.

Aristotle in his "Metaphysics" says that "all men by nature desire to know." Humans search for knowledge at all levels of his existence. At the basic level we search for food, clothing and shelter and for the knowledge that enhances the search. At the aesthetic level, we search for beauty at various levels – paintings, landscape, architecture etc. At the moral level, we search after truths regarding the proper way of conduct. At a still different level, we search after the mysterious of the universe, the ultimate meaning of the universe and of their own meaning. It is at this last level that science and philosophy appears. Basically science and philosophy are rational and systematic search for the unknown mysteries that envelope humans and their surroundings.

The history of human thought reveals that in the beginning science and philosophy moved hand in hand. The great Aristotle and the numerous Greek thinkers were both philosophers and scientists. But with the Copernican Revolution and the Galilean controversy, the two began to branch off in different directions. At times it looked as though they had no relation whatsoever. Thus came the opposing camps of empiricists (or positivists) who exalted science to the heaves on the one hand, and the idealist (or rationalists) with their glorification of speculation and abstraction, on the other hand. However in modern times, the scene has changed. The streams which broke into two and began flowing independently have started merging once again leaving behind the island of tension and meaningless competitions.

The advent of the theory of relativity, quantum mechanics and human genome project have forced us to transcend the world of sense observables to that of the unobservables. The large number of books written in the last century on the philosophical implications of these theories indicates this fact. Thus contemporary human beings look at philosophy and science as complementary to each other. They can enrich each other and in the process make human lives better and healthier.

What is science?

Etymologically science means knowledge (scire = to know). Usually science stands for natural science and can be defined as "ordered knowledge of natural phenomena and of the relations between them." It is discovering the patterns of behavior or laws of life. It is a search for causal interdependence of phenomena (or cause and effects). The aim of science is to discover and interpret certain immutable laws governing nature. From a traditional scholastic view, science is "knowledge through causes and scientific study is an endeavour to discover the hidden causes of phenomena."

Science is not merely a collection of laws and principles or a catalogue of unrelated facts. It is an ordered creation of laws and theories by human mind. It is a blend of reason and experiences. Physical theories try to form a picture of reality and to establish its connection with the wide world of sense impressions.

Experiments and observations play a crucial role in scientific study. According to some scientists the true object of scientific studies can never be the realities of nature, but only our observation on nature. This extreme emphasis on sense observation and experimental verification places science above all other disciplines, in credibility and accuracy.

Some people define science as "organized common sense." In fact it is often said that today common sense is built on yesterday's science. Although common sense does play an important role in science, it should be noted that the great pillars of modern science, like Quantum Physics and Theory of Relativity, arose only when scientists dared to counter the common sense explanation of reality. Common sense usually concentrates on what happens, while science looks for how it happens.

Van Fraassen, The Scientific Image, "Science aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true."

PHILOSOPHY AND SCIENCE

Philosophy is generally regarded as a search for knowledge through the ultimate causes. A philosopher does not seek for mere explanations of things, but seeks thing which explain themselves. In this sense, some even call philosophy as the "science of sciences."

As indicated already, science and philosophy are two distinct and related branches of the same stem of human knowledge. It has been said that "the metaphysics [philosophy] of any period is the offspring of the physics of the preceding period." History of both philosophy and science bears this fact out. Aristotle first wrote book on Physics and then on Metaphysics. The same tradition has been kept up to this day. It has been said that Science tries to explain the 'how' of things, while philosophy tries to explain the "why" of things. Science is more concerned with what happens (and how it happen s) and philosophy with what is (and why it is so?)

Science is more objective while philosophy is more subjective. By objective we mean that the results obtained are independent of the observer. Science is more quantitative in its treatment while philosophy is more qualitative. Sciences is on the look out to discover more and more new facts while philosophy usually tries to delve deeper into what has been discovered. Science is satisfied with an explanation of events in terms of secondary causes, but philosophy looks for justification in terms of ultimate causes. They both deal with the same problem, but from different angles. In other words, the formal objects of both are different while the material object are the same.

In modern times, science is highly esteemed. Apparently it is a widely held belief that there is something special about science and its methods. The naming of some claim or line of reasoning as scientific is done in a way that is intended to imply some kind of merit or special kind of reliability. What is really the special things about science? What is the "scientific method" that allegedly leads to especially meritorious or reliable results? Can it be applied to other fields of enquiry?

Coming to scientific methodology, we see that scientific theories often start with a good guess (hypothesis) based on certain insights of the scientists. Philosophy usually starts with what is given to be certain and definite.

Thus in the Aristotelain-Thomistic system, the starting point of science of sensitio-rational experience, which is an undeniable fact of human experiences. Hence the hypothesis or the starting point of a scientific study may undergo change in the course of the investigation, but the starting point of philosophy remains intact. Again the ultimate test of a scientific theory is workability or experimental verifiability. If it works, the theory is accepted. But a philosophical theory is accepted only when it has obtained justification in terms of accepted first principles.

The above reflections bring out both similarities and dissimilarities between the disciplines of philosophy and sciences. Perhaps at first glance it looks as though both oppose each together. But a deeper reflection on the pointes mentioned above will convince us that philosophy and science do not oppose each other, rather they complement one another. They deal with the same problems from different perspectives.

PHILOSOPHY OF SCIENCE

Just like philosophical cosmology is an organized and systematic reflection on the data provided by scientific cosmology, philosophy is an organized and systematic reflection on science. In other words, we can hold that the philosophy of science is a part of philosophy, which attempts to do for science, what philosophy in general does for the whole of human experience. Or in other words, philosophy of science is the application of philosophical methods to science itself and to philosophical problems as they arise in the context of the sciences. Philosophy of science deal with the method of science and some of its important discoveries and reflect their relationship to the life in general.

As Gary Gutting reminds us the subdiscipline "philosophy of science" originated in the nineteenth century in the wake of Kant's critical philosophy. It derives from the challenge posed by modern science to the very idea of a distinctly philosophical enterprise. The "scientific" achievements of Galileo, Descartes and Newton, it was thought, realized long-sought philosophical goal of answering fundamental questions about the nature of planetary and terrestrial motions. So the question gradually arose of what, if anything, there remained for philosophy to do. This question became entirely explicit with Kant and has continued to be at the centre of the philosophical enterprise ever since.

Further, as Baruch Brody tells us, philosophers of science are primarily concerned with three kinds of questions. One kind deals with the implications of new scientific findings for traditional philosophical issues; thus, for example, philosophers of science question whether the principle of indeterminacy in quantum mechanics show that human actions are not entirely determined or whether recent research on computers and artificial intelligence supports the thesis that human beings are merely very complex machine. A second kind of question deal with the analysis of the fundamental concepts of the diverse scientific disciplines; thus, for instance, philosophers of science analyse such concepts as numbers, space, force, goal and living organism. Finally, a third kind of questions deals with the nature and the goals of the science enterprise and the methods the scientist employs to attain these goals. For example they discuss on the meaning of discovery, hypothesis, explanation, theory, etc.

Further, important ethical, epistemological and metaphysical issues that emerges from scientific discoveries and that is the proper subject of philosophy of science. Again specific problems arising within the context of specific scientific disciplines, like mathematics (what is number?), biology (what is life?), social science (what is the role of culture in human life?), etc., form the topic of philosophy of science.

As such, contemporary philosophy of science has moved beyond a positivist standpoint which reduced reality merely to the observables. Today philosophy of science can comfortably ask questions that take us to meta-scientific or metaphysical realms. So today some of the legitimate questions are: Is there purpose in the universe? What is the guiding principle, if any, of evolution?

Since science has progressed tremendously in the last two centuries, It is to be expected that philosophy should take as paradigmatic for various questions of epistemology and ontology, the most extensive and coherent body of knowledge provided to it by science.

Check Your Progress 3

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) How is philosophy different from and related to science?

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2) What is philosophy of science?

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1. 6 LET US SUM UP

In this unit we have tried to give rough idea on myth, philosophy, science, cosmology and philosophy of science. In keeping with the thinking of today we have shown that myth give meaning to our lives unconsciously and instinctively, while philosophy gives it consciously and rationally. Science, a related subject is primarily concerned not with meaning, but with the external world, its laws and structures. So philosophical cosmology and philosophy of science attempt to arrive at a systematic and critical reflection on the data that science provides and on science itself. At time when science is highly praised, we need to be critically appreciative of its inventions and progress. So a course on philosophy of science and cosmology will help us to appreciate some of the underlying principles behind science and some of the discoveries made by science.

1.7 KEY WORDS

Olber's Paradox: If the Universe filled with infinitely many stars for an also infinite time, it sounded reasonable that no night could exist, as heavens would be bright by other stars even when our Sun disappeared into horizon. So Olber's paradox is the paradox between this theory of an infinite old universe with stars scattered more or less randomly throughout infinite space and the practice of dark night.

Myth: Myth is humankind's unconscious and collective method of communicating our meaning of the cosmos and answering the why and how regarding birth, life, death of humans and the rhythms of nature.

Cosmology: It is "the pursuit of the ultimate principles of the material universe ."

Philosophy of science: It is the application of philosophical methods to science itself and to philosophical problems as they arise in the context of the sciences.

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1.9 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check your progress 1

1) A myth is a symbolic story. Some of its functions are: 1.To awaken wonder by putting us back in touch with the child within. 2.To fill all corners or niches of an image with the Mystery. 3.To validate social order. 4.To teach us how to conduct ourselves during the stages of our lives. We can further add: 5. Myths enable us to live the reality of contradictions meaningfully by giving us ideals to live by!

2) Myth and science serve the same purpose of explaining the universe to ourselves at different levels. there is a movement from myth to philosophy and to science. Myths are mostly factually not true but existentially meaningful. Philosophy tries to be factually true and existentially meaningful. Science attempts to be factually true and does not direct address the existential meaning. Myths provide us with intuitive and existential meaning. Philosophy gives us rational meaning. Science shows us empirical facts

Answers to Check your progress 2

1) Philosophical cosmology may be defined as "the pursuit of the ultimate principles of the material universe." Others define it as "The study of the problem of the ultimate constitutive causes of the material world" or " a science which considers the first principles and causes of mobile beings in general."

2) From where did the universe emerge? Where does it evolve? What is the ultimate nature of the universe? How come there is something rather than nothing? How do we explain the number of galaxies? They lead us to the philosophical issues arising from scientific cosmology.

Answers to Check Your Progress 3

1) Science and philosophy are two distinct and related branches of the same stem of human knowledge. It has been said that "the metaphysics [philosophy] of any period is the offspring of the physics of the preceding period." History of both philosophy and science bears this fact out. Aristotle first wrote book on Physics and then on Metaphysics. The same tradition has been kept up to this day. It has been said that Science tries to explain the 'how' of things, while philosophy tries to explain the "why" of things. Science is more concerned with what happens (and how it happens) and philosophy with what is (and why it is so?)

2) Philosophy of science is the application of philosophical methods to science itself and to philosophical problems as they arise in the context of the sciences. Philosophy of science deal

with the method of science and some of its important discoveries and reflect their relationship to the life in general.

UNIT 2 PRE-SOCRATIC THINKERS AND THEIR CONTRIBUTION

Contents

2.0 OBJECTIVES

This unit will help us to understand the following:

- Who are the Pre-Socratics
- Schools of the Pre-Socratics era
- Pre-Socratics as Proto-Scientists or First Scientists
- Pre-Socratics and modern Science.

2.1 INTRODUCTION

It has become an academic sutra to say that the entire academic edifice of the western world is founded on firm foundation laid down by the Greeks. This revolution is said to have taken place in the sixth century BCE. But we know that science began even before the Greek period. Civilizations that developed around the basins of great rivers –the Nile, the Euphrates with the Tigris and the Indus manifest a lot of scientific know-how. These people developed science to meet their existential needs. But it was Greeks who discovered the philosophical explanation that led to the birth of theoretical science. This is accepted as their singular contribution as their contribution led to what we might call the scientific approach to the study of nature. In this unit we will study the pioneering stalwarts of the Greek tradition and understand their contribution to the rise of modern Science.

2.2 PRE-SOCRATIC THINKERS

The thinkers associated with sixth century revolution are known collectively as the Pre-Socratics Philosophers. They were called Pre-Socratics because they preceded Socratics, the great thinker of the golden era of the Greek period in thought, even as the last among them are his contemporaries. The term Pre-Socratics is not well received by some scholars as it seems to derive the identity of those thinkers from Socrates and the Socratic thinkers (Socrates, Plato and Aristotle). Moreover, it is a rough approximation that these thinkers form a unitary group. But the fact that they differ in fundamental ways from their predecessors and their great successors does justify their collective treatment in academics. Within the era of their activity, we can distinguish three main periods. The first is said to be the century of bold innovative thought, next was the period of stringent scrutiny of their early adventures and finally the period of consolidation, in which thinkers of different persuasions attempted each in his own way to reconcile the aspirations of the first thinkers. Hence, the role and importance of these Pre-Socratics cannot be brushed aside, as they have invented Philosophy and Science in the western world.

2.3 THE SCHOOLS OF THE PRE-SOCRATICS

The Greeks themselves liked to talk about the schools of philosophy when they came to write history of their own thought. They classified their philosophy in accordance to the 'schools' and were interested in the narration of 'succession' that presented the story of the master and the pupil and the place where that thought developed. This provided the framework within which the history of their thought can be expounded and understood. We can trace the Ionian school, the Pythagorean brotherhood, the Eleatic, the Atomists schools during the Pre-Socratic period.

Scholars have pointed that two basic questions formed the common denominator of their intellectual activity: (1) What is the basic stuff of everything? (2) How can we explain the process of change ? In doing so they hit upon that special way of looking at the world which is thought to be scientific and rational. They saw the world as something ordered (cosmos) and intelligible. This means the world was not a random collection of bits and its history was not an arbitrary jumble of events. Nor was it controlled by the will of some capricious Gods. This means the world could be orderly without being divinely run. Its order was thought to be intrinsic and internal principles of nature were thought to be sufficient to explain its nature and its structure.

2.4 THE IONIAN SCHOOL OR THE MILESIAN SCHOOL

It makes sense to group together, Thales (624-548) Anaximander (614-540 BCE), Anaximenes (6^{th} Century B.C), together , though the idea that they were a 'school' and master pupil relation is merely a distortion motivated by the desire to impose a systematic framework on the work of the Pre-socratics. However, Miletus being an upcoming city-state territorially small enough to allow to know each other and be acquainted with their respective work it is thought that they knew each other and were familiar with their respective work and ideas.

Thales is said to be the founder of the Ionian school or the Milesian school. He may have been responsible for the creation of the culture of 'know thyself' which was so successfully adopted by the Socratic tradition. He is credited with the introduction of public debate on the explanatory vision of the world (the universe is orderly and can be explained rationally). Launching of such an important debate at the end of the 6^{th} century BCE, a time when communication by sea was particularly frequent meant that the knowledge produced got spread more or less by itself throughout the Greek trading empire stimulating further reflection and enrichment of the same. But very little is known about this great thinker. It is certain that he attempted to raise the question of the basic stuff of everything in the universe and taught that it was water.

Heraclites (536-470), Xenophanes and Empedocles (490-360 BCE) form the later Ionian Philosophers of the Ionian school. They were separated from the earlier thinkers of the same school not merely in point of time but in respect to doctrine. They depart for the monistic dynamism of the early thinkers and adopt a mechanical dualistic concept of the universe. Heraclites is thought to be a link between the earlier thinkers with the later thinkers.

2.5 THE PYTHAGOREAN BROTHERHOOD

In the 6th century BCE, Greater Greece stretched west all the way to Sicily and Southern Italy. Pythagoras (580-497 BCE), who was born on the island of Samos at a time when the whole of Eastern Greece was becoming unsafe, settled at Croton established a philosophico-religious society. There is a huge mystery surrounding the teachings of Pythagoras. This laid in the very doctrine and teaching methods of his congregation that believed that nothing that the master taught was to be written down or divulged to the uninitiated. Even the disciples were divided into two classes the *mathematikoi,* who were the students privileged to know the thoughts of the Master and the *akousmatikoi* the mere listeners, allowed to know little of his teachings but unworthy of the name Pythagorean. The secrecy appears to be carefully guarded as we can trace relatively few of Pythagorean records. Pythagorean tradition proposed that numbers form the ultimate building blocks of the universe. Thus, we can see how numbers and their relationships have become the chief contribution of the Pythagorean tradition to the world of science. One of the important things that we have kept in mind is that Ionian school passed on the knowledge in everyday language so that it is accessible to everyone. While the Pythagoras school developed knowledge into a tradition of esoteric oral transmission, which in principle was not to be communicated to outsiders of their fold.

2.6 THE ELEATIC SCHOOL

The chief representative of this school was Parmenides (540-480) who was born in the town of Elea. He is the first thinker of whose work we have substantial fragment. This gives us access not only to his conclusion but allows us to think how he argued for his conclusions. He taught that there were two paths, the way of truth and the way of opinion, also known as the way of belief. Truth represented the intrinsic state of nature, an objective state, completely independent of the observers. He believed that our senses are misleading us. He posited an immutable being. Only being was whole continuous and permanent i.e. being was thought to be single, homogeneous, timeless, changeless and motionless. Zeno of Elea (490-430) was another zealous member of this school.

2.7 THE ATOMIST SCHOOL

The Atomist are said to be have their origin in the teachings of Leucippus at Abdera. Very little is known of this Philosopher. But he is said to have first thought that the universe was made of a void and of indivisible, unchangeable microscopic atoms. The Greek atomists are heirs of the above thinker. Democritus (460-360) was probably the student of Leucippus. He saw that there was a conflict of Permanence and change and between the continuous and the discontinuous among the Eleatics and the Ionians. Attempting to resolve these apparent contradictions, he presented the doctrine of atoms which form the ultimate building blocks of the universe and as such they were immutable and homogenous in nature and were in random motion and were governed by some kind of attraction and repulsion. The law of attraction is the principle of natural affinity where by likes attacks the likes.

2.8 CHALLENGES TO THE STUDY OF PRE-SOCRATICS

The study of Pre-Socratics has become difficult as their original works no longer exist and we have to rely on the fragments preserved by the later writers. Some of these reports are coloured by the concerns, agendas and the interests of their authors who were sometimes implicitly or explicitly unsympathetic or even hostile to the Pre-Socratics. Hence, there are fears of some degree of distortion of their views. We are indebted to the great Aristotle and his pupil Theophrastus and their successors for handing over discussions of the Pre-Socratics to us. It has been established beyond reasonable doubt that they viewed their predecessors almost entirely through the lens of their own Philosophies. For instance, it is said that Aristotle understands Thales as a proponent of materialism because he is said to have taught that everything is made of water. Aristotle construes the materialism of Thales by absorbing his teachings through the lens of this four cause theory. But this perhaps is not the case. It is more likely that Thales taught that everything started in water or rests on water. One can find precedents of such an idea in Egyptian or near Eastern mythology.

Sometimes the secondary sources preserved by the later writers are tainted with their bias. Again we can notice how Aristotle has singled out Anaxagoras and bestowed high praise on him, describing him at one point as a sober man compared to his babbling predecessors and another point as 'quite up to date in his thinking' because he taught that Anaxagoras had intuited certain element of his own thinking. The later writers on the Pre-Socratics largely depended on the lost book of Aristotle's pupil Theophrastus, called *the Opinions of the Natural Scientists*, and hence, scholars cannot assert with confidence that all the secondary sources have placed the ideas of their Pre-Socratics predecessors within the right context since almost all of them lived several centuries after them. Hence, the recovery of thought of the Pre-Socratics is indeed full of hurdles. The situation becomes even difficult when we have to churn out the scientific views of the Pre-socratics as we can never be free from retrospective imposition of our notion of science on their work.

Check Your Progress 1

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Who are the Pre-Socratics?

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2) What is the specific contribution of the Pre-Socratic schools?

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2.9 THE PRE-SOCRATICS AS SCIENTISTS

The idea that these thinkers collectively brought something into the world, that is called as a scientific or proto-scientific attitude is gaining academic currency. Some scholars call these thinkers as the Big Bang of science. But it is naïve to lump all the Pre-Socratics together as if they were somehow identical. There is considerable diversity among them. We have seen that they range from shamans like Empedocles, mystics like Pythagoras, prophets like Heraclites to metaphysicians like Parmenides, philosophers like Anagoras and proto-Scientists like the Milesians (Ionians). Although, we might trace a strong variety of views and perspective among them, we can still find something common in them all. Indeed, we can say that they collectively invented Philosophy and Science. What do we mean when we say that they invented Science or Philosophy? Indeed, the Milesians brought something scientific in the world and those like Parmenides and Heraclites reflected upon their predecessors work and were therefore engaging in philosophizing.

Let us understand the above with the help of an example. Anaximanes is a prototype of the earlier Melesian proto-scientific stage. He taught that the prime matter of the universe was air. He believed that original stuff of the entire universe is air. Air and water are closely related. Air when cooled down becomes water. Water transforms itself into various components of the universe. When heated it becomes hot and fiery and forms not just fire itself but fiery heavenly bodies. When condensed it becomes water and ultimately earth. It is interesting to note that Anaximanes chose air and not water as the chief constituent of everything. It is said that he might have been led to this position because of all pervading and dynamic nature of air and because we breathe it and it causes life in us.

2.10 SO CAN WE CALL ANAXIMANES A SCIENTIST?

A question of this kind brings us to the same issue of perceiving the work of Anaximanes and his peers through our own lenses. One thing is certain, Anaximanes himself never understood himself as a scientists in a way we understand by the term today. But he and his peers sowed the first seeds of science. Hence, many scholars teach that they were proto-scientists and as such exhibit what we may call a scientific attitude.

Scholars present the following features as markers of scientific attitude:

1. Optimistic assumption that the universe is comprehensible. "The mystery of the world is that it is comprehensible" Albert Einstein.
2. The assumption that human mind is capable of understanding the world.
3. Adherence to particular set of approaches to problem-solving and starting with simple problems before tackling more complex ones.
4. Tempered Curiosity: curiosity needs to be nurtured so that the scientists do not jump to hasty hypothesis or extravagant leaps of the imagination, nor be governed by prejudice of any form.
5. A love of and facility with abstract concepts.

The pre-Socratics somehow displayed some of theses attitudes and that is why it is reasonable to call them proto-scientists. It would be unreasonable to expect them full fledges scientists in the sense of word in our times. But we have enough reason to at least call them proto-scientists. Only condition that disqualifies them from being considered proto-scientists is the hurdle of tempered curiosity. They could be accused of what we might call a rush into wild speculation but they were first to realize that human rational mind is the right tool to understand the world. They were reductionist-that they relied on general hypothesis to explain as many things as possible but they depended on natural phenomena like air. That is why, they were instrumental in giving us the natural explanation of the phenomena rather than a theological explanations that were evoking ancient Greek Gods and Goddesses. To understand this we have to study the predecessors of the Pre-Socratics.

2.11 THE PRE-SOCRATICS AND THEIR PREDECESSORS

Can it be said with great certainty that Pre-Socratics were the first to assume that the rational mind can know the world? Did people before the Pre-Socratics not think or use their brain? In what sense then the pre-Socratics brought something new? Scholars agree that they brought the 'logos' in our understanding of the world. They saw the world around them and asked questions about it. Instead of attributing its creation to anthropomorphic Gods, They sought material and rational explanation.

The predecessors of the Pre-Socratics thought that the divine governed the whole universe. Belief in many Gods was highly systematized and the Greeks organized and regulated their life and activities around these belief. There was a highly developed hierarchy of Gods, where some of the Gods were considered more important than others. The rise and fall of Gods was indeed dynamic and dramatic as some Gods rose in importance above others, and the lesser Gods become demoted as local Gods, demigods, nymphs and so on. The rise of Gods was also connected with the politics of the day. As one settlement gained political prominence over its other neighbors, its deity or deities also gained prominence. This is how the so called major Gods (Zeus) and their extended families emerged as the chief characters of the Greek pantheon. The crystallization of the Gods and the deities into a well organized pantheon was a result of anthropomorphization. This means Gods were created in the image and likeness of humans. Not only did these Gods have family trees, they also had family squabbles. They were merely super-human beings and as such were jealous, angry and selfish like ordinary human beings. It is noted that anthropomorphism is an outstanding character of Homeric religion and hence, Greek religion as a whole.

Thus, the Gods of Greek religion did not have laws but only preferences. Such a world-view is often christened as a mythical worldview and is totally different from the 'logos' centered worldview inaugurated by the Pre-Socratics. Hence, scholars credit the Pre-Socratics for taking the seminal steps to make a leap from the mythos to the logos. Let us understand this with an example, a short glance at the work of epic poet Hesoid (around 700 BCE) can illustrate the worldview of the predecessors of the pre-Socratics. His poem theogany exemplifies some degree of rationalization. He attempts to use the family tree to order the unstructured world of Gods. A typical branch of the genealogy is that night gives birth to death and sleep and dreams. Thus, Hesoid uses genealogical model to group deities and concepts into intelligible systems. The fact that Hesoid uses the genealogical tool to organize and make sense of the plurality of deities, he still remains fully within mythic framework of his days. This does not mean that before the Pre-Socratics the Greece was inhabited by 'non-thinking' savages leading their life in accordance with random impulses and mystical associations. Indeed, their poetic mythological tradition embeds its own rationality. Anthropologists have demonstrated beyond doubt that so-called primitive people are people more governed by mythos rather than logos. They do think systematically. It is just that they use a different idiom than the one familiar to us. They have different notion of what constitutes cause and effect. They think metaphysically and analogically and more imaginatively. This means the mythical thinking is a pre-philosophical mirror of existential thinking. But our analysis of their thought is conditioned by the post-philosophical perspective.

It is precisely from this mode of thinking do the pre-Socratics distance themselves. They treated the mythical thinking as other, as childish as irrational. Earlier 'Gods are angry' would be a reason enough to satisfactorily explain a natural calamity, while the pre-Socratics inspired a belief in the order in the universe and it is precisely because of this order is intelligible, that human mind can understand it. Thus, we can notice that they truly usher in a paradigm shift in the mode of thinking in the life of humanity. The Pre-Socratics differed from their predecessors not so much in the kind of questions they asked but in the kind of answers they gave. By not adhering to the mythical frame work, they assigned functions of Gods to natural phenomena and relying on reason, they truly inaugurated a new era. Thus basing their conclusions on observation and rational argumentation, they sowed the seeds of science.

Besides their Greek predecessors, the contribution of the neighboring states of the Greece also have its role in the irruption of the scientific attitude among the Pre-socratics. Scholars both ancient and modern have assumed that there were connections between the earliest Greek thought and the intellectual concerns of the eastern empires. It is said that the advaced astronomy of the Babylonians but have surely become known on the shores of Asia Minor and have stimulated the Ionians to study astronomy for themselves. It is said that Thales Knowledge of the eclipse of the sun in 585 B C E might have been derived from Babylonian learning. The Greek scholars themselves admit that some of the ancient Greek wisdom derived its origin form Egypt as some areas of the Greek thought has some parallels in the land of Pharaohs.

2.12 PRE-SOCRATICS AND MODERN SCIENCE

We can notice a strong link between modern science and the Pre-Socratic thinkers. But they cannot be accepted as scientists as they lacked a rigor of the scientific method. Yet they did initiate an important chapter in the history of science.

Science has its own specialized technical conceptual jargon- mass, force, atoms, tissue, nerve, parallax, ecliptic and so on. This terminology and the conceptual equipment is not God given, it has been invented and pre-socratics are certainly among its first inventors. Their very attempt to develop a scientific explanation triggered the need of conceptual clarity as well as conceptual development. This process was not always self-conscious. Even today scientists are drawn by the impulse of scientific explanation to evolve and develop conceptual framework. Some of the concepts developed during the Pre-socratic era are still like *Kosmos* (cosmos), *phusis* (nature), *techne* (artifice) and are indeed part of modern science.

The pre-socratics certainly developed rational and material explanation of change in the world. this means they emphasized the empirical explanation and with the Pythagoreans emphasized the force of the mathematical explanation. Hence, they are said to be fore runners of experimental and mathematical explanation employed by modern science. It does not mean that all their empirical explanations can be accepted by modern science. Thus, for instance, the teaching of Thales that magnets have a soul because they exhibit movement cannot be appropriated by modern science. But that his explanation had seminal ingredients of a modern scientific explanation allow us to accept the pre-socatics as pioneers of a scientific explanation. Yet the pre-socratics did not show favor to every form of empirical explanation.

We indeed are indebted to the anonymous authors of the medical treatise that have come down to us, under the name of Hippocrates of Cos. Though dating these treatise has its own difficulties, some of these which we can reasonably be certain were written towards the end of fifth and sixth centuries. These writings exhibit signs of reaction against some aspects of pre-Socratics thought. They seem to react against the dogmatism of the Pre-Socratics as they felt that medicine must above all else be an empirical science. Thus, for instance, *On Ancient Medicine*, the author attacks those who made use of arbitrary postulates such as that everything is made of hot, cold, wet and dry – a typical Pre-socratic theory. Thus, we can notice that the Pre-Socratics were not scientists is the way modern scientists are. That is why, perhaps, they soon became isolated specialists and the next generation only took over their belief in our rational faculty and reasoned argument while their empirical inclinations were soon forgotten.

We can see that sophists were the first heirs of the Pre-socratics. They were more interested in language and in all aspects of logos than they were in nature and the origin of the world. The fact that several sophists were agnostics or atheists might demonstrate their links with Pre-socratic thought yet their focus on rhetoric to gain civic prominence was rooted in the socio-political factors of their times. Hence, we can notice that central concerns of the Pre-Socratics got diluted and the world will have to wait for the emergence of science only at the end of the Middle Ages. A few scientists today recognize that the pre-socratics are the forefathers of science. But a careful study of the pre-socratics can manifest the indebtedness of modern science to some of these great minds.

Although the Presocratics ushered in the shift from mythos to the logos, we have to understand this with a caution as they do manifest an overlap between these two domains. This pre-socratic combination of the vision and logic is a good model for modern science to develop a healthy relation with mysticism, religion and spirituality, since, science can de-soul our world. Perhaps this is beautifully said by the poet Friedrich Vou Schiller (1759-1805) in his poem 'the Gods of Greece'.

"Yes, home they went, and all things beautiful,

All things high they took with them,

All colors, all sounds of life,

And for us remained only de-souled Word.

Torn out the time-flood, they hover,

Saved on the heights of Pindus.

What shall live immortal in song

in life is bound to go under".

Thus, we need to stress the logos but at the same time we also cannot get out of our myths. We may not be able to discover our own myths. Perhaps the next generation might understand our myths. Hence, on one hand science can take us from mythos to logos but there is a danger of it becoming a new mythos. Hence, a healthy contribution of the two is the need of the hour.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Why do we call the Pre-socratics Proto-scientists and Proto-philosophers ?

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2) What is the relation of the Pre-socratics to modern science?

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2.13 LET US SUM UP

The journey that we have undertaken helps us to understand the role and importance of the Pre-Socratics to the emergence of Science in our world. We have tried to understand the Pre-socratic thinkers and their many schools. Due to the lack of access to the primary sources, we have come to understand that it is difficult to come to their original views. The fragments that we have although are limited yet are enough to understand their pioneering contribution in the emergence of science and the philosophy in the west. Their belief in an orderly and intelligible world as well as their preference of material, rational and mathematical explanation has been indeed seminal to the birth and growth of science.

2.14 KEY WORDS

Logos: Logos means "word," "account," or "reason," and it became a technical term in philosophy, beginning with Heraclitus (ca. 535–475 BC), who used the term for the principle of order and knowledge in the universe. The sophists used the term to mean discourse, and Aristotle applied the term to rational discourse. The Stoic philosophers identified the term with the divine animating principle pervading the universe. After Judaism came under Hellenistic influence, Philo (ca. 20 BC–40 AD) adopted the term into Jewish philosophy. The Gospel of John identifies the Logos, through which all things are made, as divine (*theos*), and further identifies Jesus as the incarnation of the Logos.

Cosmos: Cosmos is an orderly or harmonious system. It originates from a Greek term "*cosmos*" meaning order or orderly arrangement, and is the antithetical concept of chaos.

2.15 FURTHER READINGS AND REFERENCES

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2.16 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1) It is of academic currency to say that the entire academic edifice of the western world is founded on firm foundation laid down by the Greeks. This revolution is said to have taken place in the sixth century BCE. The thinkers associated with sixth century revolution are known collectively as the Pre-Socratics Philosophers. They were called Pre-Socratics because they preceded Socratics, the great thinker of the golden era of the Greek period in thought, even as the last among them are his contemporaries. The term Pre-Socratics is not well received by some scholars as it seems to derive the identity of those thinkers from Socrates and the Socratic thinkers (Socrates, Plato and Aristotle). Moreover, it is a rough approximation that these thinkers form a unitary group. But the fact that they differ in fundamental ways from their predecessors and their great successors does justify their collective treatment in academics.

2) What is a specific contribution of the Pre-socratic schools?

Scholars have pointed that two basic questions formed the common denominator of the intellectual activity of the Pre-socartic schools. They are : (1) What is the basic stuff of everything? (2) How can we explain the process of change ? In doing so they hit upon that special way of looking at the world which is thought to be scientific and rational. They saw the world as something ordered (cosmos) and intelligible. This means the world was not a random collection of bits and its history was not an arbitrary jumble of events. Nor was it controlled by the will of some capricious Gods. This means the world could be orderly without being divinely run. Its order was thought to be intrinsic and internal principles of nature were thought to be sufficient to explain its nature and its structure. In this way the pre-socratics became pro-scientists and proto-philosophers.

Answers to Check Your Progress II

1. The idea that these thinkers collectively brought something into the world, that is called as a scientific or proto-scientific attitude is gaining academic currency. Some scholars call these thinkers as the Big Bang of science. But it is naïve to lump all the Pre-Socratics together as if they were somehow identical. There is considerable diversity among them. We have seen that they range from shamans like Empedocles, mystics like Pythagoras, prophets like Heraclites to metaphysicians like Parmenides, philosophers like Anagoras and proto-Scientists like the Milesians (Ionians). Although, we might trace a strong variety of views and perspective among them, we can still find something common in them all. Indeed, we can say that they collectively invented Philosophy and Science. What do we mean when we say that they invented Science or Philosophy? Indeed, the Milesians brought something scientific in the world and those like Parmenides and Heraclites reflected upon their predecessors work and were therefore engaging in philosophizing.

2. The pre-socratic thinkers are proto-scientists but they lack the scientific rigor of modern science. We can trace many seminal attitudes of science among them. Their deliberate preference of rational, material, and mathematical explanation and their empiricism are certainly important features of modern science. The belief in an orderly and intelligible universe as well the basic conceptual terminology that they developed is even today employed by modern science.

UNIT 3 SOCRATIC THINKERS AND THEIR CONTRIBUTION

Contents

3.0 OBJECTIVES

The main objective of this unit is to introduce you to Socratic cosmology. The exposition is both historical and evaluative. Historical approach deserves only cursory approach. However, the thrust is on the type of problems which troubled Greek philosophers and the type of explanations offered by them which influenced science and philosophy for nearly two millennia. We can assess better the contributions of subsequent thinkers if we understand what the predecessors said. Against the background, you are required to know the cosmology of Socratic thinkers.

When you are thorough with this unit you will be in a position to assess both the strength and weakness of post-Socratic foundations of cosmology which is essential to understand modern astronomy.

3.1 INTRODUCTION

Cosmology took its birth with Greek philosophy and progressed remarkably until Socrates entered the stage. Plato was carried away completely by Socrates' authoritative assertions on ethical issues up to a point of time. He switched the tracks when he wrote *Timaeus* providing an interesting exposition of cosmology. This particular theory is heavily Pythagorean though a streak of Socratic influence can be easily discerned if not in content in attitude. Therefore Pythagorean orientation, to a great extent, determined the theme of this dialogue.

Number, measurement, ratio and harmony play pivotal role in Pythagoras' philosophy which in turn determined the structure of Platonic thought. Pythagoras is an uncommon fusion of science, philosophy and esoteric religion, whose obsession with the latter stunted further progress in science for quite a long time. This is one part of the story. Second part is much more crucial. Plato was convinced by the relevance of number and harmony in determining the origin and structure of the universe. Given his fascination for mathematics, Plato ought to have pursued his studies on definite lines leading to a systematic construction of a certain system of science for which a firm foundation was laid by Pythagoras. If this aspect of Pythagoreanism had influenced Plato, the development of cosmology would have been in a different direction. Instead, Plato was influenced to a very great extent by Pythagorean religion. A blend of his religion and Socrates' emphasis upon moral values resulted in the drifting of Platonic cosmology from the mainstream of what we call today science.

3.2 PLATO ON ORIGIN AND DEVELOPMENT OF UNIVERSE

The exposition begins with the distinction between *Is* and *Never Is.* What *Is* is being and what *Never Is* is becoming. The former is known through reason or intellect and the latter is known through sensation. Whatever becomes is created and is created out of necessity. In this particular context, necessity does not mean logical necessity. Nor does it mean causal according to S.Sambursky. Necessity consists in the resistance of the primeval matter to order and form. This statement points to two conclusions apart from pointing to Creator; one, the existence of this universe was preceded by 'something' and second, there was chaos. If the first statement is admitted, then creation becomes a misnomer because creation is always out of 'nothing'.

However, what is significant is that the world, since it is created, becomes unreal. This is what precisely Plato maintained throughout. Plato was unmindful of the implications of his argument. If the physical world is unreal, then no knowledge of the same is possible. Since scientific knowledge is identified with the knowledge of external world, the former naturally becomes impossible. This is how, due to Plato, ancient Greece missed the boat, the boat of Experimental Science. If the second statement is accepted, then chaos is contemporaneous with the Creator and imposition of order on primeval matter implies benevolence of the Creator. This conclusion plays vital role in Plato's philosophy.

The words, 'Creator' and 'Created' do recur again and again in Plato's and Aristotle's theories of cosmology. 'Creator' in Plato's cosmology, in the strict sense of the word, is not Creator at all. When there is no Creator there is no creation. This is because creation is always creation out of nothing. For Greeks this was simply unthinkable. When they spoke of creation they meant nothing short of production. To put it in unambiguous words the world was produced or manufactured out of primeval matter which is coeval with the so-called Creator. It is sufficient to remain aware of this difference in meaning while using these words.

What is the nature of the Creator and the created world? Sambursky's interpretation is illuminating. Creator (or God) is equated with Mind. Therefore God, Mind and Creator are alike in this context. Consequently, the Creator is endowed with two important mind-related attributes, viz. benevolence and desire. Since the Creator is benevolent, the world was modeled by him on the lines of the unchangeable, i.e., the form or heaven. It is not just the case. This world was created precisely because the Creator is benevolent, not otherwise. While the Form is most perfect, its copy ought to be very close to it, if not most perfect. This is what the Creator precisely intended. Secondly, the Creator discovered that 'created was afflicted with disorder (there is no answer to the question, 'why did the Creator create disorderly world'?). Therefore he brought order out of disorder.

At this stage Plato hit upon the core issue. What is this disorder Plato is referring to? T. S. Kuhn, in his work, 'The Copernican Revolution', says that 'observations of the appearance and disappearance of Venus were recorded in Mesopotamia as early as 1900 B.C. The appearance and disappearance of Venus suggested that the motion of planets is irregular. The irregularity was two-fold. It consisted in variable velocity and periodical retrograde motion. Normal motion of planet is eastward. Hence retrograde motion consisted in occasional westward motion. How can these problems be addressed? These problems were central to Plato and subsequent philosophers and scientists for nearly two thousand years. However, Kuhn considers this problem a pseudo- problem. In his work mentioned above, he distinguishes between two kinds of problems; qualitative and quantitative. While retrograde motion is qualitative in nature, fixation of the positions of stars and planets on different days at different times, which may stretch indefinitely, is quantitative according to him. He, further, argues that it is the latter which led to Copernican Revolution and hence it is the real problem. If Kuhn is right, then on another ground Plato is guilty of thwarting the progress of science.

The very same passage dealing with irregularity of planetary motion makes explicit reference to moral force which operates in or behind the universe. It is this moral value which is at the very base of the creation of the universe. This argument leads anyone to an amazing conclusion that the universe is no longer a fact but a value. Plato attributes not only moral value, but also aesthetic value to the design of the universe. 'Nothing can be beautiful which is…. imperfect'. If so its contraposition, naturally, holds good; whatever is perfect is beautiful. Keeping this in his mind, Plato argued that the universe was made in the form of globe which is spherical in shape. Sphere is perfect because it is completely symmetrical. Symmetry is determined on the basis of equidistance of any point on the circumference from the center. Symmetry is impossible without harmony and proportion. From these bases, it is only one step to the conclusion that the universe is not a fact, but a value. In this way Plato deprived science of its legitimate claim.

Just harmony and symmetry are not the legacy of the past. Here past means Pythagorean impact. Apart from four ingredients, viz. earth, water, air and fire, which go into the making of the universe, there are two more principles, viz. Mean and Proportion which he explains with the help of cube (or square). An example will help.

1) 4, 16, 256
2) 8, 512, ….

First one is a series of squares whereas second is a series of cubes. 4 is the square of 2 and 16 is the square of 4 and so on. Similarly, 8 is the cube of 2 and 512 is the cube of 8 and so on. Here the middle number is the mean, i.e. 16 or 512 as the case may be because first number stands to the second number in the same manner in which the second stands to the third. This explanation applies to the order of earth, water air and fire. As fire is to air so is air to water and so on. The mean is determined by proportion. Thus the making of the universe has a third dimension, viz. Arithmetic.

Arithmetic and geometry together complete the mathematical model of the universe. This should have been an ideal setting for science to take off. On the contrary, it receded to the background since religious dimension in mathematics gained ascent. There is no doubt about enormous influence which Pythagoras wielded on Plato. But the crucial point is that Plato was attracted by only one aspect of his philosophy, viz. the mystical nature of numbers. The reason has to be traced to the attitude or mindset. The mental framework decides what is acceptable and what is not. This analysis points to a strange and incredible conclusion that the birth of science is an accident. Not only its birth, but also discovery in science is an accident.

Plato's concept of universe is truly mystical. It is in conformity with his not so friendly reaction to science. It is a reminiscence of not mere mythology. It has strong semblance of primitive mindset. The following description makes this remark clear. The universe is animated by Plato in the literal sense of the word. It is not only intelligent (because God put intelligence in the soul and the soul in the body), but also consists of all intelligible beings. Hence this world is 'like the fairest and most perfect of intelligent beings'. Since all intelligent beings are put in one basket no other universe exists which is tantamount to saying that empty universe does not exist. The first question which arises is why did, in the first place, Plato animate the universe? The reason is not far to seek. Ever since Parmenides refuted all forms of change, the Greeks were confronted by a fundamental philosophical problem, viz. addressing the apparent (apparent at least according to some) problem of change. Plato evolved his theory of forms to refute generation, growth and decay. It is true that Plato restricted the refutation of change to the world of forms which is the only realm of reality. However, locomotion continued to haunt him. The Greeks could not even conceive the possibility of motion in inanimate objects. Nor could they refute motion with the same ease with which they themselves refuted one form of change. They were left with no other alternative but to animate the universe to make it mobile but with a difference. This *animal* is endowed with neither motor organs nor sensory organs because there was no need. The universe was all-inclusive. There is, therefore, nothing like external to it which means there is nothing to see. Nor can there be any sound to hear. There is nothing to enter from outside and nothing can go out either. All these conclusions follow from the denial of anything like *outside*. In the absence of legs how can the universe move? Motion is possible and plausible in seven different directions; circular, forward and backward, left and right, up and down. It is a commonplace knowledge that in the absence of legs only the first type of motion is possible. The only prerequisite is that what rotates must be circular. Therefore 'he (created) was made to move in ….a circle'. If symmetry is one reason, circular motion is another to regard the universe as spherical.

Plato's apathy to physical world is explicit in this dialogue. In *Timaeus* Plato explicitly states that God made the soul first and then the body which demonstrates that the soul is superior to the body. What is older is necessarily elder and what is elder is necessarily superior. Therefore the soul is superior to the body. Inferior should be ruled by the superior. The soul, therefore, should rule the body. Nevertheless, Plato devotes minimal space to describe the generation of the soul (there is no description in the real sense of the word). On the contrary, there is a detailed description of the manner in which the universe was brought into existence. If the description is taken seriously and accepted without any rider, then it will prompt anyone to conclude that the universe was rather *produced* or *manufactured* like any other product. The *production* of the universe is preceded by the choice of certain elements, certain mean or proportion and use of compression or force followed by separation. Again, separation was effected in a certain ratio. Plato seems to be under the impression that his theory is immune to any kind of refutation because he proceeds to specify the ratio which is 256: 243. By any stretch of imagination this sort of calculation without the aid of any kind of experiment or observation resulting from mere speculation is simply irrational and unphilosophical to say the least.

Plato considers two kinds of motion which he calls motion of the same and motion of the diverse. The latter applies to seven planets (Ancient Greeks believed that Sun and Moon were planets whereas Earth was not. The rest are Mercury, Venus, Saturn, Mars and Jupiter). It, therefore, implies that the former applies to stars. There are two circles devised by God for two kinds of motion. One is outer circle and the other is inner. Since such circles must have a common center, they are called homocentric or concentric circles. With the help of concentric circles, Plato specified the paths of planets and stars. Since the motion of stars is more or less uniform, he regarded such motion as the motion of the same. On similar grounds, he regarded the motion of planets as motion of diverse. He assigned the outer circle for the former and inner circle for the latter. Furthermore, he marked the direction of movement. While the motion of the stars is to the right, that of the diverse is to the left.

Plato's cosmology has two more important concepts, viz. space and time. Plato's theory of space is somewhat obscure and inconsistent. He calls it 'third nature' the other two being 'essence' and 'transient'. Space is eternal and citadel of sensible things though space as such is not sensible and therefore these two must be different. Such a definition may induce the belief that Plato is hinting at absolute theory of space according to which space is different from what it contains. However, it is not so simple. What makes matters worse is that space 'is hardly real', to quote from Russell's 'History of Western Philosophy', because it is neither in heaven nor on earth. Secondly, it is apprehended ('not known') neither through sense nor genuine reason but through false reason. He does not make clear what he means by 'false'. Does he mean that space is relative? If so, the theory which says that space is different from what it contains collapses. Hence his theory of space falls short of clarity. His theory of time makes up for this deficiency. Time is defined as the 'moving image of eternity.' Though the 'image of eternity' is also eternal, the difference is very clear. While eternity is at rest, time is not. Secondly, the former has neither beginning nor end whereas time, though endless, has beginning. At empirical level time becomes intelligible due to succession of day and night which in turn is due to the sun. Since within the framework of Platonic philosophy the earth is stationary, only the motion of the sun is reckoned to account for time. Obviously, ideas of months, years, etc. are all offshoots of the motion of the sun.

3.3 TELEOLOGY AND UNIVERSE

Space and time in conjunction with primeval matter complete the description of the universe. However, explanation of its origin and development remains unexplored. In other words the question *how* is answered and the question *why* remains to be answered. In the history of science the latter was answered in two distinct ways. These are known as teleological and mechanical. These approaches have far-reaching consequences in both science and philosophy. Presently, our concern is limited to the first approach. The word teleology is derived from Greek word ‘telos’, which means ‘at distance’. What is at distance in common life is aim or purpose. Therefore teleological explanation aims at searching for a purpose. Animism is the hallmark of any primitive society. Animism and action, viewed in isolation, were simply inconceivable. Though pre-Socratic philosophy, in its inception, freed itself from the influence of primitive society, either Empedocles could not wriggle out of its influence or the concept of ‘force’ which he introduced conveyed wrong message to Plato. Obviously, Plato came under its influence when he wrote *Timaeus.* It is more than evident in the passage quoted below.

‘He was good and the good can never have jealousy of anything…..desired that all things should be good and nothing bad…… brought order…..this was better than the other’.

Here clearly choice is involved and where there is choice there is purpose. Elsewhere in the same dialogue Plato continued to assert the supremacy of purpose. ‘And a lover of intelligence…. seek first for the causation that belongs to the intelligent nature’. Secondly, God created this universe because he uses the universe to meet his ends. On these grounds, Plato argued that there is purpose behind the generation and development of the universe. This is how Plato came to believe in teleological explanation of the universe which was further articulated by Aristotle.

3.4 ARISTOTLE’S TELEOLOGY AND GEOCENTRIC THEORY

In all probability Aristotle is the first astronomer worth the name of antiquity who wielded enormous influence on western mode of thought for a very long time. Paradoxically, Aristotle not only heralded the birth of Science, but also unwittingly became responsible for thwarting further progress in science. It is a well known fact that for both good and bad his followers are responsible more than Aristotle himself. He not only carried the legacy of his past, but also he passed it on to his successors. Two factors weighed heavily against anything like progress in science. One factor is teleological approach-a logical consequence of animism- to science in general and astronomy in particular and second is Plato's two-world thesis (which Kuhn, in his 'The Copernican Revolution' calls two- sphere universe), viz. the world of sensible objects and the world of forms, which cast its shadow on Aristotle. It is impossible for any thinker to go beyond his age. After all science is a product of the age to which it belongs. Against this background, we must embark upon the evaluation of his cosmology.

It is important to note that there are two determinants to Aristotle's cosmology. The definition of planet and the concept of stationary earth, which are interlocked, underlie his cosmology. It is profitable to start with the ancient Greek concept of planet. The term planet in original Greek meant 'wanderer'. It shows not only that the planet moves, but also that its movement is more complex if not erratic. The very foundation of ancient Greek cosmology has its roots in the discovery of complex motion of planets. While the sun and moon along with Mercury, Venus, Mars, Jupiter and Saturn fit into this scheme, the earth does not. The rotation of the universe should not be confused with the fixity of the earth. These two are compatible because the earth is the locus of the rotation of the universe. Obviously, mobility and fixity are not compatible. Accordingly, the Greek tradition admitted only seven planets.

Aristotle claims that more than one reason can be adduced to demonstrate that the earth is static. One of them can be briefly stated as follows. If the earth should rotate, then every part of the earth should rotate. But this is not the case. If we suppose that the earth really moves, then we should admit that it moves in a straight line towards the centre of the universe because it is what is called its natural movement as opposed to unnatural or violent motion. What is interesting is that the centre of the universe is the same as the centre of the earth too. Therefore if at all the earth moves it has to move towards its own centre which, surely, is absurd. Further, he makes a distinction between natural and unnatural motions on very strange grounds. Motion which is due to some force acting on the body is unnatural (and for the same reason he terms it violent). If so, natural motion ought to be regarded as independent of force. Then according to Aristotle motion transmitted from one body to another should not be construed as exertion of force. It is this transmission of this motion which matters most in his philosophy. This transmission follows a certain pattern which remains to be studied. Before we take up this issue we may consider other reasons. Aristotle, further, argued that if the earth moves it is capable of only rectilinear motion because it is heavy and all heavy objects move (if they move) only in straight line. He says in his work 'On Heavens' that 'we may add that heavy objects, if thrown ….in a straight line, come back to their originating point'. It means that heavy objects move in a straight line. Any rectilinear motion has an end because the universe is finite according to him, a point to which we shall return later. Aristotle accepted only perpetual motion which is possible only when motion is circular. This is second reason to reject the motion of the earth and also to regard circle as a perfect figure. One more reason is provided by Ptolemy in the very beginning of his work *Almagest.* He says that if the earth had motion, then 'it would……have got ahead of every other falling body……and would have fallen out of the universe itself……indeed this sort of suggestion…..utterly ridiculous.' We must consider another argument which is really sound. The rotation of the earth, if there was any, should have caused apparent motion of the stars. Aristotle was convinced that the stars do not rotate only because such rotation is not observed. Nor was it observable according to Aristotle. The sun was the only star (for the Greeks it was only a planet) whose motion was observable because of its proximity. If the Greeks could not observe the motion of the stars it was only because enormous distance separates the stars from the sublunary region. It was impossible to observe the motion of stars with naked eyes. When telescope itself was unknown to the ancient Greeks it would be simply anachronistic to accuse them of inability to mark or indifference to the motion of stars.

Why should the earth be regarded as the centre of the universe? Interestingly, the answer to this question is relevant neither philosophically nor astronomically. It lies elsewhere. Teleology, which pervaded Socratic and Platonic tradition, is at the root of this theory which is known as 'geocentric theory' as opposed to heliocentric theory which maintains that the sun is at the centre of the universe. This theory had far-reaching consequences which shaped the structure of western tradition for a little less than two millennia. These consequences stemmed from two nonastronomical elements in his cosmology, viz. astrology and religion which derived support from geocentric theory. Prevalence of this theory is largely responsible for what happened as well as for what has not happened between Aristotle and Copernicus.

While Plato was influenced by the immutability of mathematical entities, Aristotle was influenced by perpetual growth discernible in biology. For him growth and development are synonymous. He firmly believed that any development takes place only to enable man to meet his purpose because this is what he could observe in the growth of living being. If life is characterized by purpose, then only one step is required to reach the conclusion that there is purpose behind anything related to the universe because the universe is itself an 'animal'. When the earth is regarded as the centre of the universe, whatever constitutes the earth naturally becomes the centre of the universe. Hence the earth and man became the centre of the universe not only in geometric sense but in a much larger sense. Whatever happens in the universe is only for the sake of man. It means that the universe is the means to meet the ends of man. If something bad happens it is only an aberration. In reality, the stumbling block for the growth of knowledge is not geocentric theory as such, but it is the way in which the Greeks perceived the universe. The same mindset, if it had persisted, could as well have wrecked heliocentric theory.

Aristotle's account, in general, can be considered a 'common sense' account. Teleology and common sense go together. Today's science in general and Physics and Astronomy in particular go beyond common sense. As a result, teleological interpretation made way for mechanical interpretation. Or was the former replaced by the latter because the scientists discovered inherent difficulties or absurdities in the former? The situation is very much akin to asking which came first, whether seed or tree? This question shall not engage our attention at this stage. We have to concentrate on Aristotle's position in the history of science. If Aristotle's philosophy could not propel science it is because speculative science of his age was not mature enough to transform to fully-grown experimental science.

3.5 THE STRUCTURE OF THE UNIVERSE

Plato's two-world argument stages a comeback in Aristotle's theory of the universe. In this case the moon is chosen to separate these two worlds. The region between the earth and the moon is called 'sublunary' and the region beyond the moon is called superlunary. Therefore the moon marks on the one hand the upper limit of sublunary region and the lower limit of superlunary world. These together exhaust the universe. This universe itself is spherical which is contained within the sphere of the stars. Aristotle is not very clear about the question whether or not the heavens and the celestial sphere are identical, though he seems to suggest they are different. At one place he maintains that only celestial sphere can match the supremacy of heavens since both are immutable and only heavens initiate motion or any change on the earth. In another place he says that the sphere of the stars introduce the motion into sublunary region. Let us call Plato's world of sensible objects world-1 and the world of forms world-2. While the sublunary world may correspond to the former, superlunary world and heavens may correspond to world-2. These two worlds differ not only in content, but also in the laws which govern them.

Aristotle regarded the universe as a plenum. A universe is a plenum if it is 'full' in literal and physical senses. The entire sphere of universe is packed with one or the other kind of matter in such a manner that there is no vacuum. This is a common Greek perception during ancient age represented by the principle *horror vacui*, which means 'nature abhorrs vacuum'. It is to put it in a simpler language; where there is space there is matter and vice versa. Its inversion also holds good; where there is no matter there is no space. He believed that rejection of vacuum implies finiteness of the universe. For another very important reason the rejection of vacuum was inevitable for him. Motion originated only from heavens and then passed on to the terrestrial region to set the whole universe, with singular exception of the earth, in motion. Suppose that there is vacuum somewhere in the universe. Then motion cannot be transmitted beyond that point. Motion needs something to move. If there is nothing, then there is no motion. Therefore an important corollary which follows from this discussion is that there is no motion in vacuum. Aristotle evolved a certain mechanism to achieve his aim.

The superlunary region is filled with an element called *aether* which Aristotle regarded as solid. Though the meaning of 'solid' is neither clear nor acceptable, its rank in the scale of evaluation is very clear. Aether is superior and sublime because according to Aristotle it is incorruptible. What occupies celestial sphere ought to be so. This element has resulted in the formation of contiguous spheres called concentric spheres or homospheres. This concept of concentric spheres was given earlier by Eudoxus, a student of Plato and his successor Callipus. These spheres are concentric or homospheres because all spheres have a common centre. This is possible when smaller sphere is completely within the bigger one. Outermost sphere is the sphere of stars. In addition to this sphere Jupiter and Saturn were assigned with four concentric spheres each while the remaining planets were assigned with five each. Fig.1 shows the design. Below the legend is provided followed by concentric circles.

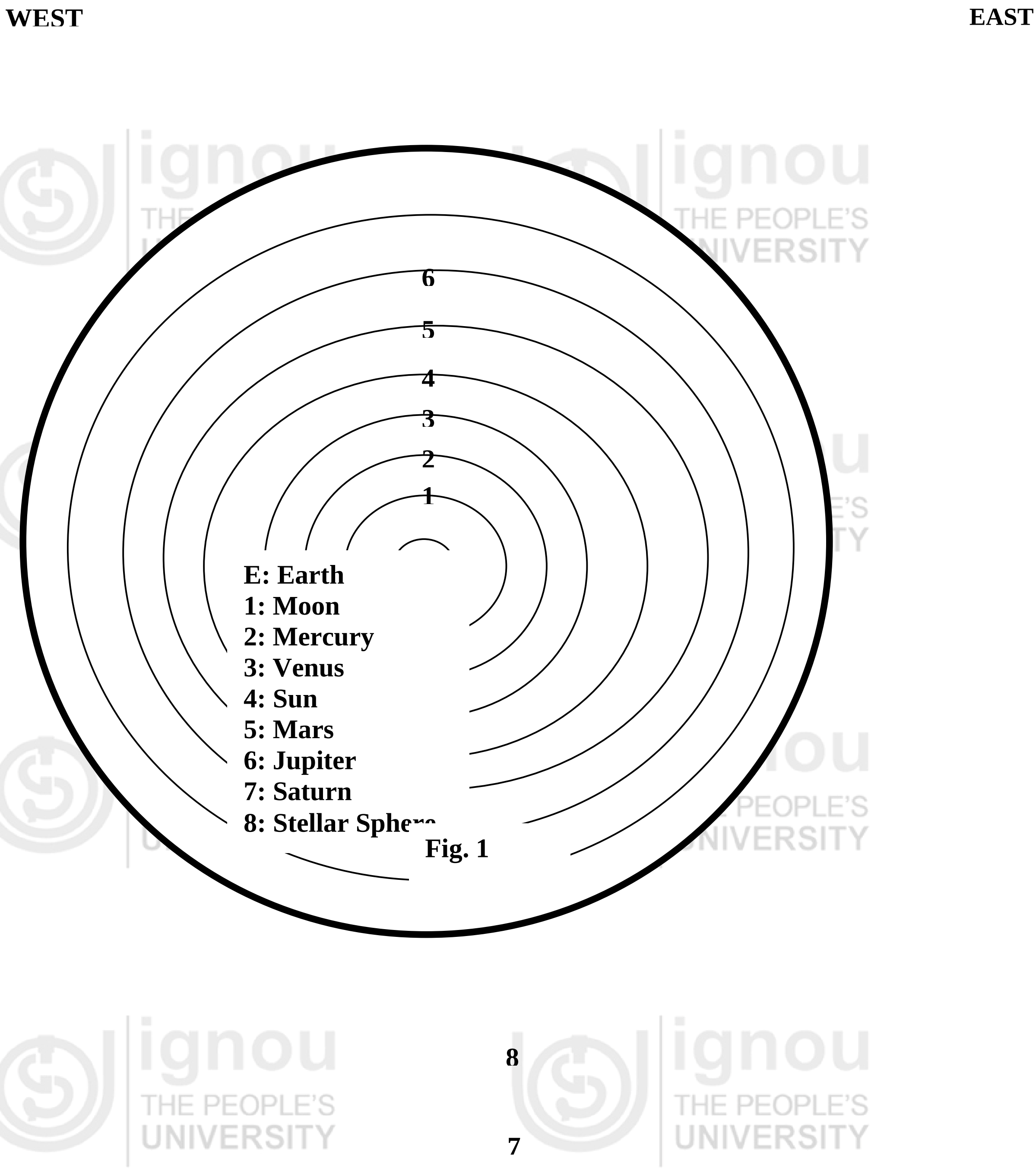

Fig. 1

These concentric spheres performed two-fold function; facilitate motion and explain the irregular motion of planets. How do these spheres facilitate or transmit motion? Imagine a cosmic train with its locomotive in place of the spheres of stars. The moon occupies the position of the last coach, whereas all concentric circles are replaced by the remaining coaches. Just as the locomotive transmits motion to all the compartments down to the last one the stellar sphere transmits motion to all planets down to the moon. Why should the motion stop at moon? What prevents motion from being transmitted further down to the earth? Does the earth remain stationary because the motion stops at the moon or does the motion stop at the moon because it is inadequate to move the earth? Aristotle does not seem to have thought about these questions.

Let us consider now planetary motion. While the eastward motion of planets was regarded as normal, occasional, but recurrent, westward motion was considered retrograde or irregular. Every sphere is thick enough to accommodate the normal and retrograde motions of planets. Aristotle nearly doubled the number of spheres to ensure contiguity in space from celestial sphere down to the terrestrial region. In Aristotle's philosophy these concentric spheres became mechanical tools to push motion further. In order to reinforce this idea Aristotle regarded these spheres as shells. At a later stage this conceptual development engineered the calculation of the size of the universe. Al Fargani an Arab astronomer (9 A.D.) took the radius of the earth as the standard to measure the magnitude of each sphere. Further computation of the results revealed that celestial sphere was about 120 million Kms. from the earth. Further, a comparison of this distance with the area of the earth showed that the latter is only a dot in the universe.

An important topic discussed by Aristotle includes the shape of the earth. Since the whole universe is a sphere, every component of the universe must be spherical in shape. Aristotle proves the shape of the earth on speculative and logical grounds. Let us consider the first one. In his own words, 'it is plain, first, that if particles are moving from all sides alike towards one point, the centre, the resulting mass must be similar on all sides; for if an equal quantity is added all round, the extremity must be at a constant distance from the centre. Such a shape is a sphere'. Aristotle admits that we must begin with imagination – imagination of 'the earth as in process of generation'. There is no reason why we must imagine what Aristotle has stipulated. If we imagine differently, which we can, then the conclusion is, evidently, different. This sort of explanation is grounded in speculation. Evidently, it lacks force. However, second proof is perfectly reasonable since it draws support from observational datum; 'if the earth were not spherical, eclipses of the moon would not exhibit segments of the shape they do'. The model is clearly hypothetico-deductive. Observation established the falsity of the conclusion and thereby the falsity of the antecedent.

Check your progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Why are the sun and moon regarded as planets but not the earth?

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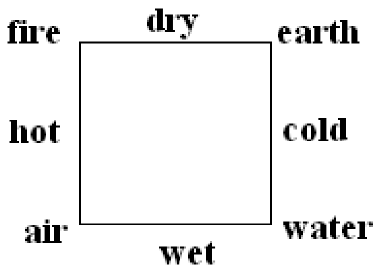
3.6 MATTER AND MOTION

A study of Aristotle's theory of universe demands that matter and motion are dealt with separately. Aristotle speaks of five elements of which aether is pure and incorruptible because it permeates the whole of superlunary region. The remaining elements are the earth, water, air and fire which fill the sublunary region. Aristotle characterizes these elements using two pairs of opposite qualities hot - cold and wet - dry. The scheme is as follows:


fire
dry
earth
hot
cold
air
wet
water

1. Which type of planetary motion is regular and which is irregular?

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3.7 LET US SUM UP

Plato and Aristotle provided teleological interpretation of the origin of universe. Animism is a common feature in both the accounts. The universe was made out of primeval matter in spherical shape. Only circular motion is eternal and perfect because circle is a perfect figure. The universe is characterized by moral value. Aristotle held geocentric theory. There are five elements of which aether alone is pure. Each element is characterized by a pair of opposite qualities. The universe is finite and there is no vacuum.

3.8 KEY WORDS

Cosmology: Cosmology means study of Universe. Plato used the word Cosmogony for Cosmology. Cosmology is a speculating study whereas its contemporary counterpart, viz., astronomy is strictly observational and more mathematical.

Sublunary and Superlunary: The region between the earth and moon is called Sublunary and the region beyond the moon is called Superlunary.

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3.10 ANSWERS TO CHECK YOUR PROGRESS

Check your progress I

1. The sun and moon are planets because they 'wander'. The earth is not a planet because it is static.

Check your progress II

2 Eastward motion is regular and westward motion is irregular.

UNIT 4 PHILOSOPHY OF SCIENCE AND COSMOLOGY IN THE MIDDLE AGES

Contents

4.0 OBJECTIVES

In this unit I propose to deal with three aspects, viz. cosmology, the concept of time and the contribution of Roger Bacon (not to be confused with his more famous namesake Francis Bacon). This unit enables you to understand what happened in Europe after Aristotle. An appraisal of cosmology in middle ages demands that you not only exhibit hindsight, but also far-sightedness while you are traversing through middle ages. This is essential because this particular age exhibited an interplay of three major factors, viz. Aristotelianism, scholasticism and Arabic science which paved the way for Copernican thought after nearly fifteen centuries. Hence the main objective of this unit is to analayse the role played by first two factors in blocking further growth of knowledge for such a long duration. While this is the main theme of this unit, Roger Bacon finds place here because he had the foresight to argue for experimental science.

At the end of this unit you must be in a position to identify the change in the mindset of thinkers when compared with philosophers of antiquity.

4.1 INTRODUCTION

The Greek civilization till Aristotle's period is known as Hellenic civilization. With his death this civilization also came to an abrupt end. This was followed by Roman civilization. Astronomy was not a favoured discipline in Roman civilization. In the real sense of the word, therefore, there was no successor to Aristotle. The rise of Christianity heralded the beginning of a very long Medieval Age which became infamous for discouraging, sometimes prohibiting, any kind of intellectual activity. If Aristotle's death is reckoned as the beginning, then in a loose sense the length of Medieval Age stretches to nearly eighteen centuries. Though historians usually reckon the beginning of this Age from 5th century A.D. for our purpose, we can say, it begins from Aristotle's death only. Similarly, it may not be proper to regard the whole of Medieval Age as Dark Age, though we cannot say that there was systematic scientific enterprise in this age. There were only irregular intellectual activities. Hence it is very difficult to say that during this age the intellectual activities came to a standstill. Then in what sense and why do we call this age Dark Age? Answers to these questions constitute the main theme of this unit.

4.2 PTOLEMY'S SYSTEM

The length of Medieval Age or Dark Age referred above, actually, is the interval between Aristotle and Copernicus. The gap is huge in the sense that the west could produce only one Egyptian astronomer of significance, viz. Ptolemy, who lived in the second century A.D. (Galen who also lived in the same century does not engage our attention only because he was a physician). While Aristotle's age is Hellenic age, Ptolemy belongs to an age called Hellenistic age. There is a subtle difference between these two. While the former is essentially Greek producing what can be regarded as speculative sciences, the latter is the synthesis of several cultures which facilitated the application of mathematics to the study of universe. Secondly, and this is vital, Ptolemy's work is the result of a systematic mathematical treatment of the subject. As a result, observation took over cosmology from mere speculation. This accounts for the birth of astronomy distinguishing itself from cosmology. Kuhn, therefore, rightly observed that Aristotle is the last great cosmologist of antiquity and Ptolemy is the last great astronomer of antiquity to which perhaps we can aptly add that Ptolemy is the primary source of modern astronomy. Shortly we will discover that these features not only distinguished Ptolemy from Aristotle in particular and Greek thinkers in general, but also laid the foundations for experimental sciences. Hence these differences proved to be vital for further growth of knowledge which took off several centuries later.

Despite prominent differences, Ptolemy inherited certain notions from Aristotle. Most important among them are as follows; dual motion in the universe, spherical shape heavens as well as the earth, the spherical motion of universe, and geo-centric theory which also implies immobility. However, the grounds on which Ptolemy made these assertions are truly significant. While the Greek philosophers, in general, indulged in speculation to arrive at results, Ptolemy resorted to observation and further maintained that at least some thinkers of antiquity also probably followed the same method. For the purpose of illustration let us consider the way in which Ptolemy, in his most important work Almagest, justified the spherical motion of the universe. 'For necessarily this point (here point means the earth because it is static) became the pole of heavenly sphere; and the stars nearer to it were those that spun in smaller circles and those farther away made greater circles in their revolutions……… and then they saw that those near ……. disappeared for a short time, and those farther away for a longer time….'. Further, according to him the earth is spherical 'sensibly'. The most interesting assertion he made about the earth is that it has the ratio of point to the heavens. There are two reasons. One reason is that in all parts of the earth the sizes and angular distances of the stars at the same time appear equal and alike. Secondly, everywhere the horizons cut the heavens into exactly half which would have been impossible had the 'magnitude of the earth with respect to its distance from the heavens been perceptible'.

Since Aristotle and Ptolemy together contributed to the creation of environment most fertile for Copernicus to develop his system, Ptolemy cannot be neglected. His work Almagest, a Greeko-Arabic word meaning 'The Greatest Compilation' is regarded as a path-breaking work. The Greeks called it the Megale Mathematike Syntaxis which means 'Great Mathematical Synthesis', which in Latin became Almagestum. It remained an authoritative source till

Copernicus entered the scene. Though, as mentioned earlier, in many important respects Ptolemy made progress over Aristotle's theory, on one cardinal count Ptolemy subscribed to traditional geocentric model, and consequently, its immobility. And this model, obviously, came with its religious baggage. His adherence to geo-centric theory to a great extent neutralized the progress which Ptolemy made over Aristotle. Not only Ptolemy held the view that the universe must be spherical because sphere is perfect, but also that the stars must move in circles. This is another important difference between Greek cosmology spearheaded by Aristotle on the one hand and Ptolemy on the other because in Greek tradition the stars are regarded as fixed. Another important difference deserves to be mentioned. The Greek tradition placed the sun just after the orbit of moon. But Ptolemy accepted subsequent arrangement which pushed the sun to the region between Venus and Mars and it became almost the official position throughout the Middle Age.

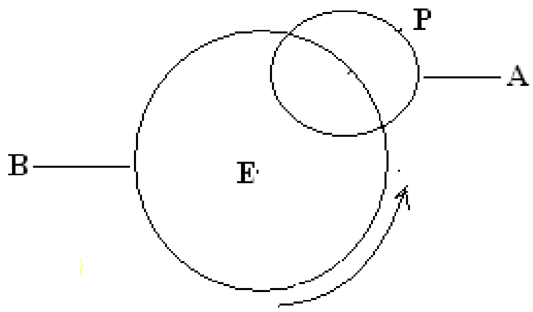
It is likely that the ancient Greeks grouped the sun and the moon together because these two planets were regarded as nonretrogressing planets since they were known for regular motion whereas the remaining five planets were grouped together because they were known for retrograde or irregular motion. This particular arrangement depended upon the observed velocity of the planets. Since the moon required only 27 (to be precise 1/3 has to be added to the number of days) days to complete the journey through the Zodiac in contrast with Saturn which required 29 years, velocity of a planet must be inversely proportional to its distance from the earth. This is precisely what the Greek tradition held. If it is acceptable then, its logical consequence is truly catastrophic. If the distance between the earth and any other body is zero then the velocity of that body must be infinite. The distance between the earth and itself is zero. Therefore the velocity of the earth cannot be zero. On the other hand, it must be infinite, which is surely absurd. It shows that mere increase in velocity is not adequate to complete the journey in comparison with, say, moon. However, an important fallout of this shift must be pointed out. The shifting of the orbit of the sun indicated better estimation of the distance of the sun from the earth. According to earlier calculation the sun would have been much closer to the earth. But now it is farther. However, it is a fact that before second century B.C. no attempt was made to calculate the distance between the earth and the sun. Better approximation of distance results in better approximation of all things related to the sun like its diameter, mass, temperature etc. which contributed to further growth of astronomy.

4.3 PLANETARY MOTION AND EPICYCLES

The greatest contribution of Ptolemy consists in his theory of planetary motion. Among seven planets the motion of the sun and moon did not pose any problem because their motion was always eastward. But it was not the case with the remaining planets. The remaining planets not only exhibited retrograde motion, but also they exhibited a certain pattern in irregularity. Irregularity meant only temporary reversal of path. Mercury reversed its path once in 116 days whereas Mars did so once in 780 days. The reversal pattern of the remaining three planets varied within this range. The astronomers thought that if irregularity is not random, then the path also must have been well-defined. This is the origin of the theory of epicycles. Indirectly, acceptance of epicycles weakened the hold of concentric circles or shells proposed by Aristotle.

Epicycle is a complex mathematical construction devoid of any physical reality unlike concentric spheres (if the claims of Aristotle with regard to the latter are acceptable). The origin of this theory is unknown. It is said that Apollonius was the first astronomer to introduce this hypothesis. In addition to this theory another theory also was suggested, viz. eccentric motion. However, the application of this concept is mainly associated with Hipparchus, a Greek astronomer, who lived in the second century B.C. because to a great extent he succeeded in explaining the retrograde motion of the planets. Later this theory assumed authority thanks to Ptolemy. Ptolemy's interpretation was so impressive that all subsequent astronomers in this age used this theory to construct their systems. An epicycle is defined by Hipparchus in the following manner; 'an epicycle is a circular path traced by a planet with its centre moving in a circle which has the earth as its centre'. Kuhn calls the circle traced by the moving centre of epicycle 'deferent'. Fig. 1 illustrates what Hipparchus and Kuhn meant.

EAST



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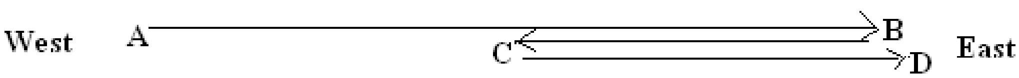
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does not seem to think so. He, it seems, believes that Hipparchus retained the earth at the centre of the deferent. If we accept Kuhn's approach, then the distinction between equant and eccentric remains intact. Whether the earth is at the centre of the deferent or not, the concept of equant involved two aspects. The velocity of deferent was expected to be uniform not with regard to the centre of the earth but with regard to the position of equant. Secondly, when equant was taken as the reference point, the sun appeared to move slower between vernal equinox and autumn equinox and faster in the next segment. Therefore the first casualty is the violation of uniformity of motion which was totally unacceptable to Copernicus. As a matter of fact, he rejected neither epicycle theory nor eccentric theory. Apart from the violation of uniformity of motion, the hypothesis of equant was another source of problem in Ptolemaic system. Against this background, the shift from geo-centric theory to helio-centric theory in Copernicus proves to be vital, whereas other sources of differences centered on technicalities. Hence the former is more significant.

4.4 POST-PTOLEMAIC ERA

Though Ptolemy belongs to what historians regard as ancient age, his theory is a sort of bridge linking ancient and modern period.. In the introduction part of this unit a question was raised on the nature of Dark Age. Now we should search for answer to this question. Therefore we are concerned with what happened in this period.

Post-Ptolemaic era has its own peculiarities. Undoubtedly, in one sense there was no semblance of intellectual inactivity. The cessation of intellectual activity (whatever may be the sense) was promptly followed by loss of literature. Surely nothing worse can be imagined. However, in a sense altogether different there was something brewing. Paradoxically, after a certain time the ancient works were retrieved and scrupulously studied evaluated and interpreted though after the fall of Hellenic civilization Aristotle was nearly forgotten. In spite of activity at this level there was no attempt to construct any new theory in any field. Therefore there was no change in the world-view. This shows that any semblance of perceptible intellectual activity was within the conceptual framework of ancient period. In other words, there was no growth of knowledge. But the Europeans succeeded in one respect. Though theories and problems remained the same, their perception underwent radical change. New dimensions were added to the theoretical framework. What made these achievements possible? There were several factors which contributed to this development.

The fall of the Roman Empire was followed by two new decisive forces; forces in different senses. The rise of Christianity and establishment of trade and commerce link with Arabs changed the very fabric of intellectual life forever. This happened in the 7th century and Ptolemy died in the 2nd century. The intervening period remained dormant. It was during this period that whatever Europe could lose, was lost. The Arabs discovered Aristotle and post-Aristotelians and therefore could restore ancient cosmology and astronomy mainly through translations from Greek to Arabic and subsequently from Arabic to Latin. Such translations stimulated interest in ancient learning giving birth to what is widely known as 'scholasticism'. Intellectual activity perceived in second sense materialized only after the Arab scholars discovered the lost literature.

Scholasticism suffered from infantile ailments. Between Aristotle's death and revival of ancient learning there were many interpretations. Aristotelians did not endorse all his arguments. They did effect changes. Ptolemy made several, if not total, structural changes. Coupled with these factors was translation of translation which was at worst misleading and at best inaccurate and incomplete. Situation was volatile enough to revolt against ancient learning which took some centuries to happen. Initially, the situation led to the belief that there were contradictions. Immediate concern was to resolve these apparent contradictions. Kuhn aptly sums up the trend in the following words. 'Where growth of knowledge should have been recorded, contradictions were noticed'. According to Kuhn this confusion arose because the whole of ancient learning was regarded as a sort of single body of knowledge. This attitude of critics, as well as of followers of Aristotle, is partly responsible for the degeneration of knowledge during the medieval period.

Cosmology and astronomy should have been considered either philosophical following the footsteps of Aristotle, or mathematical following Ptolemy. On the other hand, it acquired third dimension. It was viewed as esoteric. It did not happen overnight. The roots of theologization of cosmology are in geocentric theory established by Aristotle and carried forward by Ptolemy. Ironically, mathematical aspects of Ptolemy's doctrine were thoroughly missed. The situation is very much akin to what happened in distant past with Pythagoras when Plato absorbed his mysticism despite the fact that Plato himself was influenced by mathematics. Returning to Medieval Age, it may be pointed out that the church started gaining stronghold from fourth century onwards. St. Augustine can be regarded as the first philosopher in post-Christ era. Though a philosopher of repute, neither logic nor science meant anything to him. He had only contempt for science, though he did have a certain concept of universe. In this case what he elaborated is, undoubtedly, creation theory in the strict sense of the term. Christianity, in fact, is the first religion (as a religion itself it is the first religion) to argue for creation out of nothing. Consequently, the world must have a beginning in time. But this entire description had only religious significance for him. That is the spirit with which St. Augustine carried further his argument. The only other element of philosophical significance in his doctrine is the concept of time. He maintained that time is linear, i.e., the flow of time is in one direction only. Again, he proposed this theory not because he wanted to develop a philosophical theory. Astrology is one offshoot of Aristotle's cosmology, which earned his wrath. St. Augustine's doctrine of time is the direct consequence of his opposition to astrology. The Church believed that astrology presupposes pre-determinism and hence is an obstacle to man's freedom to choose Christian values. Behind any philosophical doctrine of St. Augustine, a certain religious purpose can be easily discerned. Progress in any field is determined by the motive. If motive is oriented to philosophy, then only philosophy can progress. On the other hand, if the motive is religion-oriented, then, religion alone becomes popular and spreads far and wide. It was not just science which fell out of his favour. Anything unrelated to Christianity is irrelevant according to him. He argues that 'it is not necessary to probe into the nature of things, as was done by those whom the Greeks call physici…. it is enough for the Christian to believe that the only cause of all created things, whether heavenly or earthly, whether visible or invisible, is the goodness of the Creator, the true one God'.

The attitude of the Church was not hostile always. Therefore no sweeping remark can be made with regard to its stand. It oscillated from one end to the other for some centuries. For a little less than ten centuries Aristotle and Ptolemy were left out by the Church because it was widely believed that their doctrines clashed with those of Christianity. In particular the Church was averse to the unreality of vacuum and timelessness of the universe because acceptance of these two theories would overthrow the Christian God. It shows that what mattered during this age was only the survival of Christianity. Perhaps St. Augustine had some role to play in this regard. If it is true, then it is truly ironical because Aristotle was almost resurrected by another equally famous Christian saint, St. Thomas Aquinas. This happened after thirteenth century when Christian Scripture, on the one hand and ancient wisdom in general and Aristotle in particular on the other hand, were reinterpreted to which the contribution of St. Aquinas is by no means meager. He maintained that the God created the universe out of nothing, a point of departure from Aristotle. Aquinas was fully aware of this crucial difference. In spite of this he indulged in a grand hermeneutic exercise because he was prudent enough to retain the potential source of support for Christianity. As a result of this exercise, the concept of central earth emerged as the single force which has the potential to reinforce the Biblical notion of universe. The Biblical notion of universe discovered sound support in Aristotelian doctrine. In the strict sense of the term this amounts to rediscovery only. Otherwise, the followers of the Church would have developed apathy to Aristotle at no point of time. If the concept of central earth is accepted, then it is very easy to establish that the heaven is above and the hell is below the earth. Further, the spherical shape and immobility of the earth reinforced the Biblical notion. This harmony was short-lived. The Church backtracked when rift arose between the doctrines of the Church and new theories proposed by science. This particular clash marked the beginning of Renaissance. This sort of vacillation points to two important conclusions. Conflict brings to the fore the determination to survive. All instances of conflict, as a matter of fact, generate the will to survive. Second, and most important conclusion, is that in the absence of conflict, the best neither comes out, nor does it survive if it comes out. Two instances which Kuhn has considered buttress these conclusions. Lactantius, a fourth century clergyman repudiated the idea of spherical earth because it was unimaginable that men could stand with their heads down. Kosmas, another clergyman of the sixth century regarded the earth as 'rectangular plane footstool of the Lord. According to him not only the earth is flat, but also the universe is the flat substratum of the earth. Further, Kuhn adds that their doctrines were not granted official status by the Church though they were clergymen, propagating Biblical thought.

No other thinker, in this age, received as much of attention as Aristotle received. The focus and intensity of support and opposition remains always the same and one includes the other. Whenever the Church needed support it looked only to Aristotle as its savior. Whenever it perceived threat, the Church feared that only Aristotle fomented trouble. Even though Ptolemy subscribed to some vital doctrines formulated by Aristotle, the Church did not take cognizance of this fact. Therefore there must be something in Aristotle which is lacking in Ptolemy. Initially, it was thought that for religion science was a source of neither support nor threat. Hence it received only contempt. Ptolemy represented science. Perhaps on this ground the Church thought that Ptolemy could be sidelined. But this was not the case with Aristotle. Aristotle's cosmology is largely speculative with its roots in ancient mythology. Common ground for Aristotle and religion was easily noticed. Therefore for both good and bad the Church perhaps thought of only Aristotle.

Aristotelian system thrives on the assumption that the laws which govern the sublunary world do not hold good in superlunary world. Hence it was aptly called two-world argument. Both Aristotle and Ptolemy rejected the hypotheses proposed by two Pythagoreans viz. Heraclides and Ecphantus, fourth century B.C. cosmologists (in fact they were not the first cosmologists to suggest the motion of the earth, be in it any form. Earlier two Pythagoreans viz. Hicetas, and Philolaus, fifth century B.C. cosmologists, made the same suggestion.), who suggested that the diurnal motion of the stars might be the effect of the eastward rotation of the earth. It seems motion was the criterion of demarcation of terrestrial from celestial. Only then the distinction could be defended. Precisely on this count astronomers from sixteenth century onwards differed from ancient astronomers. The seeds of dissent were sown in the Medieval Age itself. Two developments are worth mentioning. The critics of Aristotle used two key issues which possessed the elements of Copernican system; the possibility of moving earth and the equation of motions of terrestrial and celestial bodies. Last two are studied under disciplines known as kinematics and dynamics respectively. Nicole Oresme thought that Heraclides might be preferable to Aristotle. He did not really believe that Heraclides was right and Aristotle was wrong. He only hinted that Heraclides' position was logically tenable. Ultimately, Oresme was proved right. Thus preamble was laid to Copernicus to establish his system.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Explain notions which are common to Ptolemy and Aristotle.

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4.5 ROGER BACON AND EXPERIMENTAL SCIENCE

A brief reference to a less known philosopher, Roger Bacon, who lived in the thirteenth century, is desirable for two reasons. First, he is a precursor to Francis Bacon and second, he himself being a saint, tried to bridge the gap between science and religion. He admits that there are two sources of knowledge; reason and experience. While reason is inadequate, experience is adequate. Therefore experimental science can have its roots in experience only. He extends the range of experience to mathematics also. He criticises Aristotle for appreciating reason at the cost of experience. A man of experience who knows the reason and cause by experience is perfect in wisdom. Only experiment helps us to acquire indubitable knowledge. There are seven levels of knowledge of which knowledge at first level is satisfied by experimental science and knowledge at all other levels acquires theological and ethical dimensions. In this way Bacon tried to achieve the fusion of science and religion at nascent stage itself. He says that experimental science is advantageous because only it has the ability to test the claims of other sciences while its own claims cannot be tested by any other science. His preoccupation with experimental science encouraged him to develop interest in alchemy, medicine optics etc. He is known to have claimed that the universe is five hundred times the distance between the earth and the moon. But for this statement Bacon does not seem to have said anything else connected with cosmology.

[Note: there is no such word as theologization. I have deliberately used this word to make one point clear. 'Theologization of cosmology' means that cosmology in its essence is not theological but only some thinkers projected cosmology within the framework of theological principles rightly or wrongly.

Kinematics is the study of motion which does not include any reference to force whereas dynamics is concerned with the study of force and its relation to motion.]

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Examine the historical background of scholasticism and its nature.

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2. Give an account of St. Augustine's criticism of science.

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4.6 LET US SUM UP

After Aristotle's death the Greek civilization perished. Ptolemy accepted many aspects of Aristotle's cosmology. Ptolemy applied mathematics to cosmology. Aristotle's concentric circles were replaced by epicycles and deferents. This is a prominent difference between Aristotle and Ptolemy. Ptolemy is the last astronomer of repute who belonged to ancient age. From 4th century onwards the Dark Age sets in when ancient literature was lost only to be discovered later by Arab scholars. After the Church became powerful, science was sidelined. St. Augustine disapproved Aristotle's cosmology because it supported astrology. St. Aquinas fused Aristotelianism and Christianity. Roger Bacon supported experimental science.

4.7 KEY WORDS

Epicycle: It is a mathematical construction employed by ancient Greek astronomers to explain irregular (retrograde) motion of planets. Since it is a circle change in the direction of motion which is natural to circular motion helped them to explain retrograde motion of planets.

Experimental Science: Science is said to be experimental when a scientist can control conditions at his will and bases his study on observation of phenomena which are under his control.

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4.9 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. Ptolemy inherited certain notions from Aristotle. Most important among them are as follows; dual motion in the universe, spherical shape of heavens as well as the earth, the spherical motion of universe, and geocentric theory which also implies immobility of the earth. However, the grounds on which Ptolemy made these assertions are truly significant. While the Greek philosophers indulged in speculation to arrive at results, Ptolemy resorted to observation and further maintained that the thinkers of antiquity also probably followed the same method. For the purpose of illustration let us consider the way in which Ptolemy, in his most important work Almagest, justified the spherical motion of the universe. 'For necessarily this point (here point means the earth because it is static) became the pole of heavenly sphere; and the stars nearer to it were those that spun in smaller circles and those farther away made greater circles in their revolutions……… and then they saw that those near ……. disappeared for a short time, and those farther away for a longer time….'. Further, according to him the earth is spherical 'sensibly'.

Check Your Progress II

1. There were several factors which contributed to this development. The fall of the Roman Empire was followed by two new decisive forces; forces in different senses. The rise of Christianity and establishment of trade and commerce link with Arabs changed the very fabric of intellectual life forever. This happened in the 7th century and Ptolemy died in the 2nd century. The intervening period remained dormant. It was during this period that whatever Europe could lose, was lost. The Arabs discovered Aristotle and post-Aristotelians and therefore could restore ancient cosmology and astronomy mainly through translations from Greek to Arabic and subsequently from Arabic to Latin. Such translations stimulated interest in ancient learning giving birth to what is widely known as 'scholasticism'. Intellectual activity perceived in second sense materialized only after the Arab scholars discovered the lost literature. Scholasticism suffered from infantile ailments. Between Aristotle's death and revival of ancient learning there were many interpretations. Aristotelians did not endorse all his arguments. They did effect changes.

Ptolemy made several, if not total, structural changes. Coupled with these factors was translation of translation which was at worst misleading and at best inaccurate and incomplete. Situation was volatile enough to revolt against ancient learning which took some centuries to happen. Initially, the situation led to the belief that there were contradictions. Immediate concern was to resolve these apparent contradictions. Kuhn aptly sums up the trend in the following words. Where growth of knowledge should have been recorded, contradictions were noticed. According to Kuhn this confusion arose because the whole of ancient learning was regarded as a sort of single body of knowledge. This attitude of critics, as well as of followers of Aristotle, is partly responsible for the degeneration of knowledge during the medieval period.

2. St. Augustine can be regarded as the first philosopher in post-Christ era. Though a philosopher of repute, neither logic nor science meant anything to him. He had only contempt for science, though he did have a certain concept of universe. In this case what he elaborated is, undoubtedly, creation theory in the strict sense of the term. Christianity, in fact, is the first religion (as a religion itself it is the first religion) to argue for creation out of nothing. Consequently, the world must have a beginning in time. But this entire description had only religious significance for him. That is the spirit with which St. Augustine carried further his argument. The only other element of philosophical significance in his doctrine is the concept of time. He maintained that time is linear, i.e., which means that the flow of time is in one direction only. Again, he proposed this theory not because he wanted to develop a philosophical theory. Astrology is one offshoot of Aristotle's cosmology, which earned his wrath. St. Augustine's doctrine of time is the direct consequence of his opposition to astrology. The Church believed that astrology presupposes pre-determinism and hence is an obstacle to man's freedom to choose Christian values. Behind any philosophical doctrine of St. Augustine, a certain religious purpose can be easily discerned. Progress in any field is determined by the motive. If motive is oriented to philosophy, then only philosophy can progress. On the other hand, if the motive is religion oriented, then, religion alone becomes popular and spreads far and wide. It was not just science which fell out of his favour. Anything unrelated to Christianity is irrelevant.

BLOCK 2

It was Copernicus who initialized the Modern astronomy with his revolutionary findings. The whole of astronomy took a different direction altogether with the publication of his book. He is said to have re-written the astronomy. Times before Copernicus the thinkers gave a teleological explanation of the universe. But with Copernican revolution the whole universe was given a mechanical explanation. This is one of the major achievements of this period. This was possible because his view was very different from those thinkers of the Ancient times. Copernicus rejected the geocentric theory of Ptolemy and adopted the heliocentric theory. Copernicus is basically a theoretician with the background of mathematics and depended highly upon the observations made by his predecessors.

Unit 1 introduces the Copernican Revolution and its Philosophical implications on the world. It gave a new direction to the whole way of looking at the universe. The geocentric theory was rejected and heliocentric theory became acceptable. The universe was given a mechanical explanation. Copernicus was of the view that the replacement of earth by the sun satisfactorily explained the problem of retrograde motion.

Unit 2 highlights the contributions towards the Philosophy of Nature by the thinkers who followed Copernicus. Copernicus' system was favoured by some like Kepler and some revolted against it, like Tycho Brahe and even the Church. The whole new original explanation apparently went against the tradition that had gone by the teachings of the church.

Unit 3 probes into the contributions of Newton and his school in the area of philosophy and nature. In this unit we will be introduced to two important thinkers: Galileo and Newton. This marks the beginning of the modern science that we see today. Galileo's theory of motion, Newton and classical mechanics, the concept of force are the topics under discussion. Relativity of motion has its beginning in Galileo.

Unit 4 concludes the discussion on the Mechanical Philosophy of Nature by stating some of the implications that were immediately and even to this day have been felt in all spheres of knowledge. This unit is a brief survey of ‘cosmological upheaval’ and a close examination of Newton’s *hypothesis non-fingo*. This will clarify most of our understanding regarding Newton in relation to his predecessors.

This is an important period in the history of philosophy of science as it marks the beginning of the modern science. Kepler, Tycho Brahe, Galileo, and Newton were the stalwarts who contributed substantially original and novel, giving a new direction to the whole philosophy of nature or universe as a whole which was considered to be teleological.

UNIT 1 COPERNICAN REVOLUTION AND ITS PHILOSOPHICAL IMPLICATIONS

Contents

1.0 OBJECTIVES

This unit will bring you to the threshold of 'Modern Astronomy' set in motion by Copernicus. The principal aim of this unit is to make you familiar with those elements of astronomy which lay at the root of Copernican system. Therefore in this unit we will focus on aspects on which Copernicus agrees with his predecessors and aspects on which he dissents. Further, you must be able to evaluate Copernicus' contribution to the direction in which astronomy developed by identifying what exactly constitutes progress in Copernicus' system and this progress constitutes the essence of the revolutionary impact for which it is famous for. Therefore this aspect is highlighted in this unit.

1.1 INTRODUCTION

The beginnings of modern astronomy are traced to the year 1543 when Copernicus' De Revolutionibus Orbium Caelestium (On the Revolutions of the Celestial Spheres) was published. With the publication of this work the path of astronomy takes a different path. In antiquity cosmological study was driven by teleological explanations. One of the major achievements of Copernicus consists in the shift from teleological explanation to mechanical explanation. Therefore he can be regarded as a precursor to Modern Science. The shift became possible mainly because his perspective itself was totally different from that of Greek astronomers. Initially, the startling contents were confined to his inner circle only and he was reluctant to publish the work for a very long time though he was convinced of usefulness of his theory for two reasons; first, fear of reprisal because the Church was still too strong and second, unwillingness to share his thought with those who were mathematically untrained. In his preface to the De Revolutionibus, but addressed to the Pope Paul III, he confesses to his apparent Pythagorean orientation which was behind his dilemma to publish or not to publish the work. He admits that he was hesitant to 'give light to these my commentaries written to prove the Earth's motion or whether, on the other hand, it were better to follow the example of the Pythagoreans and others who were wont to impart their philosophic mysteries only to intimates and friends……'. The exposition of an astronomical problem in a typical mathematical language which began with Ptolemy's Almagest matures in Copernicus. For this reason, but for the first part the whole work is completely mathematical which requires sound knowledge of mathematics. As a result, those who are not mathematically trained adequately cannot grasp the essence of his work. Consequently, he argued that 'Mathematics are for mathematicians' which Kuhn regards as an 'essential incongruity'. Copernicus' awareness of this serious limitation on the part of readers prevented him from publishing his work.

Copernicus is well known for rejecting geocentric theory and opting for heliocentric theory. However, to stop at this stage alone amounts to making a mole out of a mountain. This critical aspect unfolds itself at a later stage. Further, in spite of the fact that he disagreed with not only Aristotle but also Ptolemy on many important issues Copernicus remains more Aristotelian than Ptolemaic. Cohen argues that Copernicus followed Ptolemy's Almagest in ordering the chapters and choosing the sequence and that he admired Ptolemy. Cohen's statement is misleading though the first part of his assertion may be true. The structure of these two works may be similar but there is clear opposition between these two works. What is noteworthy is that Copernicus did not make any new observations. All his arguments are based on observational data recorded by his predecessors which means that the heliocentric theory is the outcome of rigorous logical approach applied to observational data. Against this backdrop, the contribution of Copernicus must be evaluated.

1.2 GEOCENTRIC THEORY VS. HELIOCENTRIC THEORY

Apart from Pythagoreans like Philolous Ecphantus etc., according to Kuhn, there are some Neoplatonists who gave Copernicus food for thought. Kuhn's opinion has to be treated with caution. Marsilio Ficino an Italian Neoplatonist and Nicholas who lived in the 15th century are the immediate precursors of Copernicanism. Kuhn quotes from one Neoplatonist without making clear the source of the following passage: 'In the middle of all sits Sun enthroned…….. ruling his children the planets……'. Though the language is more mystical and less philosophical and lends itself to equivocation easily, for Copernicus, if Kuhn is to be believed, the message was more than clear. But this supposed latest source is, evidently, dubious. Kuhn himself admits that Ficino knew nothing of astronomy. A poetic or a mystical narration may at best help to develop an insight. But it is far from saying that such a narration is the source of an epoch-making astronomical theory. At best, Nicholas might be a reliable source because he inferred the motion of the earth from many-world theory which clearly opposed Aristotle's one-world theory. Platonic two-world theory, which found place in Aristotle's cosmology, in the form of sublunary and superlunary worlds, should not be confused with one-world in astronomical sense. Even if this possibility is allowed, it will not be of much help because none of them thought on the lines of applying this hypothesis to solve any astronomical problem, in particular planetary motion. The uniqueness of Copernicus must be discerned here. This is one part. The apparent influence of Pythagoreans will be discussed later. But there were, surely, extra-astronomical factors which guided Copernicus' thought. In his preface addressed to the Pope III, Copernicus refers to one such factor. There was urgent need to restructure calendar which heavily depended upon the exact calculation of the length of the year. Another factor which weighed heavily in favour of the suncentric argument was expeditions, resulting in the discovery of hitherto unknown parts of land, which demanded that the world map had to be rewritten. Again, the target is Ptolemy. Ptolemy's geographical knowledge is no less than his knowledge of astronomy. Charles Singer suggests that in all likelihood Ptolemy had access to the map prepared by Vipsanius Agrippa of Rome which became outdated due to several successful expeditions. Further, navigation, which had by then become almost a way of life, entirely depended upon several astronomical factors. These are the genuine extra-astronomical factors which propelled the change.

Each of these two theories implies a significant conclusion; what is central to the universe is also static. Therefore Bernard Cohen aptly describes them as geostatic and heliostatic theories respectively. It is surely profitable to contrast Copernican system with Ptolemaic system, his immediate predecessor.

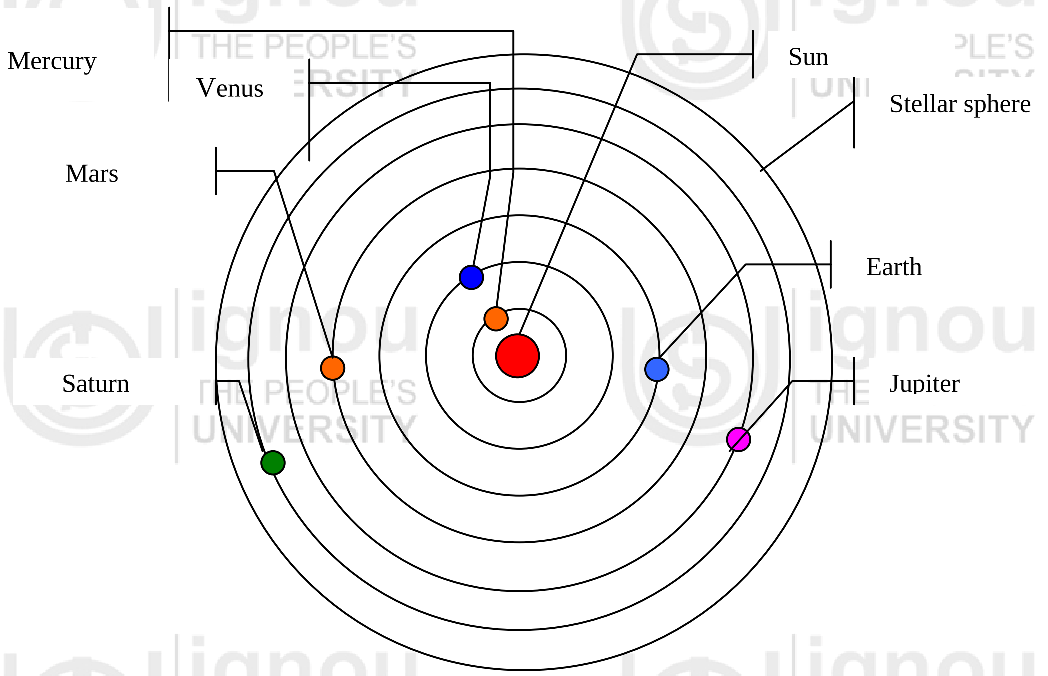

Fig.1a Copernican model of planetary system

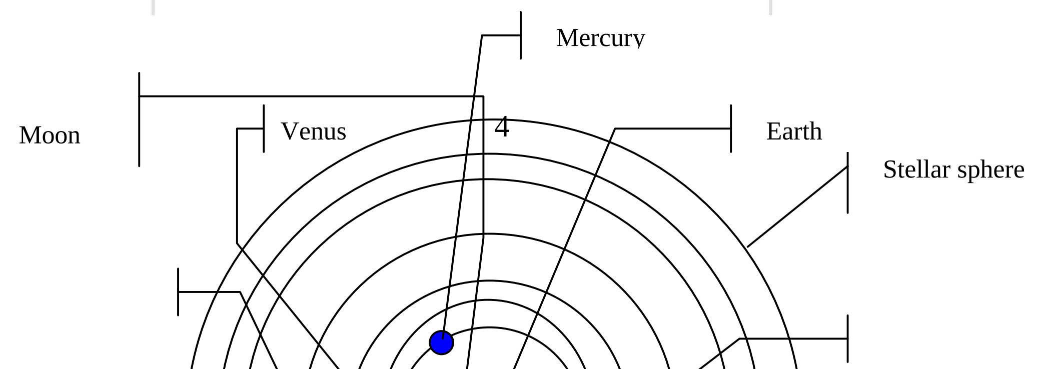

Fig.1b Ptolemaic system

From these two figures it is clear that the positions of the earth and the sun are not just transposed but there is slight reshuffling. The table 1 shows the relative positions of these two from the respective centres in Ptolemaic and Copernican systems.

Table 1

Ptolemaic System	Copernican System
1 The moon	Mercury
2 Mercury	Venus
3 Venus	The earth (with its moon)
4 The sun	Mars
5 Mars	___

It is easy to notice that there is a mismatch between these two systems because the moon is not assigned a separate orbit. Secondly, the table makes it clear that there is at least partial relocation of all bodies mentioned above. However, the positions of Jupiter and Saturn are common to both the systems. In regarding the sun as the centre of the universe Copernican system is encountering the first anomaly. Copernicus continues, surprisingly, to regard the sun as a planet despite the fact that in his system the sun is static. He ought to have changed the definition of planet itself or he ought not to have regarded the sun as a planet which he did not. The shift raises certain significant questions which need to be probed. Before we do so we must consider certain postulates which constitute the framework of his system.

1.3 POSTULATES OF COPERNICAN SYSTEM

Copernicus' investigations are based upon seven postulates which figured in his earlier work, 'The Commentariolus'. They are as follows:

1. There is not a single centre of all the celestial orbs or spheres.
2. The centre of the earth is the centre of gravity and lunar sphere, but not of the universe.
3. All the spheres encircle the sun, which is in the middle of them all, so that the centre of the universe is near the sun.
4. The ratio of the earth's distance from the sun to the height of the firmament is so much smaller than the ratio of the earth's radius to its distance from the sun that the distance between the earth and the sun is imperceptible in comparison with the loftiness of the firmament.
5. Whatever motion appears in the firmament is due, not to it, but to the earth. Accordingly, the earth together with the circumjacent elements perform a complete rotation on its fixed poles in a daily motion, while the firmament and highest heaven abide unchanged.
6. What appears to us as motions of the sun are due, not to its motion, but to the motion of the earth and our sphere, with which we revolve about the sun as (we would with) any other planet. The earth has, then, more than one motion.

7. What appears in the planets as (the alternation of) retrograde and direct motion is due, not to their motion, but to the earth's. The motion of the earth alone, therefore, suffices (to explain) so many apparent irregularities in the heaven.

(Source: The Tests Of Time: Lisa M. Dolling, Arthur F. Gianelli and Glenn N.Statile, Ed. Princeton University Press, New Jersey, 2003)

It is profitable to consider these postulates in some detail and surely some or in need of clarification considering their significance.

Consider first and third postulates together. First postulate states that there is no one centre of all the celestial orbs which means that there must be more than one. It is possible that every orb has its own centre. If so, in the strict sense of the term the sun cannot be regarded as the centre of the universe. This is what the third postulate asserts. All the spheres may encircle the sun. But it does not imply that the sun must be the centre of all orbs. If it is not the centre of all orbs, then it logically follows that it cannot be the centre of the universe. Therefore Copernicus' theory is not, strictly speaking, heliocentric. It only approximates to the same. This conclusion leads to two interesting consequences. In the first place, Copernicus is contradicting himself when he asserted in the preface to the De Revolutionibus that the use of eccentrics and epicycles by others (by 'others' Copernicus means Ptolemy and his followers) did not yield the desired results. What Copernicus has done is not different from Ptolemy and his predecessor Appolonius (3rd century B. C.) who defined eccentric as a displaced circle with reference to the centre of the earth. We only have to substitute the sun for the earth. The mathematical structure of the circle remains unaffected. In the second place, if the sun is not the exact centre of the universe, then the orbs cannot be the exact circles. Thereby Copernicus has unwittingly deviated from Aristotelian tradition. Now consider this deviation in conjunction with the third postulate. It takes Copernicus to one step short of Kepler who replaced circle by ellipse.

The second postulate is, evidently, Aristotelian. While explaining rectilinear motion Aristotle said that the natural motion of heavy bodies is towards the centre of the earth. The concept of gravity, obviously, was unknown to Aristotle. This is one part of the story. Copernicus thought that the sun is too far from the moon to regard it as the centre of the lunar sphere. Copernicus did not go that far to regard the moon as a satellite. In fact the very concept of satellite was unknown in Copernican age. The combination of these two led to a serious anomaly of which Copernicus was most likely unaware. Can any two planets (here the earth and the moon) have a common orbit? When a scientist is not aware of problem, naturally, he does not think of any answer. Suppose that the earth and the moon have a common orbit. Under what conditions can the earth be the centre of lunar sphere when they have a common orb? The earth could have been the centre of lunar sphere had the path of moon been an epicycle with the earth as the centre. This possibility must be ruled out because the orb of the earth and the moon is the same though Copernicus hinted at this possibility and this he did in rather a half-heated manner. He says that 'the lunar sphere, however, revolves around the centre of the earth and moves with it like an epicycle'. This shows that Copernicus is not sure whether the path of the moon is an epicycle or not. Evidently, Copernicus' postulate does not make sense. What is noteworthy is that in the history of astronomy this inherent problem did not render the concept of the earthcentric lunar sphere useless, but played a pivotal role. It acted as a fulcrum for Newton who propounded the theory that the earth exercised gravitational force on the moon because from the functional point there is no difference between Aristotle's concept of the centre of the earth and Newton's concept of gravity which later covered the whole universe. Both are concerned with the direction of the motion.

Perhaps these were not the consequences which Copernicus could foresee, consequences of his own theory. Kuhn aptly remarks that 'The significance of the De Revolutionibus lies, then, less in what it says than in what it caused others to say'. Further, he continued to remark that the De Revolutionibus has a dual nature….. the tradition from which it derived and…..the tradition which derives from it'. These postulates perfectly justify Kuhn's remark.

The fourth postulate is somewhat closer to Ptolemy's fourth theorem which asserts that the magnitude of the earth is imperceptible. Copernicus slightly alters the theorem. Here the earth's distance from the sun in comparison with the height of the firmament becomes imperceptible. Therefore if Ptolemy and Copernicus are taken together, then in two important respects the earth becomes atomic; magnitude and distance from the sun. This change, in one sense, undermines the significance of the earth. While the first three postulates take Copernicus much closer to the Aristotelian tradition, the fourth postulate takes him away from the same.

The fifth postulate affirms, on the one hand, the motion of the earth and on the other, denies the motion of firmament. While the former may not be a novel idea surely the latter is. This postulate, in effect, turns Aristotelian cosmology completely upside down. Aristotle and Ptolemy regarded the stellar sphere as Primum Mobile, the Prime Mover which is the source of motion of all planets down to the moon while the earth alone remained outside the influence of Primum Mobile. However, in Copernicus this Primum Mobile becomes stationary. If there is any Revolutionary idea in Copernican doctrine, it is the idea of stationary stellar sphere.

Nicole Oresme anticipated the sixth postulate which in turn laid the foundation for relativity of motion. Let us start with the narration of Oresme's account of motion which, in reality, is a criticism of Aristotle's theory. In his own words local motion can be perceived only when one body alters its position relative to another. We shall call one body 'x' and another 'y'. Aristotle says that 'x' (the earth) is stationary and 'y' is mobile. Oresme only suggested that it could be the other way round as well. Not that it was so as a matter of fact. He admits that neither reason (logic) nor faith (scriptural authority) can disprove the rotation of the earth. Nor can it prove the same. According to him it was only a logical possibility. Now imagine the antithesis of Aristotle. What if the earth moves and stellar sphere is stationary? The result remains the same. This suggestion made by Oresme must have provoked Copernicus to frame sixth postulate which is nothing but near repetition of Oresme. Again, the difference between Oresme and Copernicus consists in the application of mathematics by the latter in order to prove the mobility of the earth. Therefore Copernicus concluded that the earth must be having more than one motion. While diurnal motion causes day and night the apparent motion of the sun is caused by real motion of the earth. And in addition to these two motions, Copernicus lists third type of motion which he calls 'declination' referring to the rotation of the poles. Copernicus was convinced that the third type of motion was due to the fact that the axis of the earth's rotation is not parallel to the earth's orb around the sun but is inclined to form 230. This particular postulate has extraordinary significance because it laid the foundation for relativity of motion which acquired phenomenal importance in the history of physics.

The last postulate attempts to explain the retrograde motion of the planets. Copernicus was convinced that none of his predecessors, Ptolemy included, succeeded in satisfactorily explaining the retrograde motion of the planets. He thought that if the earth is regarded as mobile instead of being regarded as static, then it is possible to resolve more effectively the retrograde motion of the planets. Therefore Copernicus preferred new theory to old theory. In the history of astronomy we discover the first ever instance of accepting a theory on the grounds of usefulness, a doctrine which came to be known as Instrumentalism at a later stage. Is there any philosophical significance in preferring one theory to another or is it merely a random choice devoid of any merit? This aspect of Copernicus demands a closer attention to which we shall return later.

After considering these postulates Copernicus makes a very significant statement which runs as follows. ‘Accordingly, lest anybody suppose that, with the Pythagoreans, I have asserted the earth’s motion gratuitously, he will find strong evidence here too in my exposition of the circles’. The upshot of the previous statement is this; though Pythagoreans in antiquity asserted that the earth is neither the centre of the universe nor static they did not attempt to prove either deductively nor did they resort to observation to substantiate their assertion. Given the reputation which Pythagoras enjoyed and his obsession with esoteric religion, it is most unlikely that Copernicus would have acknowledged that any Pythagorean could be regarded as his precursor. What counts is, according to him, the basis for making such a proposal. The competition is between poetic imagination or mythical speculation and rigorous mathematical analysis. In this regard mathematics holds the key which seals the fate of Pythagoreanism.

1.4 SUMMARY OF BOOK ONE

It is profitable to contrast Copernicus with his predecessors. However, before we contrast them let us consider in brief Book One of the De Revolutionibus which consists of twelve sections. First section deals with the shape of the universe. It says that the universe is spherical in shape. There are three possible reasons. First one is that sphere is the most perfect shape. Evidently, Copernicus inherited this possible reason from ancient cosmology. Second possible reason is that it is all-inclusive. Third possible reason is that all planets and stars are spherical in shape. Extension certainly matters. However, third reason is significant. If the content is pressed by the container, then, obviously, the content takes the shape of the latter. Therefore Copernicus is arguing from effect to cause. Third reason is very much analogous to water taking the shape of its container. What is the consequence of the determinate shape of the universe? If we admit that the universe has determinate shape, then we have to admit that the universe is finite. So Copernicus is still in Aristotelian mould. In the second section Copernicus proves the shape of the earth on empirical grounds. He admits that its shape cannot be perceived directly. He considers what one experiences when he travels northward and compares it with what he experiences when he travels southward. The results are different. In the former case the northern vertex of the axis of diurnal motion also moves overhead and therefore the northern stars do not appear to set. In contrast, the southern stars do not seem to rise any more. The result is reversed when the journey is southward. Second reason which he considers is geometrical. It says that the inclinations of the poles have the same ratio with places at equal distances from the poles of the earth everywhere which is possible only if the shape is spherical. Remaining reasons are more or less similar. Hence there is no need to consider them separately. In the third section also the shape of the earth comes up which includes Aristotle's version. Fourth section deals with the motion of the celestial bodies. An important aspect of this section is that in this section Copernicus maintains that the motion of celestial bodies is regular. Therefore for the first time in the history of astronomy the supposed irregular motion of the planets is discarded. In the fifth section there is the first reference to the ancient Greek doctrine which regarded the earth as a planet a doctrine which never gained social acceptability. Copernicus draws support from Philolaus who is supposed to have said that it is a planet because it also moves in a circle and wanders in some other movements. Obviously, the latter applies to its revolution around the sun. The sixth section describes the immensity of the magnitude of the heavens in comparison with the earth. This is a problematic section because Copernicus is not very clear of what he says. Nor is the reason for regarding the heavens as immensely great convincing. The reason which he has advanced is that the boundary circles can bisect the whole celestial sphere if and only if the magnitude of the earth in comparison with the heavens and its distance from the centre are negligible. He does not elaborate further. Instead, he passes on to second evidence where he assumes the horizon as a circle and later he regards the same circle as ecliptic. He does not explicitly say so. It is very clear because in his analysis given straight line is the diameter of both the horizon and the ecliptic. But the problem is compounded when he says 'in this way the horizon always bisects the circle'. The same circle cannot bisect itself. Surely, it cannot be a sound reason at all. Seventh and eighth sections respectively deal with the reasons for ancient philosophers' belief in static earth and the inadequacy of those reasons. The most important reason is that immobility was regarded as divine which means that they ought to have regarded the earth itself as divine. But the real situation is different. Secondly, Copernicus maintains that it is absurd to ascribe movement to the container rather than to the content. It is absurd because it is counter-intuitive. There is no need to consider remaining sections which deal with the order of the orbits of planets and three types of movement of the earth which have already been mentioned. This is the essence of Book One written for men ignorant of mathematics. Perhaps the attempt misfired. The hazy nature of some sections, particularly, the sixth section might have earned him wrath of his detractors.

1.5 SOLUTION TO RETROGRADE MOTION

Copernicus claims, rather, rightly that the replacement of earth by the sun satisfactorily explains the problem of retrograde motion. This is an instance of trial-and-error method, may be the first instance recorded in the history of science. It is useful to begin with an example to know how he solved the problem. Assume that two trains A and B are stationary waiting to move in opposite directions. Also, assume that one of them moves. Then there are two possibilities.

a) A moves but we think that B is moving.

b) B moves but we think that A is moving.

In both the cases visual impressions are same. The difference consists only in our thought. Therefore no matter what we think, the visual impressions do not change. Let A stand for the earth and B stand for the sun. The rest can be explained easily. Philosophers in antiquity believed (b) whereas Copernicus believed (a). Both of them recorded same observational data. Shift from (a) to (b) does not make any change in observational data. Therefore Copernicus thought that this shift must be permissible provided other factors are favourable. Suppose that the earth does not have one motion, but more than one. The earth has three types of motion and all three are simultaneous. The result is that the inhabitants of the earth experience complex visual impressions. The supposed irregular motion of the planets is one such impression. Splitting these impressions, Copernicus said that the apparent diurnal motion of the sun and other planets is caused by the rotation of the earth on its own axis. On the other hand, its revolution along with other planets around the sun explained the retrograde motion of the planets. The principle is very simple; smaller the distance between the sun and the planet, smaller the orbit and greater the distance, bigger the orbit. Further, as the distance increases the orbital velocity decreases. Consequently, the positions of the planets vary from time to time. Obviously, when two trains move in the same direction with different velocities the slower train appears to recede. In reality it is not so. The same explanation holds good for planetary motion. This explanation reveals an important element. Copernicus did not require any new set of observations. He achieved his aim with the same set of data. Revolution consists in demonstrating that the retrograde motion is only apparent which can be resolved by making the earth mobile. It is not just change in the centre which matters.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Name the Neo-Platonists who influenced Copernicus.

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1.6 TELEOLOGY VS. MECHANICAL PHILOSOPHY

The foregoing discussion brings to the fore the fundamental change in the outlook of Renaissance European, a change which Ptolemy also could not bring about for obvious reasons. The earth-centric theory which ruled the roost from antiquity down to the end of the Middle ages brought with it Man-centric view, a natural corollary of the earth- centric view. Teleological explanation is the direct outcome of Man-centric view. The very idea of creation is at the root of teleology. Again, teleological approach is evident in the development of astrology as a sort of byproduct of astronomy. The dislocation of the earth's position demolished all such nonastronomical developments at one stroke. If there is no purpose anywhere in the universe, then the universe is governed by rigid laws, which in no way reflects the needs of man. And these laws alone are capable of satisfactorily explaining what happens and what does not happen in the universe. Initially, we can understand mechanical philosophy of the universe as the kind of explanation which makes the universe Man-independent. It is true that Copernicus does not mention this dichotomy in the De Revolutionibus. Perhaps it did not occur at all to him that his doctrine had the potential to generate this controversy. As Kuhn has remarked it provoked revolutionary ideas in other works though the work as such did not contain those ideas on a large scale. It laid the foundation for radical change in our world-view. This is the greatest contribution of Copernicus to the growth of knowledge.

1.7 COPERNICAN SYSTEM VS. NON-COPERNICAN SYSTEMS

Before distinguishing himself from Pythagoreans, Copernicus asserted that only knowledge of mathematics convinces that his system 'excellently…. agrees with observations'. His argument makes it very clear that astronomy is no longer speculative but essentially mathematical. Against this background, the position of Copernicus must be evaluated. Disregarding what Copernicus said on behalf of his doctrine one has to admit that conceptually moving earth is not a novel concept. Therefore what constitutes Copernican Revolution lies elsewhere. Possibly, Copernicus was aware of its relevance. This awareness may explain why, with the exclusion of the introductory part, the De Revolutionibus is entirely mathematical. This change in the structure points to the need to attempt at proof and also evolve an acceptable method of proof. Therefore it is not mere shift in the position of the earth but it is the structural change in the nature of astronomy caused by the application of mathematics and more importantly change in the attitude with which Copernicus approached astronomy that constitutes Revolution. The latter is more significant because Ptolemy also is a mathematician but his approach was not found to be satisfactory by Copernicus because he believed that Ptolemy's analysis did not bring about the required structural change in astronomy. A satisfactory explanation of planetary motion alone could effect the required change which Ptolemy's mathematics could not achieve.

We shall return to the question raised earlier. Certain historical perspective is required to tackle this question. Andreas Osiander, a theologian, added a note in the form of introduction to the De Revolutionibus. If Kuhn is to be believed, Osiander did it without the permission from Copernicus and Copernicus could not reply because he did not survive for long after the publication of the De Revolutionibus. In this preface Osiander raised certain key philosophical issues. He says that ' it is the job of the astronomer to use painstaking and skilled observation in gathering together the history of the celestial movements and then…….construct whatever causes or hypotheses he pleases such that……those same movements can be calculated from the principles of geometry for the past and for the future also'. Osiander is perhaps the first person to suggest the application of inductive method to astronomy. He agrees that these hypotheses need not necessarily be true. Nor can they be probably true. It is sufficient if any hypothesis provides a calculus which fits into these observations. Further, he observes that a particular astronomical phenomenon may generate two or more than two hypotheses. Considering the context in which Osiander made these observations it becomes clear that his observations implied that plurality of hypotheses characterize scientific approach. Is there any criterion to choose any one hypothesis from among several hypotheses? Osiander suggested that the scientist prefers the one which is easiest to grasp. This is what is understood today as simplicity. A simple theory is preferable to a complex theory. If Copernican theory is simpler than Ptolemaic theory, then the former is preferable to the latter. This view, which found support in some contemporary philosophers of science, took its birth in Osiander's suggestion. At this stage it is necessary to make distinction between psychological simplicity and logical simplicity a distinction to which Norwood Hanson has referred in The Encyclopedia of Philosophy (Vol. I). On most of the occasions, what is logically simple is not psychologically simple and vice versa. Copernican simplicity is an example for logical simplicity while Aristotelian or Ptolemaic simplicity is an example for psychological simplicity. Against this background, we should try to understand the aim of Copernicus. He argued in his preface addressed to the Pope Paul III that 'mathematicians are so unsure of the movements of the Sun and Moon that they cannot even explain or observe the constant length of the seasonal year'. Who are these mathematicians? Copernicus does not name any mathematician or philosopher in his preface. But the references, which he has made, make the point clear. Reference to concentric circles indicts Aristotle; reference to eccentrics and epicycles refutes Ptolemy and reference to equant others. Therefore when he accused mathematicians in general and Ptolemy in particular of creating a monster, Copernicus, in reality, referred to these constructions only. Why was Copernicus critical of Ptolemaic astronomy? Copernicus was not against epicycle as such, but he was against the number of epicycles which made his system a complex system. In this context, it is interesting to consider Hanson's reference to numerical aspect. He begins with comparing 83 epicycles accepted by Ptolemaic system with 17 epicycles required by Copernican system. According to him this difference is misleading because Ptolemaic system did not consider, according to him, planets collectively. On the contrary, the system considers all planets individually. According to his own admission, if any one planet is considered singly no more than 4 or 5 epicycles are sufficient. The sun, though a planet, is static. Therefore there is no epicycle associated with the sun. After its exclusion we are still left with seven planets. If Hanson's argument is accepted, then we still require 35 epicycles, more than twice the number of epicycles admissible in Copernican system. Even then the latter is simpler than Ptolemaic system. Hanson concludes that 'the number of epicycles in any calculation would tend to be, not less, than that required in a corresponding Ptolemaic problem. This simple calculation proves that Hanson's argument breaks down on this count. However, he admits that Copernican system is simpler as a 'system' because it requires only those concepts which are deductively interlocked. When the concepts are interlocked in the manner mentioned above, the number becomes irrelevant. However, what is really significant is that it did not occur to him that the concept of epicycle itself was a flawed one and that planetary motion was, really explicable without making use of this concept. Next he attributes their failure to the admissions of principles 'something foreign and wholly irrelevant'- principles entirely different from original hypotheses. Philosophers of science today call such additions ad hoc hypotheses. Copernicus did not use precisely this word, but he, evidently, meant it. Copernicus was convinced that his explanation succeeds where his predecessors' explanation fails. On this ground, Copernicus argues that his theory is preferable to the previously held theory or theories. This approach to the status of theories is known as instrumentalism.

These are the grounds on which Copernicus rejected a good part of Aristotelian and Ptolemaic theories. This rejection paves the way for the resurrection of Heraclides and others. And precisely for this reason Kuhn believes that the revolutionary element in Copernican system consists not in overthrowing philosophical and speculative elements but in applying a new system of mathematical principles which, ultimately resulted in startling revelations for which Copernican system is known for.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. How did Copernicus solve the problem of planetary motion?

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1.8 LET US SUM UP

Copernicus is the first astronomer of reputation after Ptolemy. He is more Aristotelian than many medieval philosophers. Copernicus was dissatisfied with Ptolemy and his followers. He wanted to rewrite astronomy. His main work De Revolutionibus regards the sun and moon as planets only. He did not give up the idea of epicycle. He only reduced the number because he thought that Ptolemy accepted too many epicycles. In this book he advocates to switch from the earth-centric theory to the sun-centric theory. Copernicus is credited with abandoning teleology in the explanation of the universe.

1.9 KEY WORDS

Velocity: Velocity and speed are not identical though both of them describe the quantity of displacement. The difference between the two is that when the direction changes velocity changes but not speed. Secondly velocity is always calculated per second only.

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1.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. Philolous, Ecphantus, Marsilio Ficino and Nicholas influenced Copernicus.

Check Your Progress II

1. Copernicus claims that the replacement of earth by the sun satisfactorily explains the problem of retrograde motion. Copernicus said that the apparent diurnal motion of the sun and other planets is caused by the rotation of the earth on its own axis. Its revolution along with other planets around the sun explained the retrograde motion of the planets.

UNIT 2 PHILOSOPHY OF NATURE OF THE COPERNICAN THINKERS

Contents

2.0 OBJECTIVES

There are two main objectives of this unit. In the first place, the intention is to apprise the reader of the developments which took place in Europe after the publication of the De Revolutionibus. In order to help one to understand the consequences of Copernicus' theory, we will analyse, initially, the reaction of some astronomers represented by Tycho Brahe who were not willing to concede the central thesis of the De Revolutionibus though they knew that they were not in a position to abandon the Copernican theory altogether. This will help you to understand the background of stiff resistance which Copernicanism met with initially. In the second place in this unit, it is proposed to make one familiar with the contributions of Kepler and Galileo in discovering evidences in favour of Copernicanism, evidences which Copernicus himself did not foresee.

After you are thorough with this unit you must be in a position to know why Copernicanism caused revolt in European cultural milieu resulting in clear vertical division in the sixteenth century European society. It is this understanding which should enable you to assess the contribution of Copernicus to the evolution of knowledge in general and science in particular.

2.1 INTRODUCTION

Copernicus' doctrine heralded a new era in the history of astronomy for wrong reasons. His adversaries believed that he turned the system topsy-turvy for the simple reason that in his system geostatic universe became heliostatic universe. They ignored the fact that Copernicus was not the first to suggest the latter theory. There are two possible reasons for this indifference. Either they were ignorant of the history of cosmology or what was suggested in distant past was irrelevant to them. Therefore this Copernican-switch singularly generated ignominious acrimony outside astronomical circle. First, violation of common sense by his theory made him the target of ridicule and then his assertions contrary to the Bible was regarded as a revolt against the Scripture. The difference between these two is not in kind but only in degree and this difference mattered most which alone can explain the intensity of hostility which Copernicanism invited. We shall postpone the discussion of the latter to the next section and restrict ourselves to the former and certain limitations of Copernicanism.

Reference to anti- common sense element in Copernicanism in itself is not really significant because it was spearheaded largely by poets. This aspect deserves mention because it reveals a new dimension to the controversy built around Copernicanism. It is patently wrong to conclude that Copernicanism was attacked only for its atheistic characteristics. Kuhn records that atheists did not remain far behind conservatives in attacking Copernicanism. One such atheist, according to Kuhn, who denounced Copernicanism is a German political thinker by name Jean Bodin. The battle was not just between theists and atheists. It is also centered on the limits of common sense and the differences between common sense and science. Since science, as we understand today, was itself in its prenatal state at this stage, it is certainly anachronistic and preposterous to attribute ignorance of the nature of science to the critics of Copernicanism.

Copernicus did not base his argument on any new observations though he argued for the physical reality of the earth's orbit. He depended mainly on the observational data of his predecessors. Copernican theory suffered from want of reliable observational evidences because the data in his possession were collected from a different theoretical background. Further, it should be noted that any observational datum is shallow if it has nothing to do with planetary position. This issue enjoys critical importance because before we deal with planetary positions we must be in a position to distinguish planets from what are not planets. Here we encounter first major hurdle. Copernicus fell in line with Ptolemy and others in regarding the sun and the moon as planets. Copernicus did not hesitate to regard the sun as a planet despite the fact that it became stationary in his system. Should the moon be regarded as a planet or a satellite? The very concept of satellite was unknown then. Therefore the moon can only be regarded as a planet. What happens to the accuracy of calculation of planetary position if what is not a planet is reckoned as a planet? What is still worse according to Kuhn is that Copernicus relied upon bad data on many occasions. Copernicus was more concerned with the accuracy of mathematical part than with observational part. Therefore Copernican system is not more accurate than Ptolemaic system. This is a serious problem in Copernican system which was not addressed by Copernicus at all.

2.2 TYCHO BRAHE'S COUNTER REVOLT

Brahe's (1546-1601) position in the history of astronomy is unique for more than one reason. Brahe was born three years after the death of Copernicus. He grew up in a turbulent age which witnessed intense ideological battle between Copernicans and anti-Copernicans which, indeed, acquired violent dimension after the death of Brahe. If it is possible to conceive fusion of Copernicus and Brahe in an imaginary astronomer, then this imaginary person makes an ideal astronomer. It is, therefore, profitable to contrast Brahe with his immediate predecessor Copernicus. The difference between them is somewhat similar to the difference between Plato and Aristotle. Aristotle began with the mission to correct Plato but ended up in Plato's philosophy because he could not go beyond form and matter. Something similar happened here also. Copernicus is essentially a concept-builder. He relied upon his predecessors for observational data while he was unhappy with their mathematics and therefore embarked upon error-free mathematics which was essential to calculate planetary movement as well as the positions of planets. In other words, Copernicus is basically a theoretician with the background of mathematics. On the other hand, Brahe is the first astronomer of pre-telescope era known for meticulous observation and highly accurate collection of data. Brahe hardly theorized neither prior to nor consequent to observation and collection of data. Brahe accepted Copernicus' mathematics but rejected his observational data. Secondly, Copernicus switched to heliostatic theory because it alone could protect symmetry and elegance in the structure of universe only because it could do away with equant and retrograde motion whereas for Brahe symmetry or elegance was secondary. What was of foremost importance was factual observation in place of incorrect observation. This vital difference reminds us of Plato's obsession with mathematics and Aristotle's fascination for biology. In the third place, Brahe is anti-Copernican of preeminence but only succeeded in fuelling Copernicanism through his pupil Kepler. This is what precisely Aristotle also achieved.

Brahe may or may not be a philosopher. That is not very significant. What is significant is that in Brahe we discern a vital link between Copernicus and Kepler. Roughly Kepler approximates to our ideal astronomer hypothesized above. Against this backdrop, we must try to evaluate the contribution of Brahe to the evolution of astronomy.

Brahe was fortunate to possess sophisticated instruments –sophisticated for his age- to carry out observations. In addition to his access to such instruments two hallmarks of Brahe's personality contributed to the development of astronomy. Brahe is known for perseverance and order in his observation. His method of observing planets was rather unique. He did not wait for the planet to occupy a certain position. He made it a point to observe planet throughout its course every night. Perhaps he is the first astronomer to set up a well-equipped observatory. As a result the observational data of planetary positions became very huge and also most reliable. His studies are philosophically important because they contributed to radical changes in the conception of the universe. The rest of this section is devoted to an exposition of Brahe's contribution. Since his contributions are varied in variety, it is ideal to list them first in the interest of clarity.

a) Copernican and Ptolemaic systems were ingeniously crossed by Brahe to evolve a new system.
b) In 1572 he observed a new star; and in 1577, 1580, 1585, 1590, 1593 and 1596 he observed comets.
c) He deviated from established theory which prescribed circular orbit to heavenly bodies to ellipse- like orbit for comets.
d) He gave an accurate description of perturbations in the motion of the moon.
e) He calculated the position of nearly one thousand stars with accurately measured values of longitude and latitude.

First two contributions are of strategic importance. Hence they deserve greater attention.

Brahe was a devout Christian. Naturally, he could not accept heliostatic theory. Indeed, in the strict sense of the term Brahe cannot be regarded as a Copernican. What is still worse, Brahe's entry into the field had the effect of negative catalysis on the general acceptance of Copernicanism. Paradoxically, he had a decisive role to play in the recognition of Copernicanism. His rejection of Copernicanism was partial in the sense that he had no problems with the mathematical part of his doctrine. He thought that if only he could do away with the suncentric theory Copernicanism could be allowed. Nor did he wholly accept Aristotle and Ptolemy. Therefore he retained the geocentric theory partially by regarding the sun and the moon only revolving round the earth and regarding the remaining planets as revolving round the sun. In this system the earth continues to remain at the centre of the universe. But planets with the sun as the centre of their orbits were shifted away from the centre of the universe which surely appeared odd. Fig. 1 indicates the position of the earth and planets.

Westward diurnal motion

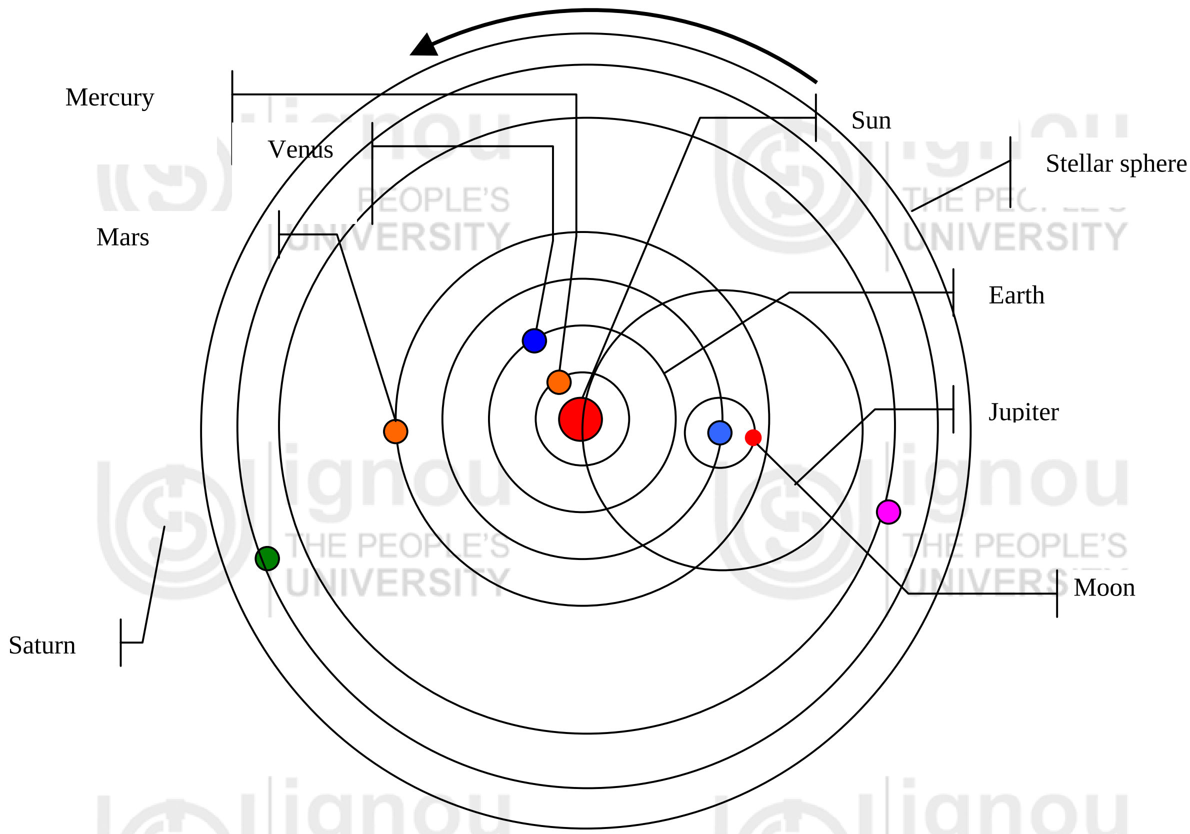

Fig 1.

Brahe did not reject the motion of the earth simply because it was against the Scripture. He provided incontrovertible reason to refute the mobility of the earth. Suppose that the earth moves. Also suppose that there is a body situated between the moving earth and the stellar sphere. An observer on the earth 'sees' the body at different positions due to the motion of the earth because along with the earth the observer also would have moved. Consider these two positions of observer and apparent positions of the body against the stellar background. It results in the formation of angle the magnitude of which varies with the orbital velocity of the earth and the distance between the earth and the body. This is what is called diurnal parallax because this particular parallax occurs due to the orbital motion of the earth. Brahe did not notice this parallax. Brahe gives one more hypothetical explanation. Suppose that the earth rotates westward. If a cannon fires the ball towards the west, then it imparts a greater range to the ball than when it fires the ball eastward because in the former case the earth advances towards the ball, whereas in the latter case the earth recedes from the ball. While replying to the objection that the ball participates in the natural motion of the earth, Brahe argued that it is impossible that the ball participates in the natural motion of the earth because natural motion and any other motion cannot coexist without affecting one another. Therefore he concluded that the earth does not revolve. On this count, the diurnal motion of the earth also is rejected.

However, the refutation of the motion of the earth does not entitle Brahe to become an Aristotelian. In fact, Brahe was more effective than Copernicus in refuting Aristotelianism. An essential element in Aristotle's cosmology is 'immutability of Heavens.' Copernicus did not try to disprove this primary theory. A theory is always disproved by observation. Brahe's observed a new star in the year 1572 which revealed startling details about the stellar sphere. The star was as bright as Venus in the beginning. Gradually it started fading. And after sixteen months it disappeared. The observation of this particular phenomenon had far-reaching consequence. Evidently, this star belongs to superlunary region because had it been a member of sublunary world, its observation should have involved parallax error owing to proximity. However, there was no observable parallax error. Further, it did not partake of planetary motion. Therefore Brahe concluded without an iota of doubt that the new body must be a star. Brahe proceeded further to calculate the exact magnitude of the star. According to his calculation the star was three hundred times bigger than the globe (the earth). Brahe argued that it would be impossible to accommodate a body of this dimension within sublunary region. Therefore it must belong to Heaven. It was this argument which makes him thoroughly non-Aristotelian. This transient phenomenon disproved the theory of immutability of Heavens. This was further reinforced by a series of comets which were visible between 1577 and 1596.

Third issue occupies our attention in the next section and the last two issues are not significant for our purpose. The outcome of Brahe's observations is relevant to us. Brahe's enormous collection of data was passed on to Kepler who was his assistant. It is natural to expect that Brahe, with the help of Kepler, should have superseded Copernicus. But it did not happen. The seventeenth century astronomers led by Kepler chose to accept Coprnicanism at the expense of the advocates of geostatic theory. They ingeniously arrived at the synthesis of Brahe's observations and Copernicus' world-view and the result is what Kuhn calls 'conceptual upheaval'. The absence of either of them would have rendered Kepler stranded and take-off of astronomy would have been surely delayed.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1 Mention Brahe's strategic discoveries.

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2.3 KEPLER'S THEORY OF PLANETARY MOTION

Johannes Kepler (1571-1630) a German astronomer, who can be rightly regarded as the founder of modern astronomy in the real sense of the word, started from where Copernicus stopped. Two distinct features mark Kepler's doctrine. In the first place, teleological explanation was replaced by mechanical explanation of the phenomena. This change provided the required orientation to develop science in the sense in which it is understood today. Further, this new orientation is also responsible for the birth of Physics as an experimental science. In the second place, uniformity of planetary motion was shown to be wrong and was replaced by variable planetary motion.

Though Kepler subscribed to Copernicus' doctrine, he was not satisfied with the role assigned to the sun and the earth. It was not sufficient to merely regard the sun as the centre of the system. Kepler was convinced that the sun has much greater role to play and conversely, the prominence enjoyed by the earth was taken away by Kepler. Strangely, Kepler was driven to this position not by any observational or mathematical study. On the contrary, Kepler's argument derives support from his religious conviction. Kepler was convinced that the sun is not merely the source of light. It is something which sustains the universe by being the prime source of motion an aspect which has strategic position in Kepler's scheme. Obviously, Christianity is not the source of inspiration because there is nothing in Christianity to uphold the dignity or divinity of the sun. Kepler must have been under the spell of Neo-Platonism as if the influence of Pythagorean mysticism and Platonism is inadequate. As a result in Kepler we trace a complex structure made up of Pythagorean mysticism, Platonic mathematics, experimental physics and observational astronomy.

In 1596 Kepler's first work, a very important one, *Mysterium Cosmographicum* (The Mystery of Cosmology) was published. In this work he gives a lengthy defence of Copernicus. This is one part. There is another part which is Platonic in spirit. A defence of Copernicus is restricted to the defence of heliostatic theory for the reasons mentioned above. Kepler makes use of Platonism to defend Copernicus. Defence is not uncritical. It is defence laced with suitable corrections. In his second major work, *Astronomia Nova* (A New Astronomy) published in 1609 he proceeds to make corrections to heliostatic theory by assigning the place to the sun which it deserves. This particular amendment, subsequently, developed into what is, today, understood as Physics. Of the three laws of planetary motion for which Kepler is well-known the first two laws are discussed in this work while the third law, which is characterized by Pythagorean orientation, is discussed in his third work *Harmonice Mundi* (The Harmony of the World) published nearly ten years later. The very title indicates Kepler's obsession with harmony which brings with it number too, since in Pythagorean tradition number and harmony go together. So Pythagoras is reborn. With this in Kepler Pythagoras- Plato cycle is complete.

Plato speaks of what are called regular solids. A regular solid is defined as a figure which satisfies a definite set of geometrical properties. Plato was aware of four such solids which correspond to first four elements recognized by ancient Greeks, viz. earth, water, air and fire. Subsequently, fifth sold was discovered which corresponds to fifth element, aether. These five solids and their corresponding geometric figures are as follows;

Solid Geometric shape

1 Tetrahedron	Four faces, each an equilateral triangle
2 Cube	Six faces, each a square
3 Octahedron	Eight faces, each an equilateral triangle
4 Dodecahedron	Twelve faces each an equilateral pentagon
5 Icosahedron	Twenty faces, each an equilateral triangle

[Note: An equilateral pentagon has five equal sides and five equal angles]

Now Pythagorean-Platonic element becomes obvious. Kepler regarded the sun as a star contrary to hitherto accepted doctrine. So including the earth we have six planets and five spheres are required to separate these six planets. Five solids correspond to five solids. Kepler did not think this correspondence to be a coincidence. On the contrary, Kepler thought that it points to brilliant mathematical computation by God. What Kepler is trying to do is to fit fantasy into fact. In such a situation justification is a distant dream. As though this association is infallible and indubitable Kepler proceeded straightaway to argue that each solid is circumscribed by one sphere while another sphere is inscribed in that solid. The scheme is so well-laid out that it is simply unimaginable to attain even with the aid of the highest level of technical know-how. For the sake of simplicity let us illustrate the scheme as follows:

1 C 2 T 3 D

Sphere of Saturn- Cube- Sphere of Jupiter- Tetrahedron- Sphere of Mars- Dodecahedron-

4 I 5 O 6

Sphere of Earth- Icosahedron- Sphere of Venus- Octahedron- Sphere of Mercury

The pattern is as follows: 1 circumscribes C and 2 is inscribed in it. Again, 2 circumscribes T and 3 is inscribed in it. Now 3 circumscribes D and 4 is inscribed in it. Next 4 circumscribes I and 5 is inscribed in it. Lastly, 5 circumscribes O and 6 is inscribed in it. The point to be noted is that there is no correlation between the number of sides and the diameter of the planets. Instead the correlation is between the size of the orbit and sphere-solid relation. Again, Kepler takes the whole thing for granted. It only speaks of his mystic tendency which made inroads into his science. What is surprising is that Brahe accepted him as his assistant after the publication of this book. Equally surprising is the fact that Kepler valued more this sphere-solid relation than his now famous three laws of planetary motion.

However, the significant contribution of Kepler which heralded a new era in astronomy comes from some other source. A major problem encountered by Brahe was the motion of Mars which, ultimately, was solved by Kepler. The problem was further compounded by its proximity with the earth which itself is in motion. For an observer of the motion of Mars the earth is the frame of reference. Therefore it was absolutely necessary to calculate the orbital velocity of the earth before resolving the problem of Martian motion. This should have been a formidable one for Kepler to resolve. Fortunately, Brahe's exhaustive collection of data came to Kepler's rescue, but not without prolonged and arduous trial-and-error method. Kepler, initially, accepted circular orbit of planets and tried different combinations of eccentrics, epicycles and equants. He did not disregard any possibility. It is said that he tested in all seventy different combinations. What was demanded by Kepler was total conformity between observation and calculation. In other words, Kepler aimed at accuracy. Kepler was not ready to settle down for anything less than this. In this respect there is a discernible and marked difference between Kepler and Copernicus or Ptolemy, difference in temperament. In Copernican or Ptolemaic system the difference between observed position of Mars and its position arrived at on theoretical considerations was of the order of 10 minute arc. Copernicus could not make any progress in observation over Ptolemy, his immediate predecessor, because he did not take observational aspect in astronomy seriously at all. Since Kepler inherited Tychonic system known for immaculate observational data, he improved upon the result to the extent of 2 minutes. He aimed at further reducing the error of 8 minutes.

At this stage it occurred to him that the very axiom of circular motion of planets (for Europeans circular motion of planets was never a hypothesis to test) must be false. If the planet does not traverse in a circular orbit, he thought that it may traverse in an orbit which is close to circle. It is likely that Kepler hit upon this hypothesis after Brahe's discovery of the ellipse-like path of comets (to Kepler's fortune Brahe was not aware of comets traversing in parabola). If one category of celestial bodies can follow a certain path why not other celestial bodies follow the same path? But for the problems posed by Mars, Kepler would not possibly give up his belief in circular motion. Given his obsession with Platonism, this is most unlikely.

Ellipse was not a curve unknown to Greeks. Apollonius, (3rd century B. C.) not only gave the properties of ellipse, but also he showed how one can get ellipse, parabola, hyperbola and circle with the help of a cone. The ancient astronomers could not go beyond circle. Only Kepler could discover that any other conic section like ellipse can occur in nature if circle can occur in nature.

2.4 LAWS OF PLANETARY MOTION

In 1609 Kepler's 'On the Motion of Mars' was published which included the results of his study of the motion of Mars. The results of this particular study paved the way for the formulation of laws of planetary motion. The discovery of these laws proved to be an epoch- making discovery. Since the chronology of these laws are mentioned earlier, without repeating the same we shall proceed to their brief discussion.

1st Law: Every planet goes round the sun in an elliptic orbit with the sun located in one of its foci.

2nd Law: The orbital velocity of each varies in such a manner that a line joining the planet to the sun sweeps through equal areas of the ellipse in equal intervals of time.

3rd Law: The ratio between the squares of the periods of revolution of any two planets around the sun and the cubes of their mean distances from the sun is a constant. It only means that period of revolution is directly proportional to the mean distance of a planet from the sun.

Why do we speak of two foci with respect to ellipse when we speak of only one centre with respect to circle? The answer consists in the way in which draw these figures. It is a well known fact that one point, which is equidistant from any part of curve, is adequate to draw a circle. But we need two points to draw an ellipse and these two points are the foci of the given ellipse. There is a method of drawing ellipse which makes this point clear.

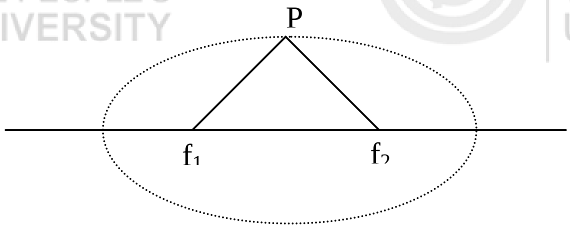


Fig. 2

Fix two pins f_1 and F_2 at some distance. Connect these two pins with a slack thread. Push the thread forward with, say, a pencil P so that the thread is held firm and tight. The scenario is somewhat like this. Join two pins with an imaginary straight line. This straight line forms the base, the tip of the pencil forms vertex and two segments of thread on either side of the pencil form two sides of a triangle. In this state move the pencil without disturbing the stiffness of the thread and the curve traced by the moving pencil is ellipse. Now replace the pencil with planet. The orbit of the planet coincides with the diagram traced by the pencil. Automatically, the sun replaces one of the pins (the second pin is rendered superfluous) and occupies one of the foci.

The significance of the first law consists in the elimination of circle which led to an important development. Astronomers no longer could maintain that at the planet is always at equal distance from the sun. This admission, subsequently, resulted in the discovery of variable orbital velocity. Interestingly, Kepler did not sacrifice symmetry even when circle could not hold fort. It is easy to show that ellipse is as symmetric as the circle.

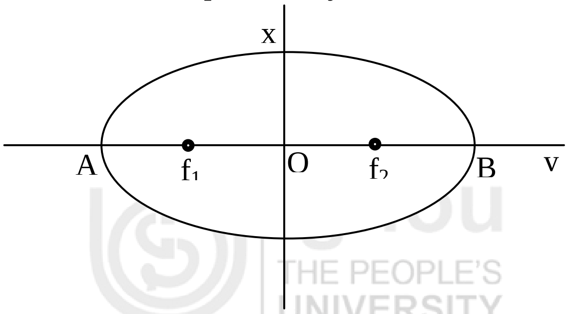


Fig. 3

The extension of F_1 F_2 is called Major Axis and XY is called Minor Axis. When XY bisects f_1 f_2 at O, four quadrants, viz. AXO, XBO, OBY and AOY are formed. The area of each quadrant is equal. A and B are called *Perihelion* and *Aphelion* respectively. The position closest to the sun is called perihelion and the position farthest from the sun is called Aphelion. The recognition of these positions plays a vital role in the development of astronomy. The formulation of second law is a direct fall-out of this particular recognition. The following diagram illustrates this law.

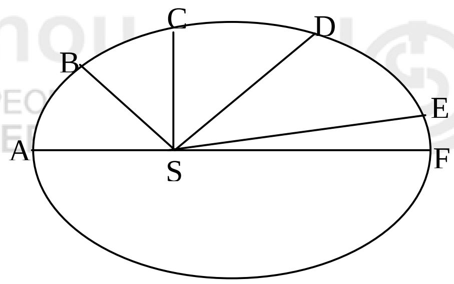


Fig: 4

For the sake of illustration consider three segments SAB, SCD and SEF. It is obvious that the stretch SEF covered on the orbit is the shortest whereas the stretch SAB is the longest. However, in all the cases the time taken for the displacement remains the same. It plainly shows that when the planet traverses SEF, it is slowest whereas when it traverses SAB it is fastest. Kepler arrived at this revolutionary result on the basis of mere observation. Hence the second law dislodged uniform orbital velocity of all planets. One advantage of variable orbital velocity is that all ad hoc mathematical constructions like equants, eccentrics, etc. disappeared from the scene. The explanation became simple and elegant. Again, Neo-Platonism makes its presence felt in Kepler.

The third law is most interesting. Kepler believed that Cosmic Harmony is manifest in this law. He derives harmony from strange numerical jugglery. First let us know what the third law is all about. Let T_1 and T_2 be the periods of revolution of the planets P_1 and P_2. Let S_1 and S_2 be the mean distances of the planets (mean or average distance of the earth from the sun is expressed in terms of what is called astronomical units and it is taken as 1). Then the third law is expressed as follows.

$$\frac{T^2}{S^3} = K$$

Kepler showed that the numerator equals denominator. Therefore if we take the reciprocal value of L.H.S., then also we get K only).

The following table simplifies our task.

	Mercury	Venus	Earth	Mars	Jupiter	Saturn
Period of revolution –T (in years)	0.24	0.615	1	1.88	11.86	29.457
Mean distance from the sun –S	0.387	0.723	1	1.524	5.203	9.539

Where can we locate in this exercise the so-called celestial harmony? Being a true Pythagorean, Kepler valued number relation most. It was equation between these two quantities which constituted celestial harmony. Secondly, the pattern in which orbital velocity varied was another factor. Kepler discovered harmony in these factors. Kepler followed trial-and- error method to discover this relation. It is obvious that $T=S$. Nor can we say that $T^2=S^2$. For illustration consider any two values.

0.242 = 0.0576; 0.3872 = 0.1439 (approx)

Second value (0.0576) is more than twice the first value (0.1439). Obviously, there is no equation. Similarly, it can be determined easily that there is no equation between T^3 & S^3. However, we derive the desired result when we take T^2 & S^3. We shall tabulate the results.

	Mercury	Venus	Earth	Mars	Jupiter	Saturn
T^2	0.058	0.378	1	3.53	141	867.7
S^3	0.058	0.378	1	3.54	141	867.9

The direct relation between orbital period and distance has two important consequences. One is that speed is determined by distance of the planet from the sun. Second is that the sun is the prime source of planetary motion. The second consequence completely altered the course of science in the days to come. Both *Mysterium Cosmographicum* and *Astronomia Nova* regarded the sun as the source. But there is fundamental difference in the essence of these two works separated by twenty-five years. The earlier work considered the sun *Anima Motrix* which means moving spirit. It shows that Kepler could not completely wriggle out of animated view of the universe. But that was only the beginning. Twenty-five years of labour taught him the axiom of science. In the later work *anima motrix* was replaced by *Vis Motrix* which means moving force.

The sun, at this stage, is regarded as force devoid of any life and hence just mechanical force. In this manner Kepler introduced to physics not just the concept of force but the concept of mechanical force. It remains to be seen how it works.

Kepler says in *Astronomia Nova* that moving force is somewhat like light. Light rays may seem to be carriers of motion. But in reality it is not so because if it were to be so, Kepler admitted, then in darkness no motion would be possible. Therefore he distinguishes light rays from moving force. The latter does not spread out in space unlike the former. In his own words 'it is aimed at substance….planet-body'. Then there must be some bond between the source and target. So in this manner the sun occupies centre stage in mechanical interpretation of the universe.

2.5 GALILEO'S THEORY OF UNIVERSE

Galileo Galilei (1564 - 1642), an Italian astronomer, succeeded in changing the world-view, though not during his life time, after his death through his influence on the succeeding generation of scientists. Galileo chose two routes to achieve this enviable task; one through putting telescope into use to study the sky and another through his theory of motion. The second component will occupy our attention in the next unit. Presently, we will confine ourselves to the first component.

In the year 1609, Galileo did something unheard of. He came to know that by combining two lenses in a certain manner it is possible to improve upon the quality of distant vision. He succeeded in producing primitive telescope only to focus it skywards. What is not clear is what made him do so. Nor is it necessary to know it. What matters is the result of his action. Since the bounds of vision were significantly stretched, Galileo could not only observe the known celestial bodies more accurately, but also he observed a large number of stars. This in itself is not really relevant. These discoveries rendered Aristotle's arguments questionable if not untenable. It is profitable to list the discoveries and then proceed to assess their role destabilizing classical cosmology. Further, it also helps us to understand the way in which science grows.

1 craters on the moon and sun spots

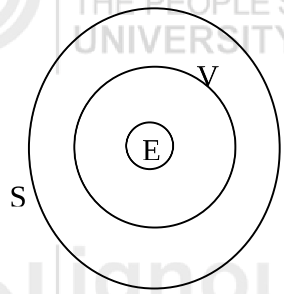
2 four satellites of Jupiter

3 the phases of Venus

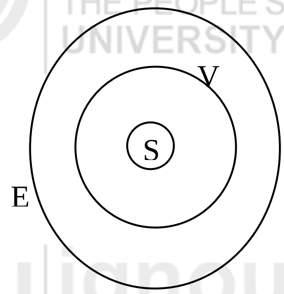
However, there was one paradox which Galileo's telescope could not solve, i. e., stellar paradox. It is desirable to start with the last. This paradox can be put in nutshell in this manner. Since the earth travels round the sun, let us take the earth as the frame of reference. When the observer moves from one end of the horizon to the other end, there must be a shift in the positions of fixed stars. Galileo's telescope did not reveal this shift. The reason is simple. Since the stellar universe is very far from the earth, only a sophisticated telescope could succeed in revealing this shift. Evidently, Galileo's telescope could not help in this regard. Hence it remained unsolved. However, first two discoveries had decisive role to play. Craters on the moon and sun spots demolished the myth that celestial bodies are immutable. Brahe's discoveries of a star in 1572 and a comet in 1577 already had cast doubts on the tenability of immutability. Galileo's discoveries further reinforced the doubt. But it could not convincingly disprove the theory of immutability. Same is the case with the discovery of the moons of Jupiter. However, the phases of Venus offered new evidence to defend Copernicanism.

This aspect will bring us to an important aspect of philosophy of science. Of course, this is related not to astronomy, but to the manner in which science evolves. It is not possible to evaluate Aristotelian and Copernican theories unless we are clear about this crucial aspect. Here there are two rival theories competing for recognition; Aristotelianism and Copernicanism. As on that day their logical status remained the same. That is, neither proof nor refutation was achieved. What should be the decision of scientist with respect to such theories in such a situation? Scientist can only tentatively accept a theory which enjoys better support than other theory or theories. This itself marks progress in science.

This clarification helps us to place Galileo in a different perspective. Invention of telescope is only a technological invention. In itself it is devoid of any philosophical significance. But the discovery of celestial bodies is significant. Undoubtedly, Copernicanism is more elegant than Aristotelianism. Equally it is doubtless that no theory can be accepted just in virtue of its elegance. In spite of internal consistency Copernicanism did not provide any evidence in defence of itself. Neither Copernicus nor Kepler could offer any evidence in support of their theory. Their theories are severely restricted because they are simply mathematical constructions. Any mathematical construction can be viewed as an idealized system. Galileo's contribution lies precisely here. Experimental physics took its birth with Galileo's work. In this respect he achieved the breakthrough. First two of his discoveries mentioned above merely strengthened earlier discoveries of Brahe. But second and decisive evidence came from the observation of phases of Venus. This is one of the defining moments in the history of astronomy. If geocentric theory is admissible, then Venus can appear in crescent shape only because in such a system Venus is locked between the earth and the sun. But if heliocentric theory is admissible, then Venus goes behind the sun. Only then it can appear nearly full and that is how Venus appears. We can accept or reject a theory only on the basis of observation statements like the one mentioned above. Let us observe the following figure.



a. Ptolemaic system



b. Copernican system

The fig. a represents geocentric theory and the fig. b represents heliocentric theory. Observation supports only fig.b.

There are two things here; one, the visible shape of Venus constitutes an important evidence and second, the last two sentences constitute what is called explanation and what distinguishes science from nonscience is the explanatory power. More a theory explains in science more satisfactory a theory becomes. Therefore whether a theory is true or false does not matter. To be more aggressive, when we ask which theory is true, we are in fact putting a wrong question. Surely, a wrong question cannot beget right answer though a right question can beget wrong answers.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. What is manifest in Kepler's third law?

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2.6 LET US SUM UP

Brahe is a great observer unlike Copernicus. Brahe's discoveries showed that the Heavens are not immutable. Brahe disagreed with Copernicus. His system of the universe differs from Aristotle's system. Kepler continued with Copernican tradition. He showed that the planetary orbit is not circular but elliptic. He derived three laws which are known as laws of planetary motion.

2.7 KEY WORDS

Harmony of the World: Harmony is a musical concept which specifies definite numerical relations at definite places. Application of this musical concept to the world shows that the world is governed by the same sort of ratio which determines the quality of music.

2.8 FURTHER READINGS AND REFERENCES

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2.9 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. The discovery of a star in 1572 and a comet in 1577 are strategic discoveries.

Check Your Progress II

1. Cosmic Harmony is manifest in this law. He derives harmony from strange numerical jugglery.

UNIT 3 PHILOSOPHY OF NATURE OF NEWTON AND HIS SCHOOL

Contents

3.0 OBJECTIVES

The main theme of this unit is a brief survey of concepts and problems which dominated physics in its initial stages. And in the process you will be introduced to the beginnings of Science in the sense in which it is understood today. This is achieved by highlighting the characteristics of Aristotelian physics which were attacked by Galileo and his own alternate world-view. Thereby some groundwork is done to appreciate not only Galileo's contribution to the birth of new science but also to prepare you to grasp the contribution of Newton.

Once we understand the spirit with which both Galileo and Newton took upon themselves the task of decoding the mystery of nature we also understand the point of departure of post-Galilean physics which aimed at mechanical interpretation of the universe distinct from teleological interpretation of the universe which dominated cosmology and physics from the time of Plato down to Copernicus.

3.1 INTRODUCTION

There are two reasons to begin our study with Galileo. In the first place, Galileo has contributed to a very important aspect of the growth of Science. It evolves the way life has evolved. This point must be clarified at the outset. Though it is true that the anti-Aristotelian wave which began with Copernicus culminated in Galileo, the break from the past was, in fact, incomplete. The success was limited to the replacement of geocentric theory by heliocentric theory. However, mere shift from the earth to the sun did not accomplish what is presumed to have been accomplished; that revolution or, to be exact, Copernican Revolution was complete. This is so because the Aristotelian cosmology has other components like the orbit of planets which Kepler did not disprove to the satisfaction of Galileo because he did not or could not offer any observational evidences. Consequently, Galileo had no problem to dispute Kepler and to go back to Aristotle's idea of circular orbit of planets. This only shows how difficult it must have been for even men of brilliance to completely free themselves from the influence of tradition. Closely related to the path of planet is the problem of motion itself which Galileo tackled. In this respect Galileo is a vital link between his past and future. Not only the legacy of his past determined his physics, but also his ideas became germane to what Newton elaborated after some decades. It only shows that Galileo retained the characteristics of his ancestors and passed on his own characteristics to his future generation. If only the ideas replace characteristics, then the sense in which science evolves also becomes clear. Secondly, Galileo introduced or invented an important distinction in his study of motion; dynamics and kinematics. If we should understand and evaluate his contribution in proper perspective, it is necessary to become clear about these sciences. Dynamics is the branch of mechanics which studies the motion under the action of forces whereas kinematics is also a branch of mechanics which studies only motion without considering the influence of forces. Galileo restricted himself to the study of kinematics leaving dynamics open to Newton, because he was concerned only with uniform and accelerated motions without considering the role played by force. Thereby Galileo prepared the ground for Newton to formulate his theory. It is customary to treat science (physics in particular) prior to Galileo as ancient and science after Galileo down to the 19th c. as classical.

3.2 GALILEO'S THEORY OF MOTION

There are two important aspects of his theory of motion; the phenomenon of falling bodies is one aspect and the concept of inertia is another. These two are closely interrelated. First aspect occupies our attention for more than one reason. In the first place, with the help of the phenomenon of falling body Galileo not only proposed a distinct theory of motion but also it helped him to establish the dual motion of the earth. In the second place, it reveals Galileo's attitude to experiment. Let us begin with the first aspect.

Earlier we referred to two types of motion; uniform motion and non-uniform (accelerated and it's opposite 'decelerated') motion. While rectilinear motion illustrates uniform motion, a falling body is an example of accelerated motion. Motion along inclined plane is another. Galileo stated that all bodies of the same material fall in vacuum with the same velocity while bodies of different materials irrespective of weight fall with velocity proportional to the specific gravity of bodies under consideration. However, in plenum the situation is different. Bodies fall with velocity proportional to the difference in the specific gravity of the body and that of the medium. This is the reason why the same body made up of a certain material is slower while descending in water and faster while descending through air. Resistance offered by a medium is directly proportional to the specific gravity of that medium. Suppose that v is the velocity in plenum S is the specific gravity of the body and s is the specific gravity of the medium. Then v is expressed as follows:

$$v \propto k\,(S-s) \quad (\propto \text{ is read proportional to})$$

where k is the proportionality constant.

This equation shows that $v > 0$ only when $S > s$. If $S = s$, then $v = 0$. It means that if specific gravity of body equals that of medium then the body does not fall. Instead it floats. On the other hand, if $S < s$ or $s > S$, then v takes negative value. If v is taken to mean descent, negative v should mean not just floating but ascent. With the help of this observation it can be easily shown that Galileo's theory is not qualitatively different from Aristotle's theory. Aristotle argued that heavy objects fall towards the centre of the earth whereas light objects ascend, i.e. move away from the centre of the earth because it is their natural motion. If so where exactly Galileo differs from Aristotle?

But Aristotle did not answer one question; when does an object become too light to descend? After all 'heavy' or 'light' is only relative. Aristotle's theory lacked this particular specificity. Galileo answered this question and in the process he made Aristotle defensible who was apparently indefensible. Galileo disputed incontrovertibly only geocentric theory. But he could not completely set aside Aristotle's theory of motion which was doubted long before Galileo. Nor is it clear whether Galileo intended to dispute Aristotle in this respect. The difference is that Aristotle only spoke of weight whereas Galileo spoke of specific gravity. Specific gravity (called relative density now) is a function of weight which is in turn the function of mass. Accordingly, Aristotle was not completely wrong. It must be admitted that the difference, surely, is not insignificant within the framework of experimental physics, though it is equally true that Galileo only corrected, but did not overthrow Aristotle's version of motion. But this is the way science evolves. It is impossible to break away from the past completely, a point very clearly expressed by Rutherford, a pioneer in nuclear physics, when he said that no one can make a sudden and violent discovery because science goes step by step and that every one depends upon his predecessors. Therefore we have to reconcile to two Galileos.

Galileo heralded a new era in the history of physics when he interpreted the motion of falling bodies in terms of specific gravity which is defined as the ratio of the density of given substance with reference to that of some other substance. Therefore specific gravity can only be understood relative to that of some other material. In so interpreting Galileo brought the concept of relativity of mass into the realm of physics.

There is another evidence which can be used to defend the pro-Aristotelian argument. A body set in motion continues to move perpetually if space is infinite. But in tune with his pro-Aristotelian leaning Galileo not only held that the universe is finite but also that motion is infinite. However, in finite universe it is impossible that rectilinear motion can be infinite. Consequently, Galileo had only circular motion to defend infinite motion which he regarded as natural and perfect.

In general, his theory of motion can be discerned in three major works. First important work, de Motu (On Motion) was published in the early nineties of the sixteenth century. In this work he proposed a theory known as the impetus theory. Under the influence of Archimedes he also tried to interpret impetus in terms of fluid statics. He intended to provide an exact counterpart of statics and in this manner he became the founder of dynamics. However, he discarded impetus theory subsequently because it could not solve the problem of accounting for the motion of terrestrial objects and the axial rotation of the earth. It was primarily designed to counter Aristotle's theory of motion. Both these theories concentrated on the cause of motion after the object in motion was detached from the source. While Aristotle traced the cause of motion to the medium, impetus theory suggests that the cause of motion can be traced to the moving object itself. In tune with this hypothesis Galileo's concept of motion stated that the cause is the object itself. Consider an example. Suppose that while travelling by train I stretch out my hand holding a ball. As long as I hold, it participates in the motion of the train. But the moment I drop it, it is freed from the motion of the train and consequently, its path is not collinear, but away from my body in the opposite direction of my motion. Now contrast this with the axial rotation. An observer on the earth moves from west to east at the same velocity at which the earth moves. Therefore the moment he drops the ball it ought to be free from the axial rotation of the earth. Therefore it ought to fall to the west of the observer. But in reality its path is exactly collinear and parallel to the observer. The difference is clear. Obviously, the impetus theory does not account for the participation of any moving object in the axial rotation of the earth after it is released from the source of motion. It was important to address the problem which stemmed out of Copernican astronomy. Therefore Galileo gave up this theory.

In Galileo's studies we discern for the first time the characteristics of scientific method. A scientist first proposes a theory and then examines whether it helps in solving the problem. If it does not, then he tries another theory. This is what is called trial – and – error method. In Galileo's approach this characteristic is distinct.

Galileo's next important work Dialogo sopra I due massimi sistemi del mondo (Dialogue Concerning the Two Chief World Systems) appeared in 1632. By two world systems Galileo meant the Ptolemaic and Copernican systems. This work is set in typical Socratic-Platonic tone. The main players in this game are Simplicio the mouthpiece of Aristotle and Salviati, the exponent of Galilean thought. When Simplicio was pressed to clarify what he means by 'centre' he says that by centre he means the centre of the universe. Simplicio's contention is that the earth cannot simultaneously be at the centre and keep moving along the circumference. Therefore what requires to be done at the outset is to show that the earth is not at the centre of the universe. But in itself this proof does not establish the circular motion of the earth. It only makes it logically a tenable hypothesis. Salviati's answer to this particular meaning is quite interesting, he says 'I might ……dispute…..such a center….neither you, nor anyone else has so far proved…. whether the universe is finite ...has shape. It is obvious that if the universe is infinite or has a shape other than spherical there cannot be anything like centre. Salviati proceeds further to demonstrate on the basis of observations that if there is anything like centre it can only be the sun. The most powerful among them is variation in the distance of planets from the earth. For instance, Venus is six times as distant from us at its farthest as at its closest, and Mars nearly eight times. Salviati reveals that there is a pattern in the variation of the distance. When the outer planets are in opposition to the sun they are very close and when they are in conjunction with it they are farthest. Huge variation in distance also accounts for the huge variation in observable size. Salviati further reinforced his position by making Simplicio draw the orbits of planets according to his (Simplicio's) theory which really did not or could not conform to actual observations.

The equation of celestial dynamics and terrestrial motion finds place in his last work *Discorsi Intorno a Due Nuove Scienze* (Discourses on Two New Sciences) published in 1638. He anticipated the concept of inertia in this work. Inertia is the property of matter that resists any change of state of motion. Giovanni Baliani, in his work de *Motu Gravium,* suggested that a passive principle is inherent in matter. It is doubtful whether Galileo was aware of this suggestion though Baliani's and Galileo's last works were published simultaneously because there is no reference in Galileo to passive principle. In fact, inertia, and passivity are similar in connotation. The point is that inertial motion does not diminish if it is a reality, but its reality is unquestionable. Therefore it must be eternal. Using falling phenomenon, he tries to prove that motion is indestructible A particle descends along an inclined plane to reach the ground and it ascends to attain the same height from where its fall started. No other motion than circular motion illustrates this feature. Therefore any anticipation of inertia is severely restricted to circular motion only. This is how Galileo achieved the identity of celestial and terrestrial phenomena.

Galileo did not make any quantitative difference between rest and motion. If motion exists relative to something that lacks it, then the converse also is true. Lack of motion is always relative to something that possesses it. According to him rest means infinite slowness. Hence motion is something which is eternal. The example which he quotes is that of a sailing ship with cargo. With reference to ports the cargo moves. But within the ship itself cargo is at rest. Again, we find here the remnants of the relativity of motion. When motion is understood in relative sense it does not require any external force. Galileo used this concept to explain celestial and terrestrial phenomena. In the case of a ball dropped by any observer on the earth moving from west to east the ball continues to share the eastwardly motion of the earth because no force operates to halt its eastward motion. Otherwise, as per the dictate of common sense the ball should have touched the ground to the west of the starting point of falling. In this way Galileo anticipated relativity of motion also.

The concept of inertia is the connective between cosmology and Galilean dynamics. It must be noted that Galileo did not use the word inertia anywhere though he meant it. Simplicius agrees that when a ball on a horizontal plane is given push it moves with uniform velocity and when the plane is extended infinitely the motion should be perpetual. Galileo gives a strange definition of horizontal plane; it is a plane where every point is equidistant from the centre. In this way Galileo was led to conclude that circular motion characterizes cosmos.

But then inertial motion (perpetual motion in Galileo) is only idealized according to Galileo's own admission because most of his laws of motion apply to motion in vacuum. All observed motion only approximate to ideal motion. Arguing in this way and by bringing terrestrial motion within geometrical analysis Galileo equated stellar motion and terrestrial motion and thereby obliterated the difference between the two worlds, the difference so fundamental in Aristotelian framework.

This will bring us to the last aspect. Contrary to widely held view, Galileo did not perform any experiment, though he was the source of experimental physics. One of the reasons is that only Torricelli, who was inspired by Galileo, showed that vacuum could be produced under laboratory conditions and as mentioned earlier, many of his laws of motion hold good only in vacuum. All alleged experiments, including the famous Pisa tower experiment, are merely thought experiments, i.e. mental constructions. When Simplicio demands that Salviati should conduct the experiment, the latter maintains that it is unnecessary since the result is a foregone conclusion. However, much later the experiments were conducted which confirmed Galileo's arguments.

Galileo believed that mathematical treatment alone of observable phenomena can produce desired results. The role of experiment is restricted only to test what comes out of calculations. This view has far-reaching impact upon the method of science. Thus Galileo has become a pioneer in visualizing the method of science.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Give Galileo's definition of Rest.

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3.3 NEWTON AND CLASSICAL MECHANICS

Mechanics is regarded as the most influential and ideal science in spite of rapid progress witnessed in other branches of physics for the past one hundred and fifty years. In two senses this claim is justified. In one sense mechanics is the primary source of the science of universe. Therefore it is impossible to study anything related to the universe without considering the elements of mechanics. In another sense it is an indication of attitude - an attitude towards the universe. Many times attitude determines the success or failure of science. This is another reason for the primacy of mechanics. This point becomes clear when we contrast 'mechanical explanation' with teleological explanation. Against this background, we understand that mechanics, unlike teleology, in its essence, signifies function without purpose. Therefore a mechanical explanation gives a different picture of the world – different from the one provided by the latter. This difference is at the root of the distinction between ancient and classical mechanics. And in the strict sense of the word – the sense in which it is understood today-ancient mechanics is not mechanics at all. Since Newton is singularly responsible for this phenomenon, it is ideal to begin with the discussion of the essence of classical mechanics which is associated with everything that is called Newtonian.

Mechanics and machine have, interestingly, one feature in common, if not in primary sense at least in derivative sense. Given certain conditions and structure the machine functions in a particular pattern. Similarly, mechanics reveals that given certain conditions and structure the universe functions in a determinate manner. It means that structure determines function. In this context function is nothing but motion. However, the word 'conditions' is not appropriate in science. A better word is 'laws'. The underlying principle in both the cases is that the laws determine the function, but not the will or desire of any Conscious Being. In other words, *law is blind*. This had far-reaching consequences in philosophy and science as well. It was Kepler who for the first time formulated what are called laws and applied the same to the universe. This change put an end to the domination of speculation and paved the way for observation causing scientific revolution. Newton formalized this legacy and went a step farther to equate terrestrial motion with celestial motion and since then Newtonian mechanics is known as classical mechanics.

3.4 THE CONCEPT OF FORCE

The concept of force, which is a fundamental concept in physics in general and classical mechanics in particular, has a long history. It was not altogether alien to pre-Socratic philosophy. However, except Heraclitus all other pre-Socratics used this word in some sort of ethereal manner which was not of much use in physics. Its origin lies in Aristotle's *entelechy* meaning unmoved mover. It was Aristotle who introduced dynamics and thereby quantitative analysis of force and its relation to motion. But it did not occur to him that units must be employed to measure and that quantitative analysis is incomplete without accurate measurement. Dynamics engaged his attention in connection with the motion of projectile. His problem can be summarized in this way. How can a projectile continue to move even after it is detached from the projector? While Aristotle attributed the source to the medium of motion, Jean Buridan (1300-1358), a French philosopher attributed the source to the projectile itself. This theory came to be known as *impetus* to which reference was made earlier and which Galileo called *vis impressa* (impressed force) to explain accelerated fall. These suggestions remained speculative only. However, Kepler made the difference in spite of his *anima motrix.* He could provide a sound base to investigate the nature of force as a physical quantity on mathematical lines with his knowledge of inverse relation between distance and the quantity of force combined with his knowledge of Gilbert's (1544-1603) work on magnetism which later developed into the concept of field.

Force and change are inseparably related and motion is one species of change. Kepler's interest on force was restricted to celestial phenomena only. Newton widened the scope of the concept by bringing terrestrial phenomena under it as well. And in the process he effected some conceptual changes which proved to be critical and integrated new concepts. In a way it helped him to axiomatize mechanics.

Before we proceed further we shall know what axiomatization means. Newton's classic *Philosophiae Naturalis Principia Mathematica* (Mathematical Principles of Natural Philosophy) appeared in 1687. By natural philosophy Newton meant what we mean today physics and wherever he used philosophy or philosophical he meant physics or physical. He set *Principia* on the lines of Euclid's 'Elements'. Axiomatization is a certain method of systematizing or organizing a work. Newton axiomatized his *Principia* with definitions of a group of words which found place in axioms which followed the definitions. Lastly he introduced theorems. An axiom is a self-evident proposition which serves as a basis for proof or from which some other statement draws support. When definitions, axioms and theorems are well-ordered in the sense that they help in arriving at definite conclusion, it becomes axiomatized or simply a system.

It is necessary to know how the concept of force evolved in Newtonian physics. Even before the publication of *Principia* Newton had formulated the notion of force and this is the reason why he became famous even prior to the publication of *Principia.* In one document he pointed out that 'some require a more potent or efficacious cause others less to hinder or help their velocity'. This power is called force. In another document he asserted that the alteration of motion is proportional to the force by which it is altered. These assertions mark one of the defining moments in the history of physics. While Aristotle maintained that motion has cause, Newton argued that it is *change* in the status of motion that needs force but not motion as such. If rest is infinite slowness as Galileo suggested, then there is no moment when the universe is free from motion. By bringing rest and motion under single umbrella, the problem of the origin of motion was simply dissolved. This change makes shift from ancient mechanics to classical mechanics total because shift from speculation to observation is complete. Later in *Principia* Newton achieved the synthesis of apparently distinct notions; force, mass, time and velocity. This synthesis marks the beginning of modern dynamics.

Fatal blow to ancient mechanics is yet to be disclosed. If force is relevant not for motion but change of motion then what is this change of motion? Newton realised that in dynamics we do not deal with mere velocity but rate of change of velocity. Change can be in any direction. In this context a new dimension entered the scene, i. e., time. This particular issue was totally alien to ancient mechanics. It remains to be seen how Newton integrated these diverse concepts.

The *Principia* consists of three parts of which first and third are significant to us. First part consists of a set of definitions and axioms or laws of motion with the help of which he established terrestrial dynamics. Second part consists of theories of fluid mechanics and waves. Third part deals with the application of the principals of dynamics to the universe.

It is quite rewarding to consider eight definitions and three axioms which are also called laws of motion.

DEFINITIONS

1 The quantity of matter is the measure of the same, arising from its density and bulk conjointly.
2 The quantity of motion is the measure of the same, arising from the velocity and quantity of matter conjointly.
3 The vis insita or innate force of matter is a power of resisting by which every body, as much as in it lies, continues in its present state, whether be it of rest or of moving uniformly forward in a right line.
4 An impressed force is an action exerted upon a body in order to change its state, either of rest or of uniform motion in a right line.

5 A centripetal force is that by which bodies are drawn …..towards …centre.

6 The absolute quantity of a centripetal force is the measure of the same proportional to the efficacy of the cause that propagates it from the centre through the spaces round about.

7 The accelerative quantity of centripetal force is the measure of the same proportional to the velocity which it generates in a given time.

8 The motive quantity of a centripetal force is the measure of the same proportional to the motion which it generates in a given time.

AXIOMS

1 Every body continues in its state of rest or of uniform motion in aright line unless it is compelled to change that state by forces impressed upon it.

2 The change of motion is proportional to the motive force impressed and is made in the direction of the right line in which that force is impressed.

3 To every action there is always opposed an equal reaction or the mutual actions of two bodies upon each other are always equal and directed to contrary parts.

Two criticisms follow. One is that the definition is circular because quantity of matter and density are the same. Secondly, first axiom and third definition overlap. Hence the structure of the work itself is said to be unsatisfactory from the point of view of logic. This has created difficulties in understanding what Newton meant when he employed certain terms and used some statements as axioms. For example, first axiom of motion is said to be the formulation of the law of inertia. However, its overlapping with third definition makes matters complicated because of reference to 'innate force'. It is likely that one may ask how can inertia and innate force ever be the same when no force is required for motion but required only for change of motion as claimed by Galileo and his successors. If inertia and innate force are same then it is impossible to substantiate the claim that planets are subject to two forces acting simultaneously. Therefore something is amiss in the very definition of inertia or force or both. Suppose that innate force is distinct from inertia. Then it becomes the opposite force of impressed force as understood by fourth definition. Newton never clarifies whether innate force is a special kind force which operates even when there is no change in motion. He unwittingly presupposes that there are opposing forces in nature. This is an issue which should have been settled while listing definitions, but it was not done. It means that axiomatization is incomplete.

First axiom of motion needs to be closely examined since it expresses the exact formulation of the law of inertia. In this context it is a profitable exercise to contrast Galileo and Newton. Galileo hypothesised a plane extended infinitely to suggest that a ball rolling down such a plane does so infinitely. Since for Galileo an infinite plane was merely a mathematical construction, the necessity of infinite universe without which infinite motion does not make sense, did not really haunt him. As a matter of fact he made this assumption only to drive home the point that a ball rolling down the plane simply falls to the ground which means that velocity is not inertial. It shows that Galileo was a Platonist in a restricted sense only. He did not further proceed with his hypothesis while dealing with the physical world. He was interested only in actual motion. However, for Newton inertia was no longer a mere mathematical construction. Nor did he ignore pure mathematics in Platonic sense. He accommodated both pure mathematics and applied mathematics in his study of the universe. Therefore Newton had absolutely no difficulty to propose the law of inertia which he applied to the planetary motion. Newton argued that the universe is infinite and hence perpetual motion in straight is not merely a possibility but a reality. With inertia discovering complete formulation in Newton another fort of ancient mechanics collapsed.

There are three important aspects of definitions. One is that the velocity is different from the quantity of velocity just as mass is different from the quantity of mass. This distinction was never made so clear earlier. Secondly, force is a function of not just mass, but of quantity of mass. One of the hall marks of classical mechanics is this particular emphasis upon this distinction. Third aspect deserves our attention. Identification of centripetal force is central to classical mechanics because the explanation of the whole of celestial dynamics hinges on the effect of centripetal force.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. State the definition of innate force.

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2. What do you mean by axiomatization?

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3.5 LET US SUM UP

Galileo was interested in the law governing the falling bodies. He accepted that circular motion is natural motion. Relativity of motion has its beginning in Galileo. He showed that in vacuum all bodies irrespective of weight fall simultaneously. Motion depends upon specific gravity. Newton defined inertia as innate force. He gave a definition of centripetal force.

3.6 KEY WORDS

Kinematics: It studies various aspects of motion without considering the role played by force in initiating motion.

Dynamics: It studies the relation between various aspects of force and motion. For Ex: the direction of force, magnitude of force etc. are given importance while studying motion by dynamics.

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3.8 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. Rest means infinite slowness.

Check Your Progress II

1. The innate force of matter is a power of resisting by which every body, as much as in it lies, continues in its present state, whether be it of rest or of moving uniformly forward in a right line.
2. Axiomatization is a certain method of systematizing a work. Definitions, axioms and theorems constitute axiomatization. An axiom is a self-evident proposition which serves as a basis for proof. When definitions and axioms are well-ordered in the sense that they help in arriving at definite conclusion, it becomes axiomatized or simply a system.

UNIT 4 MECHANICAL PHILOSOPHY OF NATURE AND ITS IMPLICATIONS

Contents

4.0 OBJECTIVES

In this unit, which can be aptly called Newton-II, I propose to give an exposition of philosophical implications of classical mechanics. The philosophical implications which I propose to explicate are two-fold. A brief survey of 'cosmological upheaval' is one part of the story; a close examination of Newton's *hypothesis non-fingo* is another. The reference to the former introduces you to Book Three of 'Mathematical Principles of Natural Philosophy' and its main theme, that is, universal law of gravitation which also includes Robert Hooke's significant contribution to classical mechanics. And the reference to the latter exposes you to the methodological controversy surrounding Newton's views on hypothesis.

When you are through this unit you will be in a better position to understand Newton's position – in relation to his predecessors and in relation to his successors and that he did not mark an end of an era but the beginning of an era.

4.1 INTRODUCTION

Scientific enterprise is a continuous activity which takes us forward sometimes without any hiccup and sometimes thwarted by controversies which appear to halt further progress temporarily. In reality, it does not stagnate at any point of time. Long debate is natural when controversies have to be resolved and that is the only way science evolves. Significantly, the latter always produces credible results. This is more than evident in Kepler- Galileo tradition. Conflict which arose between Keplerian and Galilean arguments were resolved by Newton. He could achieve remarkable progress because he resolved the dispute between these doctrines. And in the process he established a very different world-view.

In the previous unit we became familiar with the subject matter of the first two Books of *Principia.* The third part is significant because here Newton derives his universal law of gravitation. And he used simple mathematics to derive this law with the help of Keplerian and Galilean theories. It is highly rewarding to know how he mathematicised cosmology. If mechanics became an integral part of physics it is because of its very high mathematical content. Against this background, we shall concentrate on the theme of Book Three.

4.2 KEPLER AND GALILEO-A RECAPITULATION

The Book Three of *Principia* describes what Newton, aptly, calls 'The System of the World'- aptly because in this Book Newton succeeded in achieving equality of terrestrial and celestial mechanics. This success is the singular implication of the seventeenth century mechanics. A system implies 'cosmos' or 'order'. The type of order which regulates the universe is determined by the nature of law or laws. In this sense *Principia* is the logical outgrowth of Kepler's and Galileo's theories put together because the laws which Newton formulated are the syntheses of Kepler's laws of planetary motion and Galileo's laws of falling bodies and his discovery of the moons of Jupiter. The structure as well as function of the Newtonian universe is determined by these laws. It is quite interesting to know how Newton succeeded in extending these laws to the whole universe and how they changed our perception of the universe.

When Kepler formulated three laws, he restricted those laws only to planetary orbit. However, Newton extended these laws to the orbits of satellites and showed that they hold good in their case as well. Secondly, Newton showed that Galileo's law of falling bodies is a precursor to the law of universal law of gravitation. Kepler could not explain why planets move in elliptic orbits. And Galileo simply refused to accept the elliptic orbit of planets. Newton, not only explained why the planets – for that matter satellites too- move in elliptic orbit but also he showed that Kepler's constant holds good in the case of satellites also. Indeed, there is a difference. The value of Kepler's constant varies from planets to satellites, but within the realm of satellites the value is constant. In other words, planets and their satellites stand in the same relation as the sun and the planets stand. It is in this sense that Newton synthesized Keplerian and Galilean laws. Therefore the manner in which Newton achieved the synthesis of these doctrines occupies a strategic position in the history of physics.

Newton admitted that the first two Books are purely mathematical without any philosophical (pertaining to physics) discussion. On the other hand, the Book Three deals with much of physics, but not without mathematics. When Newton claimed that the structure of the world is explained with the help of the principles of motion, his claim implied that the external world can be explained only with the help of mathematical method. If a study of physics is observational or experiential and, therefore, fact-oriented and a study of mathematics is theoretical, then application of mathematical method to physics implies that theory is imposed upon fact (if there is a fact). Newton himself confesses in the beginning of the last Book that in the previous Books occasionally, he resorted to philosophical scholiums 'lest they (mathematical principles) should have appeared ….dry and barren'. Newton's observation is only a precursor to a lively debate on fact vs. theory which engaged twentieth century philosophers of science digging into the depths of the structure of science. From this point of view his observations imply that fact without theory is blind and theory without fact is barren, the last part of the statement being his own. And from the standpoint of cosmology his observations imply strong elements of a combination of Pythagoreanism and Platonism.

In the previous unit we understood what Newton meant by axiomatization. Apart from definitions and axioms the method of his axiomatization of mechanics includes theorems as well. These theorems are most enlightening. Most important among them are theorems 1, 2, and 11-13. Theorem 1 proves that the motion of a planet is along curve. Theorem 2 proves that there is centripetal, which he calls 'central', force which draws planet towards the centre. Theorem 11 proves that the centripetal force which tends to any focus of the eclipse varies inversely as the square of the distance. Immediately he proves that the path can be elliptic if the force varies inversely as the square of the distance, not otherwise. These theorems are significant because, the seeds of universal law of gravitation and his theory of force are latent in these theorems. Theorem 2 can be said to be the complement of Galileo's law of falling bodies. Galileo showed that when a body falls freely, its acceleration uniformly increases as the square of the times. Newton showed that acceleration varies inversely as the square of the distance. It is not just that Galileo chose to use 'time' instead of distance. What is significant is that Galileo argued that if velocity and square of the distance are correlated, then it results in inconsistency. In one place Galileo uses the word velocity and in some other place he uses the word acceleration as if they are interchangeable. Though they are not interchangeable, they are surely interrelated. Therefore if the correlation of velocity and distance leads to inconsistency, then naturally the correlation of acceleration and distance also ought to result in inconsistency. This aspect will become clear when we define acceleration. It is nothing but rate of change of velocity. Therefore what applies to velocity must apply to acceleration also. On the other hand, at some stage Kepler argued that velocity is inversely related to distance. Even Kepler did not think in terms of distance – square. So he could not explain why planetary orbit is elliptic. The points of divergence are now clear. Galileo insisted that the path is circular whereas Kepler argued that the path is elliptic. Secondly, Kepler related velocity and distance while Galileo related velocity and time. Conversely speaking, if correlation of acceleration and square of the distance is admissible, then correlation of velocity and square of the distance also must be admissible. It only means that if Newton's inverse square law is admissible, then Galileo's contention is not validated. But in other respect Galileo influenced Newton. He depended heavily on Galileo's explanation of freely falling body to explain the movement of planets. Here the emphasis is upon uniform acceleration. Uniform acceleration implies uniform increment to velocity. Therefore we can safely conclude that as the body falling freely approaches the centre of the earth, it uniformly accelerates or receives uniform increment to velocity. If so, when a body moves away from the centre of the earth it should uniformly decelerate. If we ignore 'uniform' for the time being, we understand that this is what precisely theorem 11 states.

Kepler and Galileo played different games. Kepler's study was restricted to celestial mechanics whereas Galileo's study of inertial motion was confined to terrestrial bodies. Newton fused these two apparently distinct studies. What happened when these findings were extended to celestial bodies was something remarkable. This development took place in two stages. In the first stage, Newton included planets and satellites. In the second stage, Newton extended the same to all bodies irrespective of their position in space and time. After regarding the sun as the centre of the solar system, the law of falling bodies was extended to them. This being the case the planets should simply fall towards the sun in the absence of inertial motion. In this sense the centripetal force, subsequently, is transformed into law of gravitation governing the behaviour of planets and satellites. In the next stage Newton proceeded to show that this law holds good in all cases and in this way Newton evolved universal law of gravitation. The difference between these two stages is that in the first stage the sun is the source of gravitation and in the second stage the gravitation becomes independent of the sun so that even very far from the sun, where its influence is nearly zero, the influence of gravitation controls movement.

While analyzing the motion of falling bodies Galileo demonstrated that the velocity of fall is directly proportional to the specific gravity of falling body. And the problem with his argument is that his definition of specific gravity itself is fallacious. First Newton replaced specific gravity by mass. Hence the fallacy was avoided. And then he effected several changes which turned out to be deciding corrections. In the first place instead of taking into account the mass of falling body alone he considered the mass of another body – its destination and secondly, he showed that the product of the masses of two bodies determine the quantity of force which in turn determines the quantity of motion. Thirdly, the relation was made mutual since the mass of second body also was made a component. In accomplishing his task Newton was immensely aided by Kepler and Galileo alike.

Galileo's discovery of the satellites of Jupiter had telling impact upon physics. In addition to this discovery Newton discovered that like Jupiter, Saturn also is surrounded by satellites. In this respect, a small change is required. The position of the sun is replaced by the respective planet. Considering this important change Newton had no difficulty in proving that in equal time intervals the satellite (in Keplerian system planets) sweeps equal areas and also that the ratio of the squares of their period of revolution to the cubes of their mean distance from Jupiter or Saturn as the case may be is constant for all satellites though the value of this constant differs from planets to satellites. Suppose that $T_1, T_2, T_3, T_4 \& T_5$ are the periods of revolution of respective satellites $S_1, S_2, S_3, S_4 \& S_5$ are their respective distances from the respective planet. Then also

$$\frac{T_1^2}{S_1^3} = \frac{T_2^2}{S_2^3} = ... = K$$

It is quite obvious that constancy of the value of K can be calculated only if there are at least two satellites to a given planet which means that the third law of planetary motion cannot be applied to the earth's moon. However, the other two laws apply to the same.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Discuss how Newton made progress over Kepler and Galileo.

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4.3 THE SIGNIFICANCE OF CENTRIPETAL FORCE

The first axiom of motion implies that motion along straight line is a natural motion. Consequently, planets ought to move in straight lines. But they move in elliptic orbits. Therefore

Newton concluded that planet is subject to a second force acting in a different direction. Let us suppose that inertia is also a force, rather innate, as Newton supposes. Then there are two forces. Suppose that two equal forces act in opposite directions simultaneously. Then one neutralises the other. On the other hand, suppose that they both act in the same direction simultaneously. Then they are compounded. What happens in the case of planets is different. What happens is neither neutralisation nor compounding. This is because the directions in which the forces apply are different. It may be perpendicular or oblique. Further, the forces may be of same quantity or different. There is no need to consider these aspects. It is adequate to accept that there are two forces acting in directions other than those mentioned above.

This is the present situation. Now let us suppose that the planet is subject to innate force only. In such a situation the central location of the sun does not make any sense. However, with reference to the location of the sun we shall consider inertial motion.

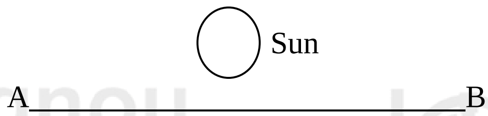
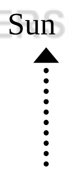


FIG 1.

Here A is randomly chosen starting point and AB is a segment of open ended path. Surely this suggestion is nonsense because such a possibility plainly eliminates day-night cycle. No such fanciful theory is credible. So this is ruled out. On the other hand, suppose that the planet is free from inertia. Then it is subject only to the centripetal force of the sun. In such a case direct collision results since centripetal force functions like a whirl and draws planet towards it. To give a contemporary example it is like black hole swallowing anything that comes within its field of influence. At this stage, interestingly Newton brings in the notion of God and points out that the present arrangement proves the existence of God and more importantly, he maintained that the absence of this possibility shows that the universe cannot be explained by matter alone. It is not clear whether Newton sincerely believed so or used it as only a ploy to make theists, who were in majority and also powerful, fall in line with him. The imaginary path is somewhat like this.



Planet

FIG 2.

Now assume that these two forces act simultaneously. It is important that the forces must be perpendicular to one another. Mark the directions in which the forces act.

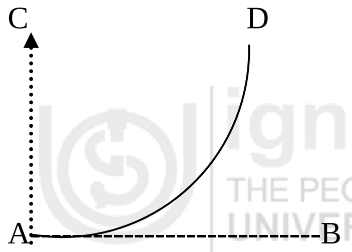


FIG 3.

The dotted line connecting A- B shows the path in which the planet would move when it is under the influence of innate force only. The dotted line connecting A-C shows the path in which the planet moves when it is under the influence of centripetal force only. These two are hypothetical. The curved diagonal connecting A-D (Fig.3) is the actual path when two forces act. While inertia acts in the direction of AB, centripetal force acts in the direction AD. A point to be noted here is that the action of forces is not sporadic but *continuous* and at a given point it is always *constant.* Therefore the path is not exactly like the one shown above. Roughly the path is something like this.

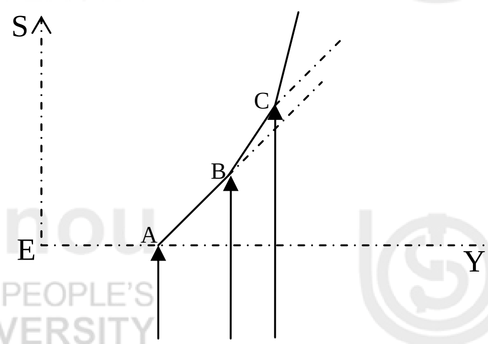


FIG 4. (the arrows indicate the direction in which force acts)

It must be noted that the path can be elliptic only when the forces are constant and continuous, not otherwise. Two important conclusions follow from this fig. the forces perform duel functions. For example, consider the force acting along the path E Y. It not only drags the planet along E Y, but also prevents the planet from falling. Similarly, the force acting along the radius EC not only draws but also prevents the planet from being dragged. So the path lies between fall and drag. This is precisely the resultant force.

The relation between acceleration and curved path finds accurate exposition in Newton. Galileo argued that circular path is an example of inertial motion. Despite the fact that Galileo spoke of acceleration he did not use it in the sense in which Newton and his successors used. Acceleration means not only rate of change of velocity but also change of direction. Therefore circular motion can never be even a crude example for inertial motion. Galileo attributed only the former to acceleration but not the latter. If circular path does not exemplify inertial motion so is elliptic path. Hence centripetal force plays major role in determining the planetary orbit. This is the logical consequence of accepting Kepler's first law.

4.4 THE ORIGIN OF GRAVITATION

Newton was involved in clash with two great personalities of his time. He clashed with Leibniz on the invention of calculus and with Robert Hooke on inverse-square law. It is quite interesting to note that though Newton admitted that he was introduced into the topic by Hooke himself, Newton does not seem to acknowledge Hooke's role in the development of this concept. From the dialogue between Newton and Hooke two points become clear. One is that the origin of gravitation is traced to the geometrical shape of planetary orbit. Second is that Hooke proposed the inverse-square law in the form of a hypothesis. That inverse-square law is a hypothesis was admitted by Hooke himself. With regard to the first issue we should try to grasp their contribution to the evolution of this concept and with regard to the second, the question to be considered is; how did Newton consider this law? While the first issue has cosmological significance, the second issue has methodological significance. Let us take up the second first.

Apparently Newton held the view that hypothesis does not enjoy any significant position in the course of scientific investigation. This is what he means by *hypothesis non- fingo* or feign hypothesis. Was Newton truly opposed to any hypothesis or was he opposed only to some forms of hypothesis? If the former is tenable, then how did he receive Hooke's suggestion?

It is said that Newton was not opposed to hypothesis *per se.* He was very well aware of the presence of several hypotheses in his system. He was only against certain type of hypothesis called auxiliary hypothesis. It is necessary to consider what an auxiliary hypothesis means in some detail. Broadly speaking, there are two groups of philosophers of science; one group maintains that science requires hypothesis or theory, only to test as severely as possible so that based on such a hypothesis it is possible to offer a viable and tenable explanation of phenomena. Generally, no philosopher of science challenges this argument. The situation takes a very different turn when the hypothesis does not live up to our level of expectation. It happens when the hypothesis is disproved or does not conform to observations. This is what is called falsification. If the test falsifies a hypothesis, then it deserves to be replaced by some other hypothesis only to repeat the same process. There is another group of philosophers of science, namely, conventionalists, according to whom a theory must be insulated against falsification as far as possible and in spite of our best efforts if it is falsified, then a way must be invented to protect crumbling theory. Generally, the escape route is to assume that observation itself must be a flawed one. Such an assumption is what is known as auxiliary hypothesis. It only means that this type of hypothesis is formed not with the intention of solving a problem. If so, it would have been assumed in the initial stage itself. But it is devised in order to protect a falsified theory which means it appears somewhere in the middle of our investigation. Such hypotheses are called ad hoc hypotheses. The advocates of this view are physicists like P.W. Bridgman, Arthur Eddington, Ernst Mach and so on.

This is the background of auxiliary hypothesis. If Newton rejected only auxiliary hypothesis, then it is most likely that he was not averse to the other forms of hypothesis. If so, universal law of gravitation can be regarded as a hypothesis which Newton accepted. Then a question naturally crops up. How did Newton arrive at this theory? There are two possibilities. One is that Newton was intuitively convinced that inverse-square law satisfactorily explains the visible phenomena and the other is that he formulated this theory by resorting to trial-and- error method. There is no evidence to suggest that he followed trial- and –error method excepting the solitary instance of centrifugal force which he assumed initially. Nor can we say that first possibility is convincing. Hence the question how did Newton arrive at this theory remains an open question.

Let us return to the first aspect. In Hooke's own words the hypothesis which he suggested is 'compounding of celestial motions of the planets of a direct motion by the tangent and an attractive motion towards the central body'. It is quite obvious that tangential motion is inertial motion in straight line and attractive motion is centripetal force acting on the body. The difference is that instead of considering distance, unlike Kepler and Hooke, he assumed that inverse – square relation may do explaining. If we can get back to Newton's views on hypothesis, in the light of previous statement we can very well know what his stand on this issue is.

In his first step, Newton shows that any curved path implies inverse – square law. Later he showed that the converse also is valid. However, the second aspect has generated some controversy. Therefore we can ignore that part. Since the path is not exactly circular, the attracting force cannot be exactly centripetal force. It is not necessary that it should be. That force is necessarily attractive becomes evident from the principle which states that deviation from the straight line is possible only when a certain force acts in a particular direction. The nature of magnetic force was already known. Further, Newton considered law of equal areas as another evidence to substantiate his claim. Therefore the reality of centripetal force was undisputed. If there is force, then there must be a source of force. This is the substructure on which the superstructure, that is, universal law of gravitation was constructed.

4.5 THE COMPUTATION OF GRAVITATION

Newton started with the calculation of acceleration due to centripetal force and found out that it is the ratio of the square of velocity and the radius of circle along which the body rotates. Again, what we get is only an approximation to radius, since the path is not exactly a circle. Therefore the result is necessarily an approximation. Working within these limitations Newton derived the value of gravitation. In accomplishing this task, Newton developed with extraordinary logical skill and clinical precision Kepler's laws of planetary motion and Galileo's analysis of freely falling body. His accomplishment is an illustration of deductive method. He exhibited the implications of the acceptability of these two theories. The type of mathematics, which was required to achieve the goal, was simple arithmetic. But what matters is the ability to 'foresee' the result. He was required, in his mission, to consider all the components of force. They are, mass, velocity, (velocity along curved path necessarily implies acceleration), time, and radius. After computing the value of gravitation it was verified experimentally by Newton. The oscillation of pendulum provided reliable evidence which helped him to verify the result of his calculation. [In this connection the student is advised to refer I. B. Cohen's *The Birth of a New Physics* pp.165 - 172]

Newton's work on gravitation settled certain issues. One is that this force is constant anywhere in the universe which means that G is actually independent of the sun. Second, gravitation is a force of attraction, not one of repulsion. Third, and this most important, the force of attraction is a function of not one body, but the masses of two bodies. Newton showed that Kepler's laws of planetary motion hold good if and only if the bodies attract mutually. This is the reason why we have to compute the masses of both the bodies while calculating gravitation. In this respect Newton made definite and decisive march ahead of both Kepler and Hooke. Third factor implies that the sun is not the sole source of gravitation, not even within the solar system. Lastly, Newton also showed that when a massive body like the sun is around, the force of attraction due to smaller bodies or much more massive bodies which are very far is negligible for all practical purposes. As a result the motion of any body, whether terrestrial or celestial, could be explained with this single principle. Thereby the Aristotelian terrestrial-celestial dichotomy was completely erased. Secondly, variation in the value of g at the surface of the earth showed that the earth is not a homogeneous sphere, somewhat oblate because the value of g was found out to be minimum at the equator and maximum at the poles. Again, the length of the pendulum was the deciding factor because the length of the pendulum had to be shortened at the poles to obtain the same period of oscillation. We must remember that the period of oscillation varies directly as the length of the pendulum and inversely as g. Determination of the shape of the earth also helped Newton to solve an ancient problem. The earth displays a certain phenomenon known as precession of equinoxes. The sun during its motion crosses the celestial equator (an imaginary line) at two points. These points are called equinoxes. Precession or precessional motion occurs when a type of force called torque is applied resulting in change in the direction of the earth's axis of rotation. Had the earth been a perfect sphere then the attracting force would have resulted in identical effect all over the earth. However, the effect is uneven, i.e., the force produced the tendency on the part of the earth to deflect from the axis of its rotation. It resembles more or less the spinning top. This is possible only if there is bulging at the middle, i. e., equatorial region which is under attraction from the sun and the moon. Hence accurate calculation of g decided the exact shape of the earth too.

4.6 NEWTONIAN SPACE AND TIME

One interesting aspect of western philosophy is that the problem of motion is seminal to almost all philosophical problems which dominated the scene for several centuries. Closely related to this cardinal issue of motion is that of space-time as it is known today or *space* and *time.* Philosophers and physicists alike consider space and time together though some of them treat these concepts as separate and independent. In the history of physics (philosophy as well) we come across two distinct theories of space and time, viz. absolute and relative. If one of them is regarded as absolute, then second one also is regarded as absolute. Same explanation holds good if any one of them is treated as relative. Newton held the view that space and time are absolute contrary to the view held by Leibniz. Absolute theory asserts that space and time are independent notions while relativity theory takes them as one. We must remember that this is mainly a metaphysical notion which has made inroads to science just like causation. The only mechanical link provided to space is his idea of absolute motion. Accordingly, absolute motion presupposes absolute space and absolute time. However, it is said that in positing an absolute theory of space Newton was driven more by theological needs than dynamical needs.

There are conflicting versions on the relevance of space in the context of Newtonian dynamics. J. J. C. Smart opines that it is wholly irrelevant because according to him Newtonian dynamics requires only the notion of inertial system. (See The Encyclopedia of Philosophy, Vol. 7, Ed. Paul Edwards, Macmillan Publishing Co., New York, p. 507, 1967.) However, Nagel analysis provides a contrary picture. He unmistakably asserts that these issues are central to Newtonian dynamics (See The Structure of Science, Routledge, London, 1982 p.203 – 214).

There is no need for us to go into the merits and demerits of this dispute. It is sufficient to know what absolute theory means and what made Newton propose this theory (rightly or wrongly). Therefore Nagel has to be taken seriously. According to this theory space exists independent of matter. Accordingly, empty space is conceivable. In Book One of his *Principia* Newton defined absolute space as something which exists 'in its own nature and without regard to anything external, always remains similar and immovable'. Further, he proceeds to distinguish between relative and absolute space. He seems to believe that there is not one absolute space, but more than one because he speaks of absolute spaces. What he says of relative space is somewhat strange. It is, according to him, a movable dimension of absolute spaces. If so, both absolute and relative spaces coexist. Just as there is no acceleration without velocity there is no relative space without absolute space. His exposition implies that relative space is sensible whereas absolute space is nonsensible. In the same place he declares that '…we ought to abstract from our senses and consider things themselves' which Mach puts more clearly; 'pure things of thought, pure mental constructs'. Most probably Kant might have been inspired by this passage when he spoke of *Noumena'.*

Before we proceed further, we must be clear about certain terms used in connection with space and motion. Frame of reference is one such term and transformation equation is another. The former may be taken to mean a standard to which a reference is made. Whenever a reference is made to some standard to judge, then the judgment may hold good only with reference to that particular standard. When there is change of standard, the judgment also changes. For example, when an object is dropped from the top of a mast, according to an observer standing on the shore, it falls exactly at the foot of the mast. However, for an imaginary Martian observer it falls to the east of the mast. This difference creates reasons to introduce the concept of frame of reference. An observer on the earth also participates in diurnal and orbital motions of the earth. Such an observer cannot notice the effects of the motion on the fall of the body. Nor can he directly perceive the motion. In this case the earth is one frame of reference and Mars is another. What applies with reference to one frame of reference does not apply with reference to another. It means that what we perceive when we are on the earth is different from what we perceive when we are on Mars. Therefore the eastward shift of falling objects, as a Martian perceives needs some sort of transformation. This transformation is effected by simply considering the rotation and revolution of the earth which would not have been reckoned otherwise. We know that any physical quantity is expressed in the form of equations. Therefore when motion expressed with reference to the earth is modified or corrected and expressed with reference to Mars (or the other way round), then such modified equation is called transformation equation. This is the background of the manner in which motion is studied.

The need for such transformation arises because equations of motion, or anything connected to it are *not invariant* or constant from one frame of reference to another. This unique aspect prompted Newton to evolve *absolute space* and *absolute time.* Nagel's argument is that according to Newton '*kinematically* all motion is relative and *dynamically* ….motions must be referred to absolute space as the frame of reference'. This point becomes evident in the distinction which Newton makes between absolute and relative uniform velocity on the one hand and absolute and relative acceleration. He strangely maintains that the former cannot be experimentally verified whereas the latter can be verified. To substantiate his analysis he provides evidence in the form of bucket experiment. Strangely, this purported evidence ran into trouble with Newton's critics. Foremost among them is Mach. The debate also suggests how interpretation of experiment is as important as the experiment itself because Newton's interpretation ran counter to Mach's interpretation (for details see, 'The Structure of Science', Routledge, London, 1982, pp. 208 – 212).

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Explain the meaning of auxiliary hypothesis.

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4.7 LET US SUM UP

Newton synthesized Kepler's and Galileo's theories. In the Book Three of *Principia* Newton applies geometrical theorems to the universe. He considers two kinds of force, viz. centripetal and centrifugal. Gravitation is a more accurate version of centripetal force. Gravitation is independent of the sun though within solar system the sun is the source. It is universal because it applies everywhere. Newton believed that his theory of motion presupposes absolute space and time because motion is absolute and absolute motion presupposes absolute space and time. A study of motion in relation to space and time requires invoking different frames of reference and transformation equations.

4.8 KEY WORDS

Inertial System: This is a concept in Physics which is employed while accounting for variations in velocity. When the source of velocity is extremely far from our planet and velocity is exceptionally high as in the case of light rays. It also studies various aspects of mass and time which apparently differ from one system to another.

Frame of Reference: This is a term used in relativistic Physics to account for the standard of reference. Frame of Reference actually means a system which is regarded as a standard to measure different magnitudes which describe events in distant space.

4.9 FURTHER READINGS AND REFERENCES

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4.10 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. Kepler and Galileo played different games. Kepler's study was restricted to celestial mechanics whereas Galileo's study of inertial motion was confined to terrestrial bodies. Newton fused these two apparently distinct studies. What happened when these findings were extended to celestial bodies was something remarkable. This development took place in two stages. In the first stage, Newton included planets and satellites. In the second stage, Newton extended the same to all bodies irrespective of their position in space and time. After regarding the sun as the centre of the solar system, the law of falling bodies was extended to the bodies. This being the case the planets should simply fall towards the sun in the absence of inertial motion. In this sense the centripetal force, subsequently, is transformed into law of gravitation governing the behaviour of planets and satellites. In the next stage Newton proceeded to show that this law holds good in all cases and in this way Newton evolved universal law of gravitation. The difference between these two stages is that in the first stage the sun is the source of gravitation and in the second stage the gravitation becomes independent of the sun so that even very far from the sun, where its influence is nearly zero, the influence of gravitation controls movement.

Check Your Progress II

1. A theory must be insulated against falsification as far as possible and in spite of our best efforts if it is falsified, then a way must be invented to protect crumbling theory. Generally the escape route is to assume that observation itself must be a flawed one. Such an assumption is what is known as auxiliary hypothesis.

BLOCK 3

Science and philosophy are two separate disciplines, having their own domains. Science is an organised by branch of knowledge which has its own subject matter and a particular method to deal with. The whole aim of science is to give satisfactory answers to the questions raised. In this way philosophy becomes a critical looking into the ways and going about of the science: philosophy of science. The term *"philosophy of science"* is of recent origin. Science precedes philosophy of science. Philosophy is called as meta-science, which is a critical way of looking at science. It is difficult to locate exactly the origin of philosophy of science and to decide whether in antiquity or in modern era there was anything like philosophy of science either in the writings of philosophers or in the writings of scientists.

This block consists of four chapters aimed at making us familiar with contemporary philosophy of science and the various movements that rose during this period.

Unit 1 studies the Introduction to Contemporary Philosophy of Science. In this unit we will be making a demarcation between science and philosophy of science, by first of all getting to know what we understand by the term "Science", the method used by science, laws and theories that are accepted and Newton's concept of scientific method.

Unit 2 familiarizes us with Logical Positivism, the Basic ideas, its implications and critique. It was one of the prominent schools of philosophy. We will be introduced to the conceptual meaning of the term 'logical' and 'positivism', the whole aim of this school, the view of science, the areas that were thought to be possible to inquire into science, the role of observation, meaning and verification, the rationality of science, and lastly the criticism it faced.

Unit 3 deals with Historicism (Social Constructivism), the basic ideas and persons who contributed. Historicism, a major school of philosophy of science, is to be understood within the conceptual and historical setting of the opposing debates pertaining to the nature and scope of science and scientific knowledge opened up by Mechanical philosophy of Nature and Logical positivism.

Unit 4 probes into the contribution of Historical Realism, the Basic ideas, persons, implications and critique. We explain the inalienable importance of history in philosophising science; understand the philosophical contribution made by Imre Lakatos, Larry Laudan and Dudley Shapere, and the connection between the history of science and philosophy of science.

The whole new direction to science as we see today began during this time and this period will very clearly give us the importance of the philosophy of science. The schools of logical positivism, historicism and historical realism are highlighting the positive effects of synthesizing philosophy and science.

UNIT 1 INTRODUCTION TO CONTEMPORARY PHILOSOPHY OF SCIENCE

Contents

1.0 OBJECTIVES

This unit introduces you to the significance of philosophy of science and its relation to science. The manner in which science differs from philosophy of science is another issue with which you must become familiar. As science progresses philosophy of science also progresses. Therefore an understanding of contemporary philosophy of science helps you to assess and evaluate contemporary science. While doing so emphasis is laid on physics since physics and cosmology are interrelated.

When you are through this unit, you will be in a position to discover the hidden elements of science and critically evaluate various claims made by science

1.1 INTRODUCTION

It is difficult to locate exactly the origin of philosophy of science and to decide whether in antiquity or in modern era there was anything like philosophy of science either in the writings of philosophers or in the writings of scientists. This observation is essential because none of those philosophers who grappled with epistemological and metaphysical issues could afford to neglect the external world. Though some problems were common to philosophers and scientists, not all are philosophers of science. In the history of western philosophy Hume was the first philosopher to criticize certain aspects of science. He was critical of two aspects; one, the method purported to be the method of science and second, the nature of scientific law. Therefore in one sense of the term philosophy of science has its beginning in the philosophy of Hume and it began with attack on infallibility of scientific law and method purported to be the method of science. These criticisms, subsequently, exposed other aspects of science to closer investigation. The role of explanation is one such aspect. Therefore it is essential to begin our enquiry with what science is and what science is not. Before we do so we should get ourselves to the sense in which we use the term philosophy of science. Philosophy of science is the critique of science and whatever that is connected with science. Common sense suggests that science precedes philosophy of science not in temporal sense but in logical sense. Therefore philosophy of science comes after science. For this reason it is apt to call philosophy of science simply metascience. What does metascience reveal? Knowledge of any science helps us to acquire world-view. This is what metascience is all about. If metascience is the critique of science, what aspect of science is evaluated? This will concern us presently.

Metascience is essentially concerned with the attitude of the philosopher towards science. This attitude is reflected in the evaluation of various aspects which constitute science. A critical evaluation of the structure of scientific investigation, questions concerning the very possibility of scientific knowledge or impossibility and distinct method or methods of science which distinguish science from nonscience, etc. constitute the core of metascience. Therefore a brief survey of these prominent issues follows which provides a glimpse of the direction in which contemporary philosophy of science is proceeding.

1.2 SCIENCE AND EXPLANATION

At the outset, let us distinguish science from *Science.* The former is any specialized branch of knowledge. Hence it can be regarded as the species whereas *Science* is the class name. We are concerned with science in this sense. One of the ways of characterizing science is to regard it as an organized common sense. So we can go a step further and say that whatever contradicts commonsense also contradicts science. But such a characterization takes us nowhere. In the first place, science, on many occasions contradicts common sense, for example, modern physics. But on that account we do not sacrifice science to embrace common sense. Secondly, we are not sure at all as to what common sense is. We do not, certainly, mean that common sense is the opinion of a normal human being. If so, a collection and organization, if it is possible, of the opinions of average men should constitute science. But it is not so. So it is not a very good beginning unless we further qualify our stand. In the second place organization is possible in different ways. So it is equally essential that we specify the kind of organization we want. Mere sky watching does not make anyone an astronomer.

It is said that science has its origin in curiosity. Curiosity is not satisfied by organization of facts alone, whatever may be the type of organization. Science is distinguished from common sense by its 'explanatory power'. Curiosity arises when we are struck by something unexpected and unfamiliar. Science has its origin in problems. Explanation is the explanation of problem. Science is an organized common sense in the sense that such an organization must be capable of explaining and solving the problem.

1.3 EXPLANATION IN SCIENCE

An understanding of scientific enterprise requires that we should first know how science proceeds with its task. A good beginning is made when we begin with the nature of scientific explanation. Since explanation is qualified by the word scientific, we can infer that there is explanation which is not scientific. So there is need to distinguish scientific explanation from unscientific explanation. This is an important task set out by philosophy of science.

If the goal of science is to provide a satisfactory explanation, then an unsatisfactory explanation can be regarded as unscientific. A satisfactory explanation always answers *why,* i.e. reveals conditions under which an event occurs are stated. Though explanation is of various kinds, it has a common structure. The problem which is in need of an explication is called 'explicandum' and the statements which we offer by way of explication are called 'explicans' The minimum requirement is that there should be at least two explicans. One of them is a singular statement which applies to the event that has occurred and is called the "initial condition" and the other is a universal or conditional proposition and it is called a law. In a satisfactory explanation, the explicandum is implied by the initial condition or conditions and the law taken together. Consider an example.

L – Whenever pressure is reduced, volume of the given gas increases.

I - In this case pressure is reduced.

C In this case volume of the given gas has increased.

In this case L represents the law (which is Boyle's law), I represents the initial condition, and C represents the conclusion or explicandum.

It should be noted that though a law is always a universal proposition, not all universal propositions are laws. We shall consider two kinds of universal proposition; restricted or numerical universal and unrestricted or strict universal propositions. Only the later is considered a law. An example illustrates the difference between the two.

P_1: All objects "now" present in "this room" are good conductors of electricity.

P_2: All metals are good conductors of electricity.

P_1 is a restricted universal because by using the words "now" and "this room" we are imposing spatial and temporal restrictions. Tomorrow a bad conductor of electricity may enter this room, or to-day only outside this room a bad conductor of electricity may be present.P_1 is numerical because it is possible to count the number of objects in this room, since we take it for granted that this room has finite dimensions and the objects in this room have minimum dimensions. Another point to be noted is that either the law or the initial conditions taken singularly will not imply the conclusion. The absence of initial condition does not help because from a conditional proposition alone it is not possible to deduce singular (unconditional) proposition. The absence of law does not help us in establishing the relation between I and c.

A close look at the example given above indicates that the explanation assumes the deductive model, i.e., c_1 necessarily follows from L and I taken together. Here the 'explicandum…. is not a necessary truth, and….neither are the explanatory premises' (i.e. explicans)'. But what is important is that though the propositions here are a posteriori, the relation between them is logically necessary. In such a case scientific explanation is "structurally necessary", though in content or material it is contingent.

This is important because often a distinction is drawn between deductive explanation and other modes of explanation. It is enough for our purpose to consider one such model, viz., probabilistic explanation. The distinction between deductive and probabilistic explanations consists in the difference between the laws employed in these two kinds. In contrast to the conditional proposition or universal law, the probabilistic explanation includes what is known as statistical law. A statistical explanation is of the following form:

L_2: The probability of x occurring under condition y is n. (symbolically L_2 can be p (x, y) =n).

i_2 : z is y.

C_2 z is y.

Since the value of n ranges between 0 and 1 without touching either extreme, the conclusion also remains probable. Before proceeding further we can consider an example.

L_2: The probability of an undeveloped country (y) coming under military rule (x) is n (it is not necessary to specify the value of n).

i_2: Nicaragua (z) is an undeveloped country (y).

C_2 Nicaragua (z) will probably come under military (x).

It is believed that in a probabilistic explanation the conclusion does not necessarily follow from the premises. This mistaken view has its roots in the confusion between universal and statistical laws. The very fact that all laws are synthetic indicates that logical necessity is not involved in any law. Naturally, all laws are rendered improbable, i.e., falsifiable. So a statistical law also turns out to be improbable because that is also capable of being falsified.

Thus it can be seen that the difference between universal and statistical laws is only apparent. There is no real qualitative difference between the two. So structurally there does not seem to be any difference between the two, and consequently, in a satisfactory explanation. Whether deductive or probabilistic, the premises should necessitate the conclusion. Thus we are left with only one method of explanation, i.e., deductive explanation which Popper calls Axiomatized deductive system.

In a satisfactory explanation the premises should satisfy certain conditions. Apart from the condition that the premises should necessitate the conclusion, they should be true statements. It is not necessary that we "should know" the truth of the propositions. But as Popper says they should have testable consequence, and this is possible only when they are 'dense'. They are dense only when they are rich in content. Such a qualification eliminates speculative and theological explanations which, according to Reichenbach, are based upon similarity and hence pseudo-explanations.

1.4 LAWS AND THEORIES

Now it is obvious that the aim of science is to provide a satisfactory explanation and that in a satisfactory explanation the explicans must have the greatest explanatory power in virtue of their density of content. The discussion will be incomplete, if a reference is not made to another problem. One of the controversial issues in metascience is whether laws and theories are different or not. While Nagel holds that this distinction is fundamental, Feyerabend and Putnam consider the distinction only apparent. The logical extension of this argument is the attempts by philosophers like Bridgman, Russell, Eddington, etc. to reduce all theories to laws.

There are two kinds of laws; 'experimental laws and theoretical laws'. It is desirable to start with what is least controversial. An experimental law is expressed in a single statement while a theoretical law consists of a group and hence a system of statements. Consequently, the scope of the former is limited whereas the latter has wider application. Often, it is possible to deduce an experimental law from a theory. Finally, it is said that theories refer to abstract concepts and experimental laws refer to concrete entities.

The last one, when further pressed, points to an important difference. An experimental law consists of only those terms associated with certain observational traits whereas a theoretical law may or may not consist of such terms.

Stating the characteristic in this way is important because most of the terms employed in physics are not about what are directly observable. For example, pressure of a gas is not observable in the sense in which colour of that gas, if it has any, is observable; but pressure is observable in the sense that it can be measured. It is for this reason that measurement is considered an important characteristic of science. Physics, as a matter of fact, is full of such notorious terms. It is sufficient to name two experiments which illustrate this point; photoelectric effect discovered by Hertz and Max Planck's experiment on black body radiation. Photoelectric effect deals with the emission of electrons which are not observable. Planck's experiment was concerned with providing a physical picture of an ideal black body which is not observable because it is nonexistent. In the case of photoelectric effect the emission of electrons was studied by measuring such obvious entities like current (here called photoelectric current) and intensity of light. In the case of Planck's experiment black body radiation was studied by making use of measurable entities like the amount of heat, the visible spectrum etc.

These examples suggest that in an experimental law every term should refer to observable or measurable traits. So an experimental law is directly testable. But what is the status of a theory? To say that a theory is beyond test is, to say the least, highly unscientific. It is said that though a theory is not directly testable, it is possible to test a theory by testing the laws which are deduced from a theory. So the initial requirement of a good theory is that though, in itself, the theory is incapable of being tested, it should "generate" laws which are directly testable.

A reference to photoelectric effect and Planck's experiment on black body radiation has indicated the complexity of modern physics. The complexity is further aggravated, when we consider thermodynamics which studies the relation between heat and mechanical energy as in the case of driving car. In 1824 Carnot advanced the concept of an ideal heat engine. It is called an ideal heat engine because of the properties it is supposed to possess like perfectly non-conducting sides, perfectly frictionless, non-conducting and air tight piston and perfectly conducting base of the cylinder. The purpose of enumerating these qualities is to show that in the world of concrete objects no object possesses such properties. Hence it is an ideal heat engine. In other words, Carnot produced a concept to which no object in the world corresponds. Hence the observation, whether direct or indirect, of such an engine is not possible at all. How, then, can we study ideal heat engine? The second law of thermodynamics, which states that heat always flows from a body at higher temperature to a body at lower temperature, gave rise to another concept, i.e., "entropy." Clausius defined it as the ratio of heat received and the temperature at which it is received. If we represent the heat receive by q and the temperature by T, then entropy e is defined as

$$e = q/T$$

It should be noted that Clausius applied this concept to a system, i.e., an engine which does not interact with its surroundings. It is obvious that all engines interact with the surroundings, that they do not preserve heat constantly, but emit heat. Hence there is no engine to which the concept can be applied in reality.

These examples show that in science, in particular in physics, we study the concepts to which no real object corresponds. Then are they just fictitious? Certainly, they are not. These concepts are helpful because all objects or engines actually existing, and which are possible, roughly approximate to these concepts. In other words, with the help of the theories involving these concepts, it is possible to formulate the laws which explain all possible engines and thus we can generalize and say that all scientific discoveries have a conceptual basis.

Nagel holds another important distinction between an experimental law and a theoretical law. A descriptive term like current may occur in different situations, but will retain the same meaning, and in all cases the measurement yields the same result. But terms occurring in a theoretical law do not necessarily convey the same meaning always. The reason is that, according to Nagel, even when an experimental law undergoes modification, its truth-value remains constant. But when a theoretical law undergoes change, its truth-value is affected. For example, the law of gravitation is a theoretical law. Though the word gravitation appears both in Newtonian mechanics and the general theory of relativity, it does not convey the same meaning because the latter is the corrected version of the former. The same explanation holds good for other concepts, such as space, time etc. But in contrast to the theoretical terms, Nagel considers experimental law like Wien's displacement law which could explain only the shorter wavelength (to this we can add the experimental findings of Rayleigh and Jeans which explained only the longer wavelength, but not the shorter wavelength). Planck's hypothesis achieved the synthesis of these two laws without affecting their truth-value. The result is that both Wien's displacement law and Rayleigh - Jeans law are to be considered partially true and their inability to explain more is to be considered their limitation. But it is doubtful whether partial truth is not partially false. This issue cannot be settled unless it is possible to decide whether the degrees of truth can be allowed.

There is a striking similarity between Nagel and Popper. Both of them believe that a theory is not the result of an empirical generalization. Popper puts it slightly differently. Theories do not originate in observation, (however accurate they may be).Both of them believe that they are the "free creations" of mankind. Possibly, Popper had this aspect in his mind, when he said that science always tries to "explain the known by the unknown the observed (and observable) by the unobserved (and, perhaps, unobservable).

Here we find the point of departure. Nagel is not very emphatic regarding the relation between theory and observation. He goes to the extent of saying that observation may "suggest" a theory, though 'the basic terms of a theory need not possess meanings which are fixed by definite experimental procedures'…. . Further, he says that 'a law may survive the eventual demise of the theory. Here he comes very close to Popper's account. Since Popper believes that the demarcation between science and nonscience is only through the criterion of falsifiability, a theory, according to him, stands in need of refutation or falsification. The function of observation is ultimately to refute the theory. If we can accept the identity between an experimental law which has observable traits and observation, then it is obvious that the experimental laws should rigorously test the theory. It is in this sense that scientific statements are objective or testable .When a theory is falsified, it gives place to a new theory which also undergoes similar treatement. Thus the so called scientific pursuit has no end. Such a characteristic reinforces Popper's idea that science is not a system of absolute certainty, but a system of guesses or theories. Accordingly, he modifies the aim of science. To say that the aim of science is to provide a satisfactory explanation is tantamount to saying that its aim is not the search of irrefutable truth, but the 'critical quest for truth, or it is not infallibility, but fallibility that is the aim.

Thus the theories are of varying degrees. Every theory is an approximation to another theory which is superior to it. Now we can finalize our findings with reference to the examples cited above, Wien's displacement law and Rayleigh- Jeans law are closer approximations to Planck's hypothesis. Similarly, all heat engines are approximations to Carnot's ideal heat engine. All theories and laws, therefore, asymptotically approach the highest truth.

We can end up our discussion on laws and theories with a very brief reference to "reductionism" and its later formulation, viz., operationalism. Some scientists believed that it is possible to reduce or translate all theoretical terms to observational terms. Thereby, they meant that any theoretical term in science can be understood in terms of sense-data. Later, Bridgman gave a modified version by saying that all concepts in science are operationally understandable. For example, we can understand the concept of heat through sensation and can judge whether it is hotter or cooler. Not that Bridgman's attempt was free from defects. But the criticisms made against his theory, notably by L.J. Russell did not destroy operationalism, but only led to its reformulation by Bridgman. What is important is to note that equating operationalism with the involvement of sense organs, either directly or indirectly, meant that there were serious attempts to subject the physical world in all its finer details to experimental procedure.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. What does metascience mean?

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1.5 METHODS

The word 'method' is derived from two Greek words,'meta' and 'odos'.'Meta'means following and 'odos' means way. So scientific method means following a way which science accepts. In our unreflective mood we may claim that the aim of science is the discovery of truth. But the nature of scientific enterprise, which we have considered, indicates that this aim is not unanimously endorsed. For example, the aim of science can be projected as the pursuit of truth knowing fully well that the truth is something that can never be discovered. So if we substitute the word discovery by 'pursuit', the aim also changes. But this change in the aim does not alter the method contrary to the expectation, but only results in the variation in the interpretation of scientific method. In other words, our analysis and critical examination of scientific method undergo considerable change. That is, the difference in our aim affects our understanding of scientific method.

All sciences (we shall ignore mathematics) are necessarily empirical. Thus the necessity of observation in scientific method is undeniable. Equally obvious is the fact that mere observation which helps us to collect data, however exhaustive it may be, does not constitute scientific method. Collection of facts or data should be purposeful. The purpose, obviously, is to explain the problem. So formation of hypothesis, its verification, etc. follow. Now we can tentatively formulate the steps involved in scientific method as follows:

1) observation, collection and classification of facts
2) formation of hypothesis
3) verification of hypothesis
4) proof of hypothesis and establishing the scientific law

At the outset, these steps constituting scientific method appear to be too simple. As it is, the formulation of these steps is defective and hence demands correction. However, a brief explanation of these steps may be of some help in our later venture.

Verification and proof:

These four steps indicate that scientific method begins with observation without which the material for investigation cannot be gathered. The second step indicates that a hypothesis has to be formulated to explain the problem. But a hypothesis is only a tentative explanation. In order to evaluate its value it is necessary that first it should be verified. Verification is possible by means of deducing the observable consequences from the hypothesis. If these consequences occur, then the hypothesis is verified; otherwise, it is not.

As far as proof is concerned, it has to be pointed out that the proof of hypothesis in its positive sense is not possible. However, proof in its negative sense is no less important. Popper's concept of falsifiability is very much close to the negative aspect of proof. If two or more than two hypotheses yield consequences which are observed, then all these hypotheses are verified. But we have to choose the best one among them. It is here that falsification plays its vital role. If an instance or experiment falsifies all but one rival hypothesis, then such an instance or experiment is said to be crucial. But a crucial experiment can only falsify hypotheses. That is all. Falsification of one hypothesis should not be taken to mean the final confirmation of the other hypothesis.

The method of falsification is as follows. Two hypotheses may explain several aspects. But one of them, say h1, may fail to explain some newly known aspect, while another hypothesis, say h2, may succeed in explaining that phenomenon. When it is possible to achieve this measure, the hypothesis becomes a universal law. The competition between corpuscular theory and wave theory of light is a very good example. While corpuscular theory could explain only rectilinear propagation, reflection and refraction of light, wave theory could explain, apart from these phenomena, other phenomena like interference, diffraction, etc. Hence wave theory gained preponderance over corpuscular theory for some time.

This is in a nut shell the explanation of the supposed steps which constitute scientific method. Several objections can be raised against such an explanation. If scientific method should start with the observation of facts, one can certainly ask the question, observation of which fact'? It is absurd to say observation of all facts. Obviously, a scientist does not and cannot observe all facts. He has to make a selection of facts, i.e., he has to distinguish between facts which are relevant and which are not. While making such a distinction the scientist is guided solely by their relation with the problem that has generated the inquiry. So apart from a collection of facts what is required is a certain kind of attitude towards these facts. What is this attitude? Popper calls this critical attitude. That observation is conditioned by the relevance of facts in the light of the problem points to two aspects. First, the origin of scientific investigation lies in the discovery of problem. It is not necessary to solve the problem, but even to discover a problem a lot of ingenuity is required. Second, to say that certain facts are related to the problem and others are not is tantamount to the assertion that a certain theoretical background is required to select facts. So observation not only tests the theory, but also its very basis is in the theory. It may appear that we are arguing in a circle. But it is not so. The theory which is tested by observation belongs to one level and the theory which makes observation possible belongs to another level

Now we have eliminated one defect in the scheme of scientific method mentioned above. However, the relation between the observation of facts and the formation of hypothesis is not yet explicit. The order in which they occur may suggest that the formation of hypothesis follows the observation of facts. But it is not so. It is only in a problem situation that a hypothesis arises. The scientist gathers facts with the help of observation only to test the hypothesis. Hence for a clearer understanding the order should be reversed.

Finally, the fourth stage asserts that the proof (in positive sense) of hypothesis is possible, and formation of a scientific law is supposed to be dependent upon the proof. This is an erroneous view. According to this view, once a law is established it becomes irrevocable. In other words, the highest truth is achieved. If so, no progress in science will be possible from this stage onwards. The last stage can be taken only as an ideal towards which science travels. Proof in its demonstrative sense, is not possible. On the same grounds, we have to reject the third step also. Accordingly, the verification of hypothesis as a permanent measure is not possible. So we shall substitute the word 'test' for verification.

To show that there is nothing like final confirmation or decisive proof we shall consider the dual nature of light. Earlier, it was pointed out that wave theory of light gained preponderance over corpuscular theory for sometime. Though several phenomena like interference, diffraction, etc., showed that light consists of waves, there were other phenomena like black body radiation, photoelectric effect etc., which wave theory could not explain. In these cases light (the word light is usually replaced by 'electromagnetic radiation') exhibited the properties of particles or corpuscules. To explain these new phenomena light was considered consisting of particles which were also packets of energy or photons. De Broglie made an attempt to synthesize these two theories and he came out with his famous concept of 'matter waves'. It should be remembered that he only attempted to synthesize, but did not deny the reality of particles in light waves or light waves or light waves in particles. Therefore the dual nature of light persists.

Now our scheme of scientific method requires to be remodeled. According to this revised pattern, scientific method can be split on the following lines.

1) The tradition or myth leading to inborn expectations
2) Formation of several hypotheses
3) Rigorous tests with the help of observation in the following way:

i) deducing the observable consequences from each hypothesis.

ii) comparing these consequences among themselves to ensure coherence.

iii) evaluation of hypothesis to decide whether it provides new information.

iv) detecting whether these consequences occur or not in the external world.

The revised pattern indicates two points. In the first place, the hypothesis, occupies the central position in scientific method. In the second place, and the most important, the method is deductive. Hence it is rightly pointed out that scientific method is characterized by hypothetico-deductive character.

1.6 NEWTON'S CONCEPT OF SCIENTIFIC METHOD

The role of hypothesis in scientific method has, very often, become a debatable issue. In some cases it is overestimated, when it is said that a hypothesis can be proved beyond doubt and hence becomes a law. In some cases it is underestimated. Mill is one philosopher who neglected the role of hypothesis. It is a point to be noted that if scientific method is identified with inductive generalization, then hypothesis will not have any place. Newton tried to strike a balance by combining inductive and deductive aspects. His method is generally known as the method of analysis and synthesis. Analysis consists in making experiments and observation and in drawing conclusions from them by induction….. and synthesis consists in '*assuming* the causes discovered' …. And with them explaining the phenomena and proving the explanations. It is obvious that analysis is inductive and synthesis is deductive according to Newton. The words in italics are very important. These words carry the same meaning which we attach to hypothesis today. But when Newton insisted that the hypotheses have no place in experimental sciences, by the word hypothesis he meant what we mean by a hypothesis that cannot be tested. His point is that observation should take precedence over hypothesis. That is what exactly we mean when we say that a hypothesis should be tested by observation. This point is made clear by the fourth rule which Newton discusses under 'Rules of reasoning in Philosophy.

Rule 4. In experimental philosophy (i.e. Physics) we are to look upon propositions collected by general induction from phenomena as accurately….true notwithstanding any contrary hypothesis that may be imagined…..

Thus what Newton sought was an explanatory hypothesis providing more and more information and, therefore, testable. If we assume that Newton used the word induction to mean observation or experience, but not the process of generalization, Popper's theory comes very close to Newtonian theory. In fact, Newtonian dynamics does not show any sign of generalization. On the contrary, dynamics exhibits the signs of abstraction from observation. Consider, for illustration, his first law of motion.

I law: Every object perseveres in its state of rest or of uniform motion in a right line unless impeded by an external force.

It is obvious that there is no object which is free from force. Yet the first law refers to such a free body. In the second place, uniform motion is not possible. So the first law is not the result of an inductive process or generalization.

Newton's emphasis on deductive approach to scientific method is illustrated by his emphasis on axiomatic method which is deductive. The axiomatic method consists in starting with a set of axioms and applying the method to the external world. The application of the axioms to the external world enables us to follow the procedure outlined earlier. Thus instead of using the word hypothesis Newton uses the word axioms, and the rest remains the same.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1. Define explicandum and explican.

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2. Explain falsification with examples.

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1.7 LET US SUM UP

Philosophy of science is of recent origin. Science precedes philosophy of science. Though science is temporally prior to philosophy of science, logically, philosophy of science is prior to science. Therefore philosophy of science is renamed as metascience. Metascience is an attitude towards science. It is a critique of science and whatever connected with science. Explanation is an important aspect of science. There are two kinds of laws; theoretical and experimental. Science is distinguished from nonscience in virtue of its method. The purpose of test is to falsify a theory.

1.8 KEY WORDS

Metascience: means critic of science. It includes a critical appraisal of the nature of laws of science, its methods and limits.

Falsifiability: There is a difference between falsification and falsifiability. The former means that a theory is, in reality, falsified. The later does *not* mean that a theory *should be* falsified. It only means that it must be possible for a scientist to falsify a theory under normal conditions. But he may not be in a position to falsify due to several limitations.

1.9 FURTHER READINGS AND REFERENCES

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1.10 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. Common sense suggests that science precedes philosophy of science not in temporal sense but in logical sense. Therefore philosophy of science comes after science. For this reason it is apt to call philosophy of science simply metascience.

Check Your Progress II

1. The problem which is in need of an explication is called 'explicandum' and the statements which we offer by way of explication are called 'explicans'

2. The method of falsification is as follows. Two hypotheses may explain several aspects. But one of them, say h1, may fail to explain some newly known aspect, while another hypothesis, say h2, may succeed in explaining that phenomenon. When it is possible to achieve this measure, the hypothesis becomes a universal law. The competition between corpuscular theory and wave theory of light is a very good example. While corpuscular theory could explain only rectilinear propagation, reflection and refraction of light, wave theory could explain, apart from these phenomena, other phenomena like interference, diffraction, etc. Hence wave theory gained preponderance over corpuscular theory for some time.

UNIT 2 LOGICAL POSITIVISM: BASIC IDEAS, IMPLICATIONS AND CRITIQUE

Contents

2.0 THE OBJECTIVES

Logical Positivism had been a prominent school of the philosophy of science. This lesson is meant to introduce students to the philosophy of science of logical positivism. Its objectives are:

- To situate logical positivism in its historical setting.
- To discuss the meaning of the terms, viz., logical and positivism
- To familiarize oneself with the central philosophical and epistemological tenets of logical positivism
- To examine critically the various claims of logical positivism
- To cultivate in students the habit of critical thinking leading to a coherent vision of reality.

2.1 INTRODUCTION

Mechanical Philosophy of Nature was the dominant worldview in the 18^{th} and 19t^{h} centuries emerging from the Newtonian or classical physics. It looked at the cosmos as a huge machine, say, a giant clock. In many significant ways Logical Positivism could be considered a reincarnation of the Mechanical Philosophy of Nature. As Frederick Suppe points out, "mechanistic materialism was quite dominant in Germany in the nineteenth century, especially in the first half." Logical Positivism originated in the German world in the first half of the twentieth century from the Vienna Circle of M. Schlick and the Berlin Circle of Hans Reichenbach. "It arose as a convergence of three streams of developments: The empiricism of Hume, Mill and Mach; the methodology of empirical science as developed by Helmholtz, Mach, Poincare, Duhem, Boltzmann, and Einstein; and symbolic logic and linguistic analysis, as developed by Frege, Whitehead, Russell, and Wittgenstein." Logical positivism could be described as "a philosophical movement risen in Austria and Germany in 1920s, primarily concerned with the logical analysis of scientific knowledge, which affirmed that statements about metaphysics, religion, and ethics are void of cognitive meaning and thus nothing but expression of feelings or desires; only statements about mathematics, logic and natural sciences have a definite meaning. Its members included Rudolf Carnap (1891-1970), considered the leading figure of logical positivism, Herbert Feigl (1902-88), Philipp Frank (1884-1966), Kurt Grelling (1886-1942), Hans Hahn (1879-1934), Carl Gustav Hempel (1905-97), Victor Kraft (1880-1975), Otto Neurath (1882-1945), Hans Reichenbach (1891-1953), Moritz Schlick (1882-1936), Friedrich Waismann (1896-1959)."[i]

Einstein's theory of relativity had its indirect impact on the origin of logical positivism as the logical positivists explored the philosophical significance of the theory of relativity. Also the developments in quantum mechanics and the related epistemological and philosophical issues boosted the growth of logical positivism. The developments of formal and symbolic logic also exerted influence on logical positivism. By 1930s logical positivism was a prominent philosophical movement across Europe and USA.

2.2 THE GOAL OF LOGICAL POSITIVISM

Logical positivism is a particular approach to knowledge in general and to science and philosophy in particular. Vienna circle was a group of scientists, mathematicians and philosophers. They were reacting against the intrusion of mathematics in science. They believed that metaphysics is harmful to science. They criticized the use of metaphysical categories like Vital force (Henry Bergson) , Substantial Form (Aristotle), etc. The two-fold goals of the logical positivists could be articulated as follows:

1. They wanted to demonstrate the meaninglessness of metaphysics in general and science in particular.
2. They wanted to establish a firm foundation for science. They did not want metaphysics to be its foundation. This approach of the logical positivists was in sharp contrast with the method advocated by the Kantians.

2.3 LOGICAL POSITIVISM – CLARIFYING TERMS

Logical positivism is a combination of the two approaches upheld by positivism and symbolic logic. Positivism is a particular school of knowledge which advocates that valid knowledge must be based on sense knowledge. Any knowledge which is not based on senses is meaningless. It could be noted here that positivism is the extreme form of empiricism as the empiricists do not claim that knowledge not based on senses is invalid or meaningless, though they too advocate that knowledge should begin with sense experience. According to A. F. Chalmers, Logical Positivism is "an extreme form of empiricism according to which theories are not only to be justified by an appeal to facts acquired through observations, but are considered to have meaning only insofar as they can be so derived."

The recourse to 'logical' in logical positivism is on account of their emphasis on the use of symbolic logic. Symbolic logic is developed by formulating logical principles in symbolic and mathematical terms. For instance, if P stands for a statement, then in Px, x is a mother; In Qx x is a woman, then Px   Qx = if P, then Q. Px = Qx is a simple illustration of symbolic logic. This follows certain mathematical rules. Therefore symbolic logic is called mathematical logic. They advocated the use of symbolic logic in the analysis of science. Symbolic logic has the advantages of clarity and exactness and anything in science should be translated in terms of symbolic logic. If science is formulated in mathematical logic, then science is clear, distinct and exact. The principal function of the philosophy of science is the logical analysis of science.

2.4 IDEA OF SCIENCE

Logical positivists had a very narrow perspective towards science, whereby they thought of science as a set of laws, theories and principles. In tune with their focus on symbolic logic they conceived science as having two aspects; viz.,T and C.

T = Theoretical aspect

C = Corresponding rules

Every theory must be put in the symbolic form of T and C. Corresponding rules are rules which concretize the theory. It puts theory in contact with observable consequences. Corresponding rules are the interpretative system. These rules specify also the reliable experimental procedure.

For example, Boyle's law concerning the behavior of gas states that when the volume increases the pressure decreases. Gases are made up of molecules. These molecules move fast and they collide with each other. When Boyle proposed these things, its assumptions were merely theoretical. Nobody had observed molecules or collision between them. However Increase of pressure or decrease of volume or vice versa can be observed. This observable part belongs the 'C' part and the unobservable part belongs to the 'T' part. Science must be constructed mostly out of 'C.'

2.5 SCIENTIFIC KNOWLEDGE

Scientific knowledge can be had in two ways through empirical research and logical analysis. Empirical research is done by conventional science whereas logical analysis is done by the philosophy of science. A scientific statement has two parts, viz., Form and Content. For instance, the Newtonian idea of the law of gravity states that all physical bodies in the universe attract each other. It has a universal logical form which can be formulated mathematically. Therefore by Form is meant the structure or the logical model which covers the form of scientific explanation, law and theory. The content in this law refers to the force of attraction, nature of bodies, etc. A philosopher of science should be busy with the form of scientific explanation than with the content of the explanation. Content is the concern for conventional scientists. This is because they believe that the scientific character resides in the form. Form makes a statement a scientific statement. A particular phenomenon is explained by science when that is deduced from certain given laws and existing conditions.

2.6 AREA OF INQUIRY IN PHILOSOPHY OF SCIENCE

Is a philosopher of science obliged to study every bit of science? For logical positivists, the answer is, no. According to them, a scientific activity has two aspects:

1. The context of Discovery
2. The context of Justification

The context of discovery refers to all the personal, contextual and philosophical factors and processes that are involved is a new discovery. The context of justification refers to all that go into establishing the theory scientifically. The context of discovery is not the concern of Philosophy of science. It should be left to historicists, psychologists, sociologists, and others. The context of justification is the concern of the philosophy of science.

Their discard of the context of discovery conversely implied that the worldview of the scientist was irrelevant as far as the scientific work was concerned. A worldview refers to a cluster of factors like the cultural, social, religious, and personal aspects of the scientist. The educational background, family upbringing, prejudices and preferences, etc., also become part of the worldview. Logical positivists believed that these factors had no bearing on the science of the scientist. Every scientist from any part of the world with any type of background would arrive at the same scientific results as long as he/she proceeded scientifically.[ii]

Check Your Progress 1

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What is the goal of Logical Positivism?

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2) Write a short note on Scientific Knowledge.

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2.7 MEANING AND VERIFICATION

Logical positivists advocated the verification theory of meaning. The verification principle states that a contingent proposition is meaningful if and only there is an empirical method for deciding whether it is true or false. For example, the statement that 'light travels along straight path' can be experimentally verified and therefore a meaningful proposition. Whereas, there is no empirical method to prove the proposition that 'God exists.' Therefore this statement is false. It could be noted that logical positivists were atheists or agnostics in one way or the other.

According to logical Positivism, inductivism is the right method of scientific inquiry and that alone is capable of constituting authentic knowledge. It also believes that inductivism is an effective means to formulate infallible scientific generalizations on the basis of factually significant statements. "We say that a sentence is factually significant to any given person, if and only if, he knows how to verify the proposition which it purports to express – that is if he knows what observation would lead him under certain conditions to accept the proposition as being true or reject its opposite as being false." The factual significance of a statement is identified with verifiability, and verifiability in turn is identified with observation. The statement that can never be verified by observation is considered as insignificant and an insignificant statement is treated as unauthentic. Logical positivism is generous enough to recognize two kinds of verification – 'verification in practice' where the actual verification is possible and 'verification in principle' where only a possibility of actual verification is envisaged.

Logical positivism makes a distinction between authentic and pseudo statements. Consequently, it bifurcates the human claims-to–know into two irreconcilable systems – science and non-sciences. It has no doubt about the infallibility of authentic claims and the fallibility of psuedo claims. The inductivistic verifiability alone is the criterion to make such a bifurcation, and by means of the verification principle it grants permission to the scientific hypothesis to remain part of the authentic claims though a `conclusive verification' of hypothesis is not possible.

2.8 THE PRIMACY OF OBSERVATION

Logical Positivists made a sharp distinction between observation and theory, in other words, between O-terms and T-terms; O-terms are not problematic, whereas T-terms are confusing and misleading. Quantities pertaining to colour, length, warmth, etc., are examples of O-terms. Electric fields, electrons, atoms, etc., are examples of T-terms. Theories must be subsequent to observation. T-terms get their meaning and cognitive significance only through their connection with O-terms. If a T-term can somehow be connected with O-term, it will have legitimacy. "Sense observation was absolutely fundamental for LP (Logical Positivism). In a way scientific knowledge originated and terminated in observation, since all valid knowledge should be based on observational data and must be validated by observation. It made a sharp distinction between observation and theory, observational terms and theoretical terms. The former were usually reliable and non-problematic, whereas the latter problematic and messy. LP did not *reject* theoretical terms but said that they had validity and meaning as long as and in so far as they were related to observational terms. In fine, observation was the final court of appeal, as far as LP was concerned."

2.9 RATIONALITY OF SCIENCE

Logical Positivists looked at science as a privileged form of knowledge, a unique form of knowledge. Aristotle had called scientific knowledge *episteme* which meant firm, immutable, and certain knowledge. "It was different from *doxa*, which was only opinion, yielding only probable knowledge. This also meant that science and scientists were a breed apart, away from the ordinary run of things. In its extreme form Logical Positivism claimed that scientific knowledge was completely rational; irrational or even non-rational elements had no place in science. Scientific knowledge was unchanging since once something was established as science, it would remain essentially immutable (some modifications by way of extending the domain of its application, etc., were possible). Hence science gave eternal and universal truths. Scientific knowledge was objective, uncontaminated by personal elements. The passions and prejudices of the scientist exerted no influence on scientific knowledge."

2.10 CRITICAL EVALUATION OF LOGICAL POSITIVISM

Several recent developments in the philosophy of science have challenged the claims of logical Positivism and exposed their shallowness and untenability. Logical Positivism is no longer held as a viable philosophy of science. The decline in the influence of logical positivism was natural and essential on account of the bombastic and absolutist claims made by them.

The elitist view of science upheld by logical positivism was a sort of rational mythology. New schools of the philosophy of science arose in an attempt to demythologize the extreme claims of logical positivism. The schools of Historicism (also called Social Constructivism) and Historical Realism (Critical Realism) have struck a major blow to logical positivism.

Let us critically examine the various claims of logical positivism:

1. **Negation of Metaphysics:** The metaphysical antagonism of logical positivism poses a fundamental question. Should science use metaphysics? Logical positivists' very denial of metaphysics implies metaphysics. The illusory faith of the logical positivists in the infallibility of scientific claims resides in the hope that every fact could be explained in terms of theories based solely on observation. A scientific law is universal and has its basis in observation. But, is its universality observable? If not, how can logical positivists justify their acceptance of these laws? Again, what is the validity of the fundamental methods of science like induction and inference? Logical positivists' denial of metaphysics is finally a metaphysics of scientific megalomania. Alan Wallace's observation has an explicit message to them. "A disinterest in metaphysics may result not in abstention from such concerns, but in unconscious, unintelligent adoption of a particular form of metaphysics."[iii] Denial of metaphysics and its necessary prelude of observation as the ultimate criterion of truth seem to be philosophically a very minimalist approach to Reality.

2. **Distinction between Discovery and Justification:** Their distinction between the context of discovery and the context of justification betray a very naïve and parochial vision of

science. The process of discovery or the moment of discovery is cherished as one of the most exciting aspects of the scientific enterprise. The irrational imaginative leap taken by Max Planck in the discovery of the quantum hypothesis, or Einstein's personal conviction of the inherent harmony of the cosmos which led him to the formulation of the relativity theory, etc., are classical examples of the significance of the context of discovery. Delinking justification from context is a mere idealization of science.

3. **Absolutization of Mathematics:** They over-emphasized the importance of mathematics in science. There is no perfect or ultimate axiomatisation or mathematization possible in science. There are several phenomena in contemporary science which cannot be adequately formulated mathematically. The quantum paradoxes like regeneration, mechanincal stability, wave-particle duality, probability, uncertainty, etc., encountered in the subatomic world are examples to it. The anti-metaphysics attitude of the logical positivists forced them to attribute natural laws to the "software" of the universe. It reduces reality to a mere process of computation. The classical physicists' radical conviction of translating reality into mathematizable quantities was a scientific practice based on this view. To this assumption, Einstein has given a severe jolt: "As far as the laws of mathematics refer to reality, they are not certain; as far as they are certain, they do not refer to reality."[iv] Eventually logical positivists themselves had realized that only a very few theories could be mathamatized completely. So they had partly given up the idea of mathematizing the whole scientific theories. Law reductionism in some ways seems to be scientifically presumptuous because it would mean, "such elementary laws are *more intelligent than we are ourselves.*"[v] Ultimately, this tendency to reduce everything to mere laws is the projection of an extreme faith in the omnipotence of those laws without daring to look at the power and mystery behind them.

4. **Meaning Invariance:** As for the logical positivists, the meaning of scientific theories does not change. They claim that even in the case of the transition from the geocentric worldview to the heliocentric worldview there was only a minor change. There is no radical change in science. Logical positivists were very much in the line of Aristotle. New findings may be added, but no radical change. But this is not the case in science.

Scientific theories are always changing and evolving. The concepts, meaning, theories and explanation of science are often radically replaced.

5. **The Distinction between O-terms and T-terms:** Logical Positivists made a sharp distinction between Observational terms and Theoretical terms. But no absolute distinction is possible between these two terms. As science develops more and more, many T-terms become O-terms. The very concept of absolutely independent and objective observation is questionable in several aspects of the present-day science. Today many scientists and philosophers of science say that most observations are theory laden. For example, our observational statement that 'sun rises in East' is still governed by the geo-centric worldview. On the basis of the uncertainty principle in quantum physics, physicists have argued that "microrealism"[vi] is an illusion in the quantum world. In the wider sense, the collapse of microrealism implies that in the ultimate analysis the world is "non-separate" from us. In quantum theory the measuring device plays an important role in our picture of Reality. Associating the collapse of the wave function with the observer's consciousness, physicist John Wheeler and colleagues have said that it is consciousness that creates Reality. In Wheeler's words: "Nothing is more important about the quantum principle than this, that it destroys the concept of the world as 'sitting out there,' with the observer safely separated from it by a 20-centimetre slab of plate glass.... To describe what has happened, one has to cross out that old word 'observer' and put in its place the new word 'participator.' In some strange sense, the universe is a participatory universe."

6. **Verification Theory of Meaning:** As for logical positivists, verifiability (empirical) becomes the criterion for meaningfulness. According to logical positivism, inductivism is the right method of scientific inquiry and that alone is capable of constituting authentic knowledge. It also believes that inductivism is an effective means to formulate infallible scientific generalizations on the basis of factually significant statements. But this should be noted that the very verification theory itself cannot be subjected to the verification method. Thus in the formulation itself, this principle is self-defeating. It could also be noted that the very inductive method of science goes contrary to the claims of logical positivism. For instance, to treat water as H_2O is a universal statement. In every kind of

water we find the combination and make the absolute statement that water is H_2O. Can it be valid for all time and space? As a logical positivist one is supposed to go only by observation and verification and one has not experimented with every water molecule to conclude that water is H_2O. Given their principles, one's conclusion is not authorized by the premises. The logical positivists' model of the philosophy of science unambiguously propagates both methodologism and methodological monism.

7. **Karl Poppers' Critique:** Karl Popper launched a massive assault on the verification method of the logical positivists. Popper is considered to be the bridge-builder between logical positivism and historicism. According to him the greatest problem in philosophy is the problem of the growth knowledge and the best way to know the growth of knowledge is to know the growth of the scientific knowledge. Instead of verifiability, he advocated falsifiability as the criterion of meaning in science. Scientific knowledge is to be assessed in terms of *Falsification*. The notion of falsification is his unique contribution to the philosophy of science. History of science shows that science is a series of conjectures and refutations. A scientist proposes a hypothesis. Instead of trying to establish it, he tries to refute it. If the hypothesis is refuted, it should be given up. If the hypothesis is refusing to be refuted, it is corroborated and becomes hypothesis two and subsequent hypotheses are added. One can always find positive instances in everything that one brings out in each subsequent hypothesis. This technique, Popper calls the Falsification. The criterion of demarcation between science and non-science is the falsifiability. A scientific statement is a statement that can be subjected to the method of falsification. He stresses the role of observation and at the same time doesn't make a sharp distinction between theory and observation.

8. **Historicist Criticism:** Historicism arose mainly as a reaction against logical positivism. Its main aim was to demythologize the logical positivist understanding of science. Historicists were of the opinion that there are non-rational elements also in science as opposed to the logical positivists' view. Historicists emphasized the history of science. They studied about what went on in the past and what is going on in the present. The historicists looked at science as it is, whereas the logical positivists looked at science as it should be. Historicists

showed that there are also irrational elements in science. Science is a mixture of rational and irrational elements. There are also subjective elements in science. Historicists also emphasized the concept of ***Weltanschauung.*** *Weltanschauung* or worldview is a collection of factors like background, training, passions, bias, prejudices, etc., of the scientist. The worldview of the scientist plays a crucial role in science. The worldview colors and controls the world of the scientist. Philosophy of science is meant to identify this worldview. The unique claim to truth by science of the logical positivists is proved to be mythical. Science is just one among many other disciplines.

2.11 LET US SUM UP

- In many significant ways Logical Positivism could be considered a reincarnation of the Mechanical Philosophy of Nature.
- Logical Positivism wanted to demonstrate the meaninglessness of metaphysics in general and in science in particular.
- Logical positivism is a combination of the two approaches upheld by positivism and symbolic logic.
- For logical positivists, the context of discovery is not the concern of Philosophy of science. The context of justification is the concern of the philosophy of science.
- A philosopher of science should be busy with the form of scientific explanation than the content of the explanation.
- The verification principle states that a contingent proposition is meaningful if and only there is an empirical method for deciding whether it is true or false.
- Logical Positivists made a sharp distinction between observational terms and theoretical terms.
- The various claims of logical positivism are loaded with serious philosophical problems and have lost their relevance in the contemporary scientific and philosophical context.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What do you understand by rationality of science?

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2) Write a short note on Verification Theory of Meaning.

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2.12 KEY-WORDS

Vienna Circle: The Vienna Circle was a group of philosophers who gathered around Moritz Schlick when he was called to the Vienna University in 1922, organized in a philosophical association, of which Schlick was Chairman. Among its members were Gustav Bergmann, Rudolf Carnap, Herbert Feigl, Philipp Frank, Kurt Gödel, Hans Hahn, Tscha Hung, Victor Kraft, Karl Menger, Richard von Mises, Marcel Natkin, Otto Neurath, Olga Hahn-Neurath, Theodor Radakovic, Rose Rand and Friedrich Waismann. With the exception of Gödel, members of the Vienna Circle had a common attitude towards philosophy, characterized by two main beliefs: first, experience is the only source of knowledge; second, logical analysis performed with the help of symbolic logic is the preferred method for solving philosophical problems.

Quantum Physics: Quantum physics is a branch of science that deals with discrete, indivisible units of energy called quanta as described by the Quantum Theory. There are five main ideas represented in Quantum Theory: 1. Energy is not continuous, but comes in small but discrete units. 2. The elementary particles behave both like particles *and* like waves. 3. The movement of these particles is inherently random. 4. It is *physically impossible* to know both the position and the momentum of a particle at the same time. The more precisely one is known, the less precise the measurement of the other is. 5. The atomic world is *nothing* like the world we live in.

2.13 FURTHER READINGS AND REFERENCES

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2.14 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1. Logical positivism is a particular approach to knowledge in general and to science and philosophy in particular. Vienna circle was a group of scientists, mathematicians and philosophers. They were reacting against the intrusion of mathematics in science. They believed that metaphysics is harmful to science. They criticized the use of metaphysical categories like Vital force (Henry Bergson) , Substantial Form (Aristotle), etc. The two-fold goals of the logical positivists could be articulated as follows: They wanted to demonstrate the meaninglessness of metaphysics in general and science in particular.They wanted to establish a firm foundation for

science. They did not want metaphysics to be its foundation. This approach of the logical positivists was in sharp contrast with the method advocated by the Kantians.

2. Scientific knowledge can be had in two ways through empirical research and logical analysis. Empirical research is done by conventional science whereas logical analysis is done by the philosophy of science. A scientific statement has two parts, viz., Form and Content. For instance, the Newtonian idea of the law of gravity states that all physical bodies in the universe attract each other. It has a universal logical form which can be formulated mathematically. Therefore by Form is meant the structure or the logical model which covers the form of scientific explanation, law and theory. The content in this law refers to the force of attraction, nature of bodies, etc. A philosopher of science should be busy with the form of scientific explanation than with the content of the explanation. Content is the concern for conventional scientists. This is because they believe that the scientific character resides in the form. Form makes a statement a scientific statement. A particular phenomenon is explained by science when that is deduced from certain given laws and existing conditions.

Answers to Check Your Progress II

1. Logical Positivists looked at science as a privileged form of knowledge, a unique form of knowledge. Aristotle had called scientific knowledge *episteme* which meant firm, immutable, and certain knowledge. "It was different from *doxa*, which was only opinion, yielding only probable knowledge. This also meant that science and scientists were a breed apart, away from the ordinary run of things. In its extreme form Logical Positivism claimed that scientific knowledge was completely rational; irrational or even non-rational elements had no place in science. Scientific knowledge was unchanging since once something was established as science, it would remain essentially immutable (some modifications by way of extending the domain of its application, etc., were possible). Hence science gave eternal and universal truths. Scientific knowledge was objective, uncontaminated by personal elements. The passions and prejudices of the scientist exerted no influence on scientific knowledge."

2. As for logical positivists, verifiability (empirical) becomes the criterion for meaningfulness. According to logical positivism, inductivism is the right method of scientific inquiry and that alone is capable of constituting authentic knowledge. It also believes that inductivism is an effective means to formulate infallible scientific generalizations on the basis of factually significant statements. But this should be noted that the very verification theory itself cannot be subjected to the verification method. Thus in the formulation itself, this principle is self-defeating. It could also be noted that the very inductive method of science goes contrary to the claims of logical positivism. For instance, to treat water as H_2O is a universal statement. In every kind of water we find the combination and make the absolute statement that water is H_2O. Can it be valid for all time and space? As a logical positivist one is supposed to go only by observation and verification and one has not experimented with every water molecule to conclude that water is H_2O. Given their principles, one's conclusion is not authorized by the premises. The logical positivists' model of the philosophy of science unambiguously propagates both methodologism and methodological monism.

UNIT 3 HISTORICISM (SOCIAL CONSTRUCTIVISM): BASIC IDEAS, PERSONS, IMPLICATIONS AND CRITIQUE

Contents

3.0 OBJECTIVE

The objective of this section is to introduce students to the main ideas of historicism, one of the schools of philosophy of science. In doing so a very brief explanation of the main exponents of historicism is also given. At the end a very short critique of historicism is given as to encourage students to facilitate in them the process of critical reasoning. Some of the basic questions are placed at end of each section in order to contribute to the better understanding of the subject.

3.1 INTRODUCTION

Historicism, a major school of philosophy of science, is to be understood within the conceptual and historical setting of the opposing debates pertaining to the nature and scope of science and scientific knowledge opened up by Mechanical philosophy of Nature and Logical positivism. Several important developments in the philosophy of science led to the collapse of the extreme positions held by logical positivism. The setting of Historicism and its major contentions may be succinctly put as follows:

> The influence of LP began to wane in the second half of the twentieth century, thanks to the strong and almost violent reaction to it from Historicists (also called the Social Constructivists). Karl Popper, Norwood Hanson, Stephen Toulmin, Thomas Kuhn, Paul Feyerabend, and others challenged many of the claims of LP, and showed them to be untenable and unnecessary. They challenged the "elitist claims" of science propounded by LP and argued that science could make no claim to uncompromising rationality, objectivity, stability, and certainty. Science's claim to deliver eternal and immutable truths was shown to be unjustified by hard historical data. They also emphasized the role played by the worldview of the scientist in determining and defining the science of the scientist. The supreme role accorded to observation in science was shaken when the Historicists persuasively argued that all observations are theory-laden, influenced by theory.

Historicists are called so because they emphasized the history of science. They studied about what went on in the past and what is going on in the present. In future, the present will become part of history. Therefore, every scientific theory has to do justice to the history of science. If it does not fit into the history of science it fails to be a good scientific and rational theory. Historicists, in Thomas Khun's words, try to present "… quite different concept of science that can emerge from the historical record of the research activity itself." Historicists, in contrast to the logical positivists were more realistic to the reality of science unlike the idealistic vision of the logical positivists. The historicists looked at science as it is, whereas the logical positivists looked at science as it should be. It is also known as social structuralism.

3. 2 OBJECTIVE OF HISTORICISM

Historicism arose mainly as a reaction against logical positivism. Its main aim was to demythologize the logical positivist understanding of science. For logical positivists, scientific knowledge is governed by strict rules of rationality. Non-scientific factors like prejudices, upbringing, etc., have nothing to do with science. Historicists were of the opinion that there are non-rational elements also in science as opposed to the logical positivists' view. The real model of science should emerge from a serious and genuine involvement in the history of scientific enterprises.

3.3 REFUTATION OF THE LOGICAL POSITIVISTS

Historicists were the ones who initiated attack on the ideas of logical positivism. Most of the characteristic features of logical positivism are rejected by historicist school of philosophy of science.

> Some of the views of Historicism against LP (Logical Positivism) were excessive and went to the other extreme, but they exposed the inner weakness and the innate poverty of LP. The criticism by Historicism has been so powerful that LP lost its claim as a viable philosophy of science; today it has been reduced to a part of the history of philosophy of science. With the decline of LP its objections to a constructive engagement between science and religion also recede to the background.

Given below are the ways how major tenants of historicism are discarded by the proponents of the historicism.

RATIONALITY OF SCIENCE

For centuries science is characterized by its rationality. Anything to be scientific has to be rational. Irrational elements had no place in science, whether in the process of evolution of scientific theory or discovery. With logical positivists rationality got to the upper rung of the scientific projects. Historicists hold that there are also irrational elements in science. Science is a mixture of rational and irrational elements. Historicists, like Thomas Khun, are of the opinion that sociological and psychological factors do play a greater role in the explanation of the evolution of science and its history. You cannot really demarcate between 'the world of facts' and the 'world of mathematics.'

OBJECTIVITY OF SCIENCE

Objectivity, for long, has been considered as the trademark characteristic of science. While logical positivists held on to the validity of scientific knowledge irrespective of place, person and time, historicists were reluctant to perceive science as something absolutely objective. Scientific projects are influenced by subjective elements also. Thomas Khun writes, "Among those legitimate possibilities, the particular conclusions he (scientist) does arrive at are probably determined by his prior experience in other fields, by the accidents of his investigation, and his own individual makeup." They claim that logical positivists' unique claim of truth is proved to be mythical. Science may be just one enterprise in the expedition towards truth among many other disciplines but as Stephen Toulmin puts it, "This is not work for the untutored imagination. It may be an art, but it is one whose exercise requires stiff training."

OBSERVATION

Traditionally scientific truth has been intimately allied to observation. It was and still is very difficult for the scientific community to accept anything as 'true' unless it is observably verifiable. But the fact is that some scientific phenomena need not always be observable. For the logical positivists anything that is scientific should always be observable. However, the quark theory in physics suggests that quarks are the rock bottom of any reality. Everything is made up of quarks. A quark can't be observed in isolation. Yet it is a real entity, because it can be observed as a group. Thus observability is no more an absolute criterion of scientific truth.

MEANING INVARIANCE

Logical positivists were the staunch supporters of the invariance of meaning irrespective of place, time and person. However, for historicists nothing in science is permanent. Every scientific enterprise aims at initiating a 'paradigm-shift.' Therefore, scientific meaning, criteria, theories, methods, laws and everything in science change. Historicists, especially Thomas Khun, expound a kind of scientific arbitrariness in scientific activities. He, however, does not see any place of an uninhibited arbitrariness but "that element of arbitrariness does not, however, indicate that any scientific group could practice its trade without some set of received beliefs."

This element of unpredictability does play a significant role in the process of scientific development. It is this variance in the process of a scientific project that makes science ever endearing to the scientific community. To quote Thomas Khun “What were ducks in the scientist’s world before the revolution are rabbits afterwards. The man who first saw the exterior of the box from above later sees its interior from below.”

EMPHASIS ON *WELTANSCHAUUNG* (WORLDVIEW)

For long scientific developments were conceived as objective, unaltered by the persons and their backgrounds involved in that process. But with historicists worldview of a scientist or the one who engages in any scientific enterprise has a major impact on the outcome of the process of scientific evolution. *Weltanschauung* or worldview is a collection of factors like background, training, passions, bias, prejudices, etc. of the scientist. The worldview of the scientist plays a crucial role in science. Thomas Khun states it very clearly when he writes,

> Transformations … though usually more gradual and almost always irreversible, are common concomitants of scientific training. Looking at the contour map, the student sees lines on paper, the cartographer a picture of a terrain. Looking at a bubble-chamber photograph, the student sees confused and broken lines, the physicist a record of familiar subnuclear events. Only after a number of such transformations of vision does the student become an inhabitant of the scientist’s world, seeing what the scientist sees and responding as the scientist does.

The worldview colors and controls the world of the scientist. According to the historicist school of philosophy of science, the task of philosophy of science is to identify this worldview.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) How does worldview or weltanschauung affect scientific enterprises according to historicists?

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2) How do historicists critique Logical Positivists?

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3.4 EXPONENTS

The major exponents of the school of historicism are Thomas Khun, Paul Feyrabend, Stephen Toulmin and Noorwod Russell Hanson.

THOMAS KUHN

He is the most popular among historicists. *The Structure of Scientific Revolution* is his most famous book. According to him science is a communitarian enterprise done by a group united from the possession of a common paradigm or model. Paradigm for him is a general theory or a comprehensive theory accepted by all the members of the group. It is an encompassing sort of theory. Scientific community is a community, which accepts one particular theory of reality.

ANOMALY, REVOLUTION, NORMAL SCIENCE AND INCOMMENSURABILITY

Science is an ongoing chain of revolution interrupted by periods of normal science. "…normal science means research firmly based upon one or more past scientific achievements, achievements that some particular scientific community acknowledges for a time as supplying the foundation for its further practice." Revolution and normal science are the two events of which the science is made up. Revolution is a special event in which an existing paradigm is discarded and another is accepted. Revolution in science is the threshold to a new world view. "… during revolutions scientists see new and different things when looking with familiar instruments in places they have looked before." Normal science is the period of consolidation and conversion. After the new paradigm is accepted, we try to get the maximum benefit of it. This is what ordinary people consider as science. Khun says that normal science grows cumulatively whereas the growth of revolutions in science is non-cumulative.

Scientific community while working on a paradigm notices anomalies or deviations from the expected paths. It is the anomalies that give rise to revolutions and subsequent paradigms. Anomalies are the launching pad for new scientific discoveries. These crisis periods are assumed to be the prerequisite for the emergence of new scientific theories. As explained by Thomas Khun, novelties in science are the derivative of anomalies or "counterinstances". Anomaly is an "awareness of something wrong or does relate the effect to something that has gone wrong before." A new paradigm is accepted not on rational reasoning alone. It is more accepted by persuasion. Irrational factors also play a role in the acceptance of a new paradigm.

During the time of revolution, scientists experience incommensurability or communication breakdown. Scientists belonging to two different paradigms will try to communicate each other but will not succeed. They will be talking at cross-phenomena. They will use the same word, but will mean different things. This state is called incommensurability. It will take some time before scientists belonging to different paradigms could communicate easily. "The normal-scientific tradition that emerges from a scientific revolution is not only incompatible but often actually incommensurable with that which has gone before."

STEPHEN TOULMIN

Toulmin was the first to propose an alternative to logical positivism. He has authored a number of books, *The Philosophy of Science: An Introduction*, the first one and *Human Understanding* being his most famous. According to him, the function of science is to build up a system of ideas about nature, which has a legitimate claim to reality. He argued that truth is a relative quality dependent on culture and history.

TOULMIN'S UNDERSTANDING OF SCIENTIFIC THEORY

According to him a scientific theory consists of three parts:
Natural Order: In every science, there are certain things accepted as natural and therefore need not be explained. These items are the natural order. Eg. The velocity of light is a constant.

Law: Law is a regularity, which has been found useful. Laws explain deviation from ideals or natural order. Scientific laws are irregularities found in the natural order. Scientific law is the answer to the 'why' of the irregularities in the natural order.

Hypothesis: Hypothesis is a regularity whose usefulness is still in question and remains to be established. Established propositions cease to be hypothesis. Stephen Toulmin writes, "…we are debarred from speaking of the established propositions as being hypothetical unless and until they themselves become once again the subjects of active doubt."

NOORWOOD RUSSELL HANSON

His most famous work is *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science.* Hanson believed that logical positivists concentrated more on the finished product. They did not look upon science as a process or becoming. Logical positivists do not look upon the process of discovery in science. Hanson kept just the opposite view. The logic of scientific discovery is identifiable and definable. According to him, science is theory laden in every way. He is the one who pioneered the argument that observations are theory laden. To say that the facts are objective is a misrepresentation of state of affairs. Even some of the fundamental principles we hold are theory laden. There is an intrinsic connection between cause and effect. Similarly observation language and theory language are entwined. He is the one who initiated a movement against the traditional opposition between history of science and philosophy of science and stood for an interdisciplinary approach towards truth.

METHOD OF RETRODUCTION

His unique contribution is the proposal of the method of retroduciton. He characterizes retroduction or abduction in the following way, “Theories put phenomena into systems. They are built up "in reverse"- retroductively. A theory is a cluster of conclusions in search of a premise. From the observed properties of phenomena the physicist reasons his way towards a keystone idea from which the properties are explicable as a matter of course.”

The logic proper to scientific discovery is retroduction or abduction. Let us say, firstly, some surprising phenomena p1, p2, p3 have occurred. Secondly, suppose a hypothesis H is accepted, then p1, p2, p3 are not surprising. They are natural and expected. Thirdly, therefore, there is good reason to accept it. But, this in fact is not the logic of scientific discovery. This is a very simplistic account. If H is obtained, it is settled. But the question is how to obtain the H. The discovery of H is the fundamental question of retroduction and therefore the process of the formation of the hypothesis should have a considerable character in the philosophy of science.

PAUL FEYRABEND AND HIS IDEA OF SCIENCE

Paul Feyrabend’s famous works and *Against the Method* and *Science in a Free Society*. His explanation went to the other extreme of the logical positivists. In his book, *Against the Method*, he represents science as a discipline without any method since any method would limit the scope of scientific activity and consequently would affect scientific development adversely. He promoted pluralism of theories in its place. There will be many theories at a time. Hence plurality is to be acknowledged even if there are contradictions. As opposed to the logical positivists’ invariance principle, Feyarabend held that meaning variance is the principle. “… argument against meaning invariance is simple and clear. It proceeds from the fact that usually some of the principles involved in the determination of the meanings of older theories or points of view are inconsistent with the new, and better, theories.” Meaning of the scientific terms does change as science progresses. E.g. The term planet.

3.5 CONSEQUENCES

Relativism: Science becomes very much relativistic because of the exaggerated role they attribute to the worldview of the scientist. In the historicists scheme of things the world view of the scientist is colored by a number of factors like upbringing, cultural context and social background. Therefore an absolutely objective scientific enterprise, according to historicists, is not possible though in fact, many scientists are capable of overcoming their worldview.

NON-RATIONALISM

Most of the historicists are critics of rationalism. They do hold that reason is not the only factor in the evolution of science. Non-rational elements do play a greater role in the scientific enterprises. Sociological and psychological factors influence science. Therefore the "explanation of the evolution of science is to be done externally and not internally." This emphasis on the non-rational elements by the historicists run into the danger ending up in irrationalism.

SUBJECTIVITY

Imagination, passions and other related factors of subjectivity of the scientists are emphasized in science. Subjective factors, for long, have been crafted out of science and with historicists subjectivity makes a comeback. "…And scientists, contrary to the myth that they themselves publicly promulgate, are emotional human beings who carry a generous dose of subjectivity with them into the supposedly 'objective search for truth.' Though it is true that subjective elements have a say in science, historicists do present an exaggerated role of subjectivity in science. It is not only the external factors of the scientists that would affect the scientific projects but consciousness also plays an important role in what was supposedly regarded as detached scientific efforts.

3.6 CRITIQUE

Having seen the characteristics and the main proponents of historicism let us now see some of the common criticism leveled against historicism.

CROSS PARADIGMS

Historicists idea of paradigm is that new paradigm is evolved at the degeneration of the old paradigm. This is paradigm shift. But in most of the evolved paradigms in science we see a cross connection of ideas and theories. Many elements, even basic, are taken from the discarded paradigm and is carried onto the new paradigm. Hence critics of the historicism do find problems to call this process a ‘paradigm shift, as the new paradigm that has evolved is new in its entirety. Therefore the new paradigm that has been evolved is a mixture of old and new and thus defies the absolute claims of novelty by the historicists.

ACCEPTANCE OF THE PARADIGM

A particular paradigm is seen as the prerogative of a particular scientific community. Important question here is that how about the acceptance of a particular paradigm. Is it the acceptance by the entire group or the usefulness of a theory that determines the acceptance and validity of a scientific research programme? Again do we need the acceptance by each and every individual scientist for a scientific programme to be accepted by the entire community of the scientists? Historicists are silent on the criterion of the acceptance of a programme as paradigm by the community. It is also true that the current paradigm have solved more ‘anomalies’ than its predecessor but critics doubt the possibility of a completely anomaly free paradigm. Therefore, the acceptance and rejection of an anomaly is not guaranteed on the basis of the presence or absence of problems rather on the conviction of the present one being better one to solve the problems of science.

CRITIQUE OF THE IDEA OF INCOMMENSURABILITY

Historicists are not consistent in their understanding of incommensurability. Historicists among themselves swing between the mild and extreme forms of incommensurability. Furthermore, there is less consensus among them about the criterion to determine the communication breakdown. While they all agree on the problem of communication breakdown, historicists also fail to find an appropriate solution so as to make communication between different scientific programme could be made more easier which ultimately leads to the development. It is understood that incommensurability happens due to the rejection of the tools, concepts and methods of the old paradigm, but it is also seen that many a times old concepts and methods are sustained in the new paradigm too. It is to be critically examined that whether semantic incommensurability is bred by methodological incommensurability or vice versa.

CRITIQUE OF SUBJECTIVISM

Historicists over emphasis on subjective elements in scientific research programme renders truth a result of our own desires, passions and imaginations rather than the way world out there is. Science is a reflection of our subjectivity. Another danger of this kind of unbridled emphasis on subjectivity is the problem of relativity and ultimately there is a proliferation of theories and chaos of opinions. Their over emphasis on history has rendered science the picture of a cultural artifact.

3.7 LET US SUM UP

Disproving the logical positivists was one of the central concerns of the Historicists. Hence they tended to make absolute statements, which seemed to betray the nature of science and the scientific methodology. Relativism, non-rationalism, etc., were the major consequences of the historicist philosophy of science. Therefore, historicists paved the way to another school of thought in philosophy of science, viz, Historical Realism. In this section we have seen the main characteristics of Historicism, its main proponents and the criticism leveled against historicism. This is an attempt to introduce a student of philosophy to historicism as a school of philosophy of science.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Critically evaluate historicism.

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2) What are the main criticisms placed against historicism?

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3.8 KEY WORDS

Historicism: School of philosophy which emphasizes on history of science, subjectivity and the social and cultural background of the scientist.

Incommensurability: Communication breakdown across different scientific programmes.

Paradigm: Scientific Research Programme

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3.10 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1. Worldview or weltanschauung is a collection factors that create the background for the scientist.Experiments, theories and observation all are colored by the way we are brought up.

2. Scientific projects are colored by several subjective factors. But the influence of subjective factors are not arbitrary.

Answers to Check Your Progress II

1. Historicists have to face the problems of subjectivism, relativism and non-rationalism.
2. The main criticisms placed against historicists are the problem of cross paradigms, criterion of acceptance of a Paradigm and the confusion about incommensurability.

UNIT 4 HISTORICAL REALISM: BASIC IDEAS, PERSONS, IMPLICATIONS AND CRITIQUE

Contents

4.0. OBJECTIVES

In this Unit we deal with the contemporary philosophy of science, more specially, the school of historical realism, which is the mid way between logical positivism and historicism. So we explain the inalienable importance of history in philosophising science.

By the end of this Unit you should be able to:

- Understand the connection between the history of science and philosophy of science;
- Understand philosophical contribution made by:
    - Imre Lakatos,
    - Larry Laudan and
    - Dudley Shapere.

4.1. INTRODUCTION

Contemporary philosophy of science is rapidly becoming a discipline concerned with science as actually practiced, yet at the same time doing philosophy. Science, as practiced involves an ongoing process of observation, experiment, and construction of theories, to obtain systematic knowledge about the world. In short, a central and characteristic activity of science is *the use of reason* in the suggestion and development of hypotheses and theories and in evaluating the knowledge claims made by those who advance such hypotheses and theories. Contemporary philosophy of science is realizing that there are patterns of reasoning in the construction or discovery of scientific hypotheses and theories, and that a great deal of illumination of the scientific enterprise can be attained by examining them, and that the philosophical examination of them is central to a viable philosophy of science. Such an investigation and systematic philosophical understanding of the justification of knowledge claims requires paying close attention to actual scientific practice, both historical and contemporary. Such is the focus of Imre Lakatos, Larry Laudan and Dudley Shapere.

Is there any essential connection between the history of science and philosophy of science? And if so, what that connection is? A common distinction in history of science is between *external history* and *internal history*. Although the distinction is somewhat vague, internal history tends to regard the history of science as the history of rational thought about nature, evolving according to its own inner logic. The understanding of it requires only an attempt on the part of the historian to think the scientist's thoughts after him. On the other hand, external history is the view of science as an irreducibly social and cultural phenomenon, subject alike to rational and irrational influences, to magic as well as mathematics, religious sectarianism as well as logic, politics and economics as well as philosophy, and which is itself one of the major causative influences upon the general historical scene and inseparable form it. And, of course, a given historical work can be some combination of internal and external history.

Given its emphasis on the (historical) examination of reasoning in science, it may seem that contemporary philosophical work on the growth of scientific knowledge is just internal history of science done by philosophers of science. However, such a view is seriously mistaken. *First*, not all philosophers working on the growth of scientific knowledge confine themselves to just the considerations of internalist history. For example, a central theme of Stephen Toulmin's *Human Understanding* is that an adequate account of the evolution of scientific concepts must be based on both internalist and externalist historical concerns. *Second*, philosophical work on the growth of scientific knowledge involves doing good internal history of science.

The internalist historian of science and the historically oriented philosopher of science differ significantly in the nature of their concern with reasoning in scientific progress. Historians of science *often* are concerned with the development of generalizations about the historical events they discuss. Both the historian and the historically oriented philosopher generalize from the historical cases they examine, perhaps the difference lies in the sorts of generalizations they draw. In establishing his generalization, the historian is concerned to discover patterns of regularity in the growth of science – patterns which regularly occur unless there are special complicating factors which interfere with or alter the progress of science; and when such deviations do occur, the historian will look for those complicating factors in an attempt to understand why the expected patterns were not realized in that episode.

By contrast, the historically oriented philosopher of science is concerned with generalization primarily as a prelude to critical analysis and evaluation. First, he examines the patterns of reasoning involved in the advancement, evaluation, and justification of scientific hypotheses. Then, having identified the reasoning patterns used in a particular historical episode, he asks whether the reasoning in question was good or not. Do the reasons advanced really make the hypothesis plausible? Does the evidence adduced strongly favor the truth of the hypothesis as claimed? If the philosophical examination yields affirmative answers to these questions, the philosopher can abstract the reasoning pattern and generalize that when, or to the extent that, the following factors re present such and such a sort of history is likely to be true, or that it is reasonable to accept the theory as being established, and so on. And if the philosophical evaluation is that the reasoning patterns are deficient, the philosopher becomes concerned with what alternative reasoning patterns could or should have occurred given the available information in the scientific domain of the time and available background knowledge.

In dealing with these issues, the philosopher is free to invent alternative reasoning patterns that were feasible at the time which can be evaluated as to their adequacy; and if such invented patterns of reasoning are both feasible and successful, the philosopher may generalize from them just as he does from actually exemplified patterns which pass the test of philosophical scrutiny. Thus, although both the internalist historian and the historically oriented philosopher are concerned with reason in the growth of scientific knowledge, and their concerns may overlap, ultimately their focuses are quite different – the historian is explaining historical episodes and possibly generating historical generalization useful in explaining such episodes, and the historically oriented philosopher is showing how the reasoning patterns science does or could employ to justify science in claiming to provide knowledge about the world, and in analyzing what the nature of that knowledge is.

Thus, the philosopher is not resorting to historical material merely to *illustrate* his philosophical views. Rather, the history of science functions as *evidence* for his philosophical views. For he is claiming that much of what science does *is* rational and capable of yielding knowledge, although he also recognizes that not all of science is rational and thus that not everything science does yields knowledge. He is also concerned with whether, or how, the techniques, concepts, information, and so on, available to science could or should have enabled science to obtain knowledge had better reasoning occurred. His aim is to establish a philosophical theory of rationality, reflective of good science as actually practiced, where in such actual science is capable of yielding knowledge. And in order to substantiate any claims to have established such a theory of rationality, the historical evidence such a theory of rationality, the historical evidence must play an essential role.

Although the historical evidence provides essential evidential warrant for the historically oriented philosopher's findings, it does not provide the entire warrant. Part of what the philosopher does is *evaluative* in nature – claiming that various patterns of reasoning from evidence to hypotheses *do* make it plausible to suppose a certain type of theory will be true, or *do* justify certain knowledge claims and so on. And such evaluations do not generally consist in showing that the reasoning patterns are logically valid- that the conclusions drawn are entailed by the available evidence – for it is clear that few of the reasoning patterns employed in science meet this standard. Thus the evidential warrant for the historically oriented philosopher's findings about rationality in the growth of scientific knowledge is part historical and part philosophical.

4.2. LAKATOS

Research Programmes

Lakatos' contribution to the philosophy of science was an attempt to resolve the perceived conflict between Popper's Falsificationism and the revolutionary structure of science described by Thomas Kuhn. Popper's Falsificationism implied that scientists should give up a theory and replace it as soon as they encounter any falsifying evidence. But Kuhn described science as consisting of periods of normal science in which scientists continue to hold their theories in the face of anomalies, interspersed with periods of great conceptual change. So, Lakatos sought a methodology that would harmonize these apparently contradictory points of view, a methodology that could provide a rational account of scientific progress, consistent with the historical record.

The history of science reveals that theories start as rather vague, imprecise, and somewhat incoherent ideas and only gradually become clear, precise, and coherent. Scientific concepts (e.g., force, mass, heat) acquire precise meanings only by being parts of coherently structured theories. Scientific theories grow and develop by being open-ended and having "research programs. For Lakatos, the typical unit of science is not an isolated hypothesis, but rather a *research programme*- a succession of slightly different theories and experimental techniques developed over time, that share some common ideas, or hard core. Research programmes consist of a hard core (theory), a protective belt (auxiliary hypotheses), and a heuristic, i.e., problem solving machinery.

Hard core consists of very general hypotheses that give the research program its essential characteristics. (e.g., the thesis in Copernican astronomy that the planets orbit the sun). This is not open to negotiation, and in effect lays down the foundations of the programme. For example, Newton's three laws of dynamics, which define quantities such as force. These are not open to falsification within the Newtonian system, but are defended at all cost by a 'protective belt' of statements that are open to falsification.

Protective belt consists of auxiliary assumptions, assumptions underlying the description of the initial conditions, and observation statements that can be changed or augmented without abandoning the program itself. (e.g., assumptions about the relative accuracy of telescopic and naked-eye observations of the planets). But not all changes of the auxiliary hypotheses within research programmes (problem shifts) are equally acceptable. They are evaluated by their ability to explain apparent refutations and to produce new facts. If it can do this then, they are progressive. If they do not, if they are just 'ad-hoc' changes that do not lead to the prediction of new facts, then he labels them as degenerate.

A heuristic is a problem solving machinery, which with the help of sophisticated mathematical techniques, digests anomalies and even turns them into positive evidence. For instance, if a planet does not move exactly as it should, the Newtonian scientist checks this conjectures concerning atmospheric refraction, concerning propagation of light in magnetic storms, and hundreds of other conjectures that are all part of the programme. He may even invent a hitherto unknown planet and calculate its position, mass and velocity in order to explain the anomaly. In short, a heuristic is a hint about how to change the auxiliary assumptions so that the theory better fits the facts. A research programme will have a negative and a positive heuristic associated with it.

Negative heuristic is the stipulation that the hard core of the program not be abandoned or modified. It forbids scientists to question or criticize the hard core of a research programme. Instead the hard core is rescued by auxiliary hypotheses. The positive heuristic is the research policy of the programme – the puzzles to be solved, the models to be constructed, and the questions to be investigated. It consists of a partially articulated set of suggestions or guidelines on how to change the 'refutable variants' of the research programme, and how to modify the 'refutable' protective belt.'

How do research programmes die? Are there objective criteria for their death? Research programmes, scientific or pseudoscientific, have, at any stage, both undigested anomalies and unsolved problems. Programmes are eliminated when superior programmes supersede them. This is the rational reason for their death.

A research programme is progressive to the degree to which it leads to the discovery of hitherto unknown novel facts and new phenomena. But if a programme is degenerative (ceases to be progressive), i.e., it is no longer generating theories with no empirical content, and fails to the discover new phenomena, then it remains a part of the body of science. A research programme that is in a state of constantly defending its hard core, and which appears not to be extending itself into new areas, becomes degenerate. Such research programmes are in danger of being superseded by more vigorous competitors. Subsequently, research program A is preferable to competing research program B if either A is more *progressive* than B or is *degenerating* less than B. In this way, one can distinguish a scientific programme from a pseudoscientific programme.

This is what Lakatos says is happening in the historical periods, Kuhn describes as revolutions and what makes them rational as opposed to mere leaps of faith. Thus, there is cumulative progress in science as a result of scientific revolutions. Scientific change can be explained largely as a *rational* process.

Check Your Progress I

Note: a) Use the space provided for your answer.

b) Check your answers with those provided at the end of the unit.

1. Differentiate between the internalist historian of science and the historically oriented philosopher of science.

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2. What is a research programme?

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3. When can you say that a research programme is progressive?

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4.3. LARRY LAUDAN

The Aim of Science

Larry Laudan proposes problem-solving model of scientific progress. Hence, the aim of science is to secure theories with a high problem-solving effectiveness. From this perspective, science progresses just in case successive theories solve more problems than their predecessors.

Kinds of Problems

Laudan separates *empirical* from *conceptual* problems. Further at the empirical level, he distinguishes between *potential*, *solved*, and *anomalous* problems. Potential problems constitute what we take to be the case about the world, but for which there is, yet no explanation. Solved or actual problems are that class of putatively germane claims about the world which have been solved by some viable theory. Anomalous problems are actual problems which rival theories solve but which are not solved by the theory in question. Unsolved or potential problems need not be anomalies. A problem is only anomalous for some theory if that problem has been solved by a viable rival. In addition to empirical problems, theories may be confronted by *conceptual* problems. Such problems arise for a theory T, in any of the following circumstances:

- When T is internally inconsistent or the theoretical mechanisms it postulates are ambiguous;
- When T makes assumptions about the world that run counter to other theories or to prevailing metaphysical assumptions, or when T makes claims about the world which cannot be warranted by prevailing epistemic and methodological doctrines;
- When T violates principles of the research tradition of which it is a part (to be discussed below);

- When T fails to utilize concepts from other, more general theories to which it should be logically subordinate.

Conceptual problems, like anomalous empirical problems, indicate liabilities in our theories (i.e. partial failures on their part to serve all the functions for which we have designed them). The problem-solving model argues that the elimination of conceptual difficulties is as much constitutive of progress as increasing empirical support. Indeed, on this model, it is possible that a change from an empirically well-supported theory to a less well-supported one could be progressive, provided that the latter resolved significant conceptual difficulties confronting the former.

Solutions

A theory solves an *empirical* problem when it entails, along with appropriate initial and boundary conditions, a statement of the problem. A theory solves a *conceptual* problem when it fails to exhibit a conceptual difficulty of its predecessor. (Note: many different theories may solve the same empirical or conceptual problem). The worth of a theory depends on how many problems it solves. Unlike those explanations which insist high degree of confirmation, the problem-solving approach allows a problem solution to be credited to a theory.

Progress without Cumulative Retention

According to some models, earlier theories required to be contained in later theories. Unfortunately, history teaches us that theories rarely stand in this relation to one another. So to rescue the notion of scientific progress from cumulative retention and allow for the possibility of progress even when there are explanatory losses and gains, Laudan proposes Cost-benefit analysis within a problem-solving model:

- assess the number and the weight of the empirical problems, a theory is known to solve;
- assess the number and weight of its empirical anomalies;
- Finally, assess the number and centrality of its conceptual difficulties or problems.
- Based on this scale, Laudan prefers that theory which comes closest to solving the largest number of important empirical problems while generating the smallest number of significant anomalies and conceptual problems.

The Spectrum of Cognitive Modal Life

Scientists often claim that even if a theory is unacceptable, it deserves further investigation and elaboration. But when do theories are worthy of further investigation and elaboration? For Laudan, attitudes of acceptance and rejection can be seen as the functions of the relative problem-solving progress of our theories. A highly progressive theory may not yet be worthy of acceptance but its progress may well warrant further pursuit. A theory with a high initial rate of progress may deserve to be entertained even if its net problem-solving effectiveness - compared to some of its older and better-established rivals – is unsatisfactory.

Theories and Research Traditions

Theories represent more fundamental views about the world. And the cluster of beliefs which constitute such fundamental views is called 'research traditions.' Research tradition consists of at least two components:

1. A set of beliefs about what sorts of entities make up the domain of inquiry;
2. A set of epistemic and methodological norms about how the domain is to be investigated.

Research traditions are not directly testable, because their ontologies are too general to yield specific predictions and their methodological components are not straightforwardly testable assertions about facts. But associated with research traditions, there is a family of theories which can be tested. Research traditions serve several specific functions.

- They indicate what assumptions can be regarded as uncontroversial 'background knowledge' in that tradition;
- They help to identify those portions of a theory that are in difficulty and should be modified or amended;
- They establish rules for the collection of data and for the testing of theories;
- They pose conceptual problems for any theory in the tradition which violates the ontological and epistemic claims of the parent tradition.

Adequacy and Promise

Compared to single theories, research traditions are enduring entities. Theories may be abandoned frequently, but research traditions are long-lived. They establish continuity in the history of science amidst the theory change. But even research traditions can be overthrown, if one is more adequate than the rival research tradition.

But to move to theories or traditions which can solve more problems than the present one, we need to seek theories which can extend the range of what we can now explain and predict. But new theories and research traditions rarely manage to achieve a degree of problem-solving effectiveness as high as that of old, well-established theories. So how do we judge when such novel approaches are worth taking seriously? The answer is by assessing the rate of progress of such theories and research traditions. And progress is the difference between the problem-solving effectiveness of the research tradition in its latest form and its effectiveness at an earlier period. The rate of progress is a measure of how quickly a research tradition has made whatever progress it exhibits. Obviously, one research tradition may be less adequate than a rival and yet more progressive. Hence, highly progressive theories should be accepted and pursued whereas only the most adequate theories should be accepted.

Co-Existence of Rival Theories

According to Kuhn's period of normal science, one paradigm reigns supreme. But in the problem-solving model, the co-existence of rival research traditions is the rule rather than the exception. At a given time, one or other research traditions may have the competitive edge, but there is a continuous struggle taking place, pointing out to each other the empirical and conceptual weaknesses and their problem-solving progressiveness. Thus, dialectical confrontations are essential to the growth and improvement of scientific knowledge.

Check Your Progress II

Note: a) Use the space provided for your answer.

b) Check your answers with those provided at the end of the unit.

1. What are the different kinds of empirical problems?

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2. State the solutions to the different kinds of problems.

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3. Write a short note on Theories and Research Traditions.
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4.4. DUDLEY SHAPERE

The Character of Scientific Change

Shapere's view of scientific change starts with the idea that science builds on what it has learned. Its established theories and laws guide the construction of new theories, and also constrain possible conjectures. Thus, *all* aspects of science - its substantive beliefs about nature, and its methods of reasoning - are subject to radical change.

Science and Its Development

According to Shapere, two lessons have to be learnt from the history of science: the "Principle of Rejection of Anticipation of Nature" and the "Principle of Scientific Internalization."

The first principle states: the results of scientific investigation could not have been anticipated by common sense, by everyday experience, or by pure reason. The significance of this principle is that contemporary science departs radically from our common sense everyday beliefs. On the basis of common sense everyday beliefs, no one could have anticipated complex theories such as the quantum theory, the general theory of relativity, and evolutionary Darwinism. And their complex claims depart very radically from the dictates of everyday common sense beliefs.

According to the second principle of scientific internalization, whenever possible, every aspect of our beliefs ought, to be formulated, and to be brought into relation to well-founded beliefs, in such a way that it will be possible to test that aspect.

History of science indicates that scientific research is always conducted on the basis of some presumed facts, laws, and theories, taking their *truth* for granted. For instance, the solar physicist researches on stars by taking for granted things such as: $E = mc^2$; natural phenomena are governed by strong, electromagnetic, weak, and gravitational forces; the theory of stellar evolution; etc. These presumed set of facts, theories, and beliefs that guide research is the background knowledge of that field of inquiry.

Shapere explains the fact that the principle of internalization governs scientific activity by a comparing the Milesian science with the science of 17th century Europe. The Milesian approach was "holistic." Their subject matter of study was *all* aspects of existence, *all* forms of change, and *all* aspects of nature. They did not focus on problems generated by specific fields (such as gasses; chemical reactions; etc). But the 17th century approach was "piecemeal," that examined individual subject-matters in isolation from others. These subject matters are called domains of inquiry.

Scientific *domains* are a number of items of information (facts, accepted theories, and laws) which are associated as a body of information, and these unified associations generate problems that scientists try to solve in their research activities. For example, astrophysics is a scientific domain because it is made up of a *body of information* ($E = mc^2$; there are four main forces in nature; there was a big bang; there are elementary particles; there is stellar evolution, etc.) which generate the problems that scientists try to solve in their research.

The classification of science into various domains of inquiry is a result of growth of knowledge. The early classifications were based on sensory similarities, pragmatic functions, etc. For example, metals were classified into salts and crystals on the basis of their sensory appearances.

But with the growth of knowledge, the initial basses of classifications are rejected; the previous distinct *domains* are unified, and new domains identified.

The development of domains also have shaped the methods of inquiry. The methods we consider appropriate for arriving at well-grounded beliefs about the world are shaped by those very beliefs, and have evolved with the evolution of knowledge. Thus, the method not only determines the course of science, but is itself shaped by the knowledge attained in that enterprise.

Methodology

Scientific research is always conducted from and within background knowledge. There are four types of *background knowledge:* specific theories; general theories; highly general metaphysical principles; well-established empirical facts and observational laws. They perform a dual function in a scientific research: (1) they function as substantive claims - specific assertions about the nature of the world (e.g. light is a wave-like disturbance in a medium). (2) and these assumptions also perform heuristic roles: (i) they specify what sorts of explanations, conjectures and theories are admissible within a domain (e.g. new theory of light must explain the wave-like properties of light); (ii) they also specify the kinds of modification that are acceptable within their domain (e.g. as long as the principle of determinism is accepted, any explanation in fluid mechanics must not rely on indeterministic assumptions).

Certain theories are specific, because there are some higher level theories within which they are developed. For instance, under the wave theory of light, we have various specific theories, such as the transverse wave theory of light, and the longitudinal wave theory of light.

When specific and general theories are accepted, they constrain the explanations and conjectures that are allowable in scientific research. However, changes are possible in specific and general theories. For instance, when the corpuscular theory of light was finally replaced by the wave theory, scientists stopped explaining optical phenomena in terms of light particles.

Changes in substantive claims occur in a definite but complex manner. When scientists are confronted with *refutations* of a specific theory, they look for a different specific theory of the same general kind. For instance, the longitudinal wave theory (specific theory) was rejected in favor of transverse wave theory (another specific theory of the same general kind). It is only after various attempts to produce specific theories of the same general kind have failed that scientists challenge their more general theories.

Metaphysical assumptions would include principles such as determinism and mechanism; the perfectionist and compositionalist theories of material substances, etc. These principles are more general that they cut across different general theories, "paradigms" or "research programmes". For instance, the assumption that optics involved only mechanistic and deterministic processes formed part of the background knowledge of both corpuscularians and wave theoreticians.

As metaphysical assumptions are more firmly established than specific and general theories, they often provide justification for the acceptance or rejection of less general theories. When empirical difficulties arise in a domain, scientists hold on to the metaphysical principles and find out alternative general theories. Highly general assumptions are replaced only after repeated failures. For instance, there have been radical changes in the theory of light from particle theory, through wave theory to electromagnetic theory, but the general metaphysical assumptions that optics involved mechanical and deterministic processes remained constant.

The above discussions show that methodology can, and has changed along with the substantive developments of science. But only the empirical aspect of scientific knowledge has been essentially cumulative. For example, in the history of modern optics, there have been changes at the theoretical level, but not at the empirical level.

The particle theory of light was rejected in favor of wave theory. At the theoretical level, there was a radical change from luminiferous ether to electromagnetic field to photon theory. But at the empirical level, the particle theory gave correct empirical accounts of reflection and refraction, and the wave theory gave account for these and more of diffraction, interference, and polarization. The electromagnetic and photon theories added to the empirical successes of their predecessors.

Methodological Relativism

According to relativism: if a theory *T*1 (or research programme *R*1), upholds *M* (set of methodological rules), and another theory *T*2 (or *R*2) upholds *M*0 (rival set of methodological rules), and these rival rules are all *correct* according to their internal criteria, then there is no question of pronouncing the rules of any of these theories wrong. There are no possible evaluations beyond a specific theoretical unit.

According to Shapere, although all aspects of science are in principle subject to change, relativism is avoided insofar as change is effected by the *best* background beliefs of the domain in which change occurs. The *best beliefs* of any domain are a subset of that domain's *background knowledge*. Specifically, they are those background beliefs which are 'successful' and 'free from specific and compelling doubts. In short, rationality depends on using "successful" beliefs that are "free from specific and compelling doubts" as the source of reasons for holding other (theoretical) beliefs. So, a theory (or belief) is "successful" if it accounts for the facts of its domains, or if it provides adequate solutions to the problems of its domain. The condition of "freedom from doubt" is this: unless there is a particular reason to doubt a theory, the mere general skeptical doubt or universal doubt that theory might be wrong, should not be the sole reason for rejecting that theory.

Check Your Progress III

Note: a) Use the space provided for your answer.

b) Check your answers with those provided at the end of the unit.

1. What is the character of a scientific change?

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2. What are the two Principles that Shapere has identified from the history of science?

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3. What is methodological relativism?

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4.5. LET US SUM UP

During the last five or six decades there have been important shifts in philosophical thinking about scientific discovery and the growth of scientific knowledge. The positivists distinguished the context of discovery and the context of justification, dismissing the former as the subject matter of history. The only aspects of the growth of scientific knowledge relevant to philosophy were inductive justification or confirmations of knowledge claims and the incorporation of older theories into more comprehensive theories via intertheoretic reduction. The resulting view of scientific knowledge was a static one which led to a highly distorted portrait of science and the knowledge it provided. Rejecting such a view by Hanson, Feyerabend and Kuhn made scientific knowledge a social phenomenon in which science became a subjective and to varying degrees, an irrational enterprise. More recently philosophers such as Lakatos, Laudan and Shapere have attempted to steer a middle course between these two extremes wherein science is a rational enterprise concerned with obtaining objective knowledge of the real world.

4. 6. KEY WORDS

Skepticism: Skepticism denotes any questioning attitude, or some degree of doubt regarding claims that are elsewhere taken for granted. In classical philosophy, skepticism referred to the teachings and the traits of the 'Skeptikoi,' a school of philosophers of whom it was said that they 'asserted nothing but only opined.'

Relativism: Relativism is the idea that some elements or aspects of experience or culture are relative to, i.e., dependent on, other elements or aspects.

4.7. FURTHER READINGS AND REFERENCES

Lakatos. *The Methodology of Scientific Research Programmes: Philosophical Papers*. Volume 1. Cambridge: Cambridge University Press, 1977.

Ian, Hacking, ed. *Scientific Revolutions*. Oxford: Oxford University Press, 1981.

4.8. ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1. The internalist historian of science and the historically oriented philosopher of science differ significantly in the nature of their concern with reasoning in scientific progress. Historians of science *often* are concerned with the development of generalizations about the historical events they discuss. By contrast, the historically oriented philosopher of science is concerned with generalization primarily as a prelude to critical analysis and evaluation.

2. For Lakatos, the typical unit of science is not an isolated hypothesis, but rather a *research programme*- a succession of slightly different theories and experimental techniques developed over time, that share some common ideas, or hard core. Research programmes

consist of a hard core (theory), a protective belt (auxiliary hypotheses), and a heuristic, i.e., problem solving machinery.

3. A research programme is progressive to the degree to which it leads to the discovery of hitherto unknown novel facts and new phenomena. But if a programme is degenerative (ceases to be progressive), i.e., it is no longer generating theories with no empirical content, and fails to the discover new phenomena, then it remains a part of the body of science. A research programme that is in a state of constantly defending its hard core, and which appears not to be extending itself into new areas, becomes degenerate. Such research programmes are in danger of being superseded by more vigorous competitors.

Answers to Check Your Progress II

1. The empirical problems are *potential*, *solved*, and *anomalous* problems. Potential problems constitute what we take to be the case about the world, but for which there is, yet no explanation. Solved or actual problems are that class of putatively germane claims about the world which have been solved by some viable theory. Anomalous problems are actual problems which rival theories solve but which are not solved by the theory in question. Unsolved or potential problems need not be anomalies. A problem is only anomalous for some theory if that problem has been solved by a viable rival.
2. A theory solves an *empirical* problem when it entails, along with appropriate initial and boundary conditions, a statement of the problem. A theory solves a *conceptual* problem when it fails to exhibit a conceptual difficulty of its predecessor. (Note: many different theories may solve the same empirical or conceptual problem). The worth of a theory depends on how many problems it solves.
3. Theories represent more fundamental views about the world. And the cluster of beliefs which constitute such fundamental views is called 'research traditions.' Research tradition consists of at least two components: (1) A set of beliefs about what sorts of entities make up the domain of inquiry; (2) A set of epistemic and methodological norms about how the domain is to be investigated. Research traditions are not directly testable, because their ontologies are too general to yield specific predictions and their methodological components are not straightforwardly testable assertions about facts. But associated with research traditions, there is a family of theories which can be tested.

Answers to Check Your Progress III

1. Shapere's view of scientific change starts with the idea that science builds on what it has learned. Its established theories and laws guide the construction of new theories, and also constrain possible conjectures. Thus, *all* aspects of science - its substantive beliefs about nature, and its methods of reasoning - are subject to radical change.

2. According to the Principle of Rejection of Anticipation of Nature, the results of scientific investigation could not have been anticipated by common sense, by everyday experience, or by pure reason. According to the "Principle of Scientific Internalization, whenever possible, every aspect of our beliefs ought, to be formulated, and to be brought into relation to well-founded beliefs, in such a way that it will be possible to test that aspect.
3. According to relativism: if a theory *T*1 (or research programme *R*1), upholds *M* (set of methodological rules), and another theory *T*2 (or *R*2) upholds *M*0 (rival set of methodological rules), and these rival rules are all *correct* according to their internal criteria, then there is no question of pronouncing the rules of any of these theories wrong. There are no possible evaluations beyond a specific theoretical unit.

BLOCK 4

At the end of the 19th century, some of the age-old traditions of the past came to be questioned and re-looked. Concepts such as absolute motion, absolute space, absolute mass, wave nature of particles, unlimited perfectibility of experimental results were reconsidered. Some of the prominent thinkers of this time were Albert Einstein, Max Plank, Louis de Broglie, and so on. They brought in certain radically new concepts, altogether new and original theories and gave new insights into several puzzling phenomena in nature that were considered as mystery. The questions regarding the finiteness and infiniteness of the universe which were probed from the ancient times were again taken up. This period will show us that there is a relationship between science and philosophy; for instance, Einstein himself was a philosopher and a scientist.

This block as a whole consists of four units, making us familiar with the contributions and developments in the philosophy of science in the contemporary times.

Unit 1 deals with the Relativistic Revolution and its Scientifico-philosophical Implications. The main person behind this is Albert Einstein, who proposed the relativistic theory of a number of phenomena of nature. This unit will first present the historical and scientific background in which the theory was born. Next we will present the basic elements of the Theory of Relativity. Finally, we will discuss the important consequences and philosophical implications of this theory.

Unit 2 studies the theory of Quantum Mechanical Revolution and its Scientifico-Philosophical Implications. Max Plank is the one who discovered the Quantum Theory. Relativity deals mostly with the mega-world, whereas Quantum Mechanics deals with the micro-world and its philosophical implications. Quantum Mechanics is the most successful theory ever proposed by humans but with its inherent limitations.

Unit 3 probes into the Finite / infinite Nature of the Universe. This is one of the problems faced from the ancient times and yet a clear and distinct answer on the question has always eluded us. Thus, this unit on the finite/infinite universe, tries to unravel the question from four different perspectives: the mythical, the philosophical, the religious and the scientific. This unit takes a close look at all the possible explanations that have been so far put forward.

Unit 4 highlights some of the Scientific Theories on the Origin and End of the Universe and their Critique. The unit inquires into the present structure of the universe: the galaxy that we live in, many other galaxies, and thus the unit takes us to the question, where are we? The Big Bang Theory, Hubble constant, and Friedmann's Three Models of the Universe are some of the important contributions.

This block becomes the culmination of the preceding units. But a satisfactory solution to the many problems like origin and end of the universe, and finiteness / infiniteness of the universe still remains a mystery. The proposed theories appear to be convincing for the time being but their credibility cannot be considered undisputable since the future is unpredictable.

UNIT 1 RELATIVISTIC REVOLUTION: SCIENTIFICO-PHILOSOPHICAL IMPLICATIONS

Contents

1.0 OBJECTIVES

The main objective of this unit is to introduce the student to one of the most revolutionary and creative theories in science and to point out some of its deeper philosophical implications. The theory under consideration is the Theory of Relativity, which was discovered by Albert Einstein. This unit will first present the historical and scientific background in which the theory was born. This is done to bring home to the student that scientific theories do not arise in a vacuum. They have a clear-cut historical setting and context. Next we will present the basic elements of the Theory of Relativity. This discussion will show that many of the concepts in science have a philosophical aspect. Finally, we will discuss the important consequences and philosophical implications of this theory. This section will show that the Theory of Relativity has tremendous philosophical significance. From the philosophical point of view the most important objective of this unit is to show that philosophy and science are closely related. Often many think that these two are very different, and hence philosophy of science is something unnatural and artificial. Our study of the Theory of Relativity and its philosophical implications will show that philosophy and science are closely interconnected. In this theory we will see the close connection between the two. In fact, Einstein himself was both a scientist and a philosopher. Often he is considered a philosopher-scientist because in his thoughts and discoveries one can see both science and philosophy coming together in a natural and harmonious way.

1.1 INTRODUCTION

The advent of the Theory of Relativity and of Quantum Mechanics has revolutionized the whole domain of science. They questioned some of the age-old concepts such as absolute motion, absolute space, absolute mass, wave nature of particles, unlimited perfectibility of experimental results, etc. They brought in certain radically new concepts, and gave new insights into several puzzling phenomena in nature.

Towards the end of the nineteenth century it became abundantly clear to scientists that the real trouble spots in scientific inquiry were in the subatomic world at one end and in the fathomless depths of intergalactic space at the other end. Quantum Mechanics arose in an effort to answer the problems hovering in the subatomic world and Relativity in the 'ultra-giant' and 'ultra-fast' world. In this chapter we discuss the Theory of Relativity only.

THE IMPORTANCE OF THE THEORY OF RELATIVITY

To show the all-pervasive importance and relevance of Relativity in theoretical science today, we give a few quotations from leading writers. Thus H. Margenau writes, "In fact the theory is now so well corroborated by experience and assimilation into the whole of modern physics that its denial is almost unthinkable. The physicist is impressed not solely by its far flung empirical verification, but above all by the intrinsic beauty of its conception which predisposes the discriminating mind for acceptance even if there were no experimental evidence for the theory at all." Again, Hutton, "Relativity has profoundly changed the whole of physics. By the analysis of the fundamental concepts of space and time, of mass and of force, it has given a new orientation not only to science, but also to our approach to philosophical problems in general. The concepts of space and time, force and mass and causality have undergone a radical revision through relativity. The model we make of the physical universe has changed." Again, "Here the concept of thing and mass are replaced by the concept of field, and with it disappear the forces between things. Since force and causality are closely connected in classical physics, the concept of causality is also affected." Also L. Barnett says, "Relativity and Quantum Mechanics are the two pillars of modern physical thought." Such quotations can be multiplied indefinitely. The quotations here from eminent science writers show that the coming of Relativity brought very important changes in the fundamental concepts of space, time, mass, force, etc. Since these concepts are closely related to philosophy, Relativity had a very important impact on philosophy as well.

1.2 HISTORICAL BACKGROUND OF THE THEORY OF RELATIVITY

Sir Isaac Newton was one of the greatest scientists ever lived. He is famous for his discovery of the Law of Universal Gravitation. This law states that all material bodies attract each other with a certain force. The more the mass or quantity of material stuff in a body, the higher the force with which that body attracts other bodies towards it. Thus the sun exerts an attractive force on the earth. That is why the earth goes around the sun. Now we need to keep in mind that the sun is 150 million kilometres away from the earth. Still the sun exerts a physical force on the earth and drags the earth around it. Surprisingly, there is no observable physical connection between the sun and the earth – no rope or string is tied from the sun to the earth. So the sun seems to be dragging the earth around it without any physical connection. This situation is usually referred to as "action at a distance." Now in physical science such a situation is not understandable since some kind of linkage is needed for one body to move another body physically. It was proposed that there was a medium linking the sun with the earth, and the sun exerts its gravitational attractive force through this medium. This medium was named "ether." This ether was expected to pervade all space.

Ether was called in to play another role also. This came from the discovery that light is made up of waves which go up and down like water waves. Now this kind of up and down wave motion also requires a medium. It was found that light travels not only in the atmosphere where there is air as the medium, but also in vacuum or empty space where there is no known physical medium. For instance, when light comes from the sun to the earth, it passes through areas which are empty of matter. How can real light waves travel through empty space? This also was unthinkable in physical science in the 19th century. Hence scientists assumed that the whole empty space was filled with ether, and light waves were travelling through the ether medium. Again, Newton believed that absolute motion existed. As we know, usually we experience motion as relative. For instance, a little child inside a smoothly moving bus will say that the people on the road are moving (in the opposite direction), whereas the people on the road will say that the child and the bus are moving away from them. When a body is having absolute motion, everyone in the universe will say that that body is moving. Now this absolute motion needs an absolute frame of reference. Newtonian scientists said that ether was this absolute frame of reference. Thus ether medium became very important in science in the 19th century having many crucial functions to perform. But no one had any experiential or experimental knowledge of this ether medium. Scientists, therefore, started an all-out hunt to detect and identify this medium of ether.

Many new theories were proposed and ingenious experiments were devised by scientists to identify and detect this medium of ether. The most important one was done by two ingenious experimental scientists by name Michaelson and Morley in 1887. This was a brilliant experiment, and was performed with utmost care and ingenuity. They got the Nobel Prize for this experiment. Commenting on this experiment a science writer, Gaston Bachelard, wrote: "Michaelson-Morley Experiment roused Classical Physics (Newtonian Physics) from its dogmatic slumber." We will not go into the theories and technicalities of this experiment. The interested student can find them in any standard book on the topic. Suffice to say that the experiment was a grand success, but it could not detect any ether medium. The failure to detect the ether medium by such an ingenious and well-executed experiment became a shocker for scientists. Several attempts were made to explain the "negative result" of this experiment. Practically all of them tried to save the ether medium by saying that the medium existed, but because of certain special circumstances we were not able to detect it.

It is here that Einstein showed his real genius and creativity. First of all he said that a well-performed experiment would never give a negative result, it would always reveal a positive fact about nature. It is our duty to find out what this positive fact is. According to him, what the Michaelson-Morley experiment had revealed was that there was no way to detect the ether medium. He further showed that there was no need for the ether medium in science. Einstein's answer to the "negative result" of this experiment gave rise to the Theory of Relativity.

It may be noted that some historians of science hold the view that the Michaelson Morley experiment did not have any central role in the origin of the Theory of Relativity. In this small unit we will not discuss this view since our focus is not on the history of science, but is on the philosophy of science.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Why is a discussion of the Theory of Relativity important in philosophy of science?

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2) Explain the historical background of Relativity and its significance for philosophy of science.

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WHAT IS RELATIVITY?

Some Important Concepts

The Theory of Relativity is a highly technical theory, and so to understand it clearly we need to clarify a few concepts.

Absolute: Absolute in this context means same for all or applicable for all in all places and at all times. Thus an absolute principle is a principle that is applicable to all human beings in all places and at all times. For instance, when I say "2 + 2 = 4" is an absolute statement, what I mean is that this equation is accepted by all at all places at all times.

Relative: Relative is the opposite of absolute, and it means "in relation to something else." When I say that the motion of a car is relative, what I mean is that the car is in motion relative to or with respect to the surface of the earth. The earth here is taken as stationary.

Frame of Reference: A frame of reference is the point or place from which observations are made and measurements are taken. Any place can be a frame of reference. Your school compound can be a frame of reference since from there observations can be made and measurements can be taken.

Velocity: Velocity is the same as speed, with one difference that for velocity we have to specify the direction of motion. A car moving at 60 kilometres per hour from North Delhi to South Delhi has a speed of 60 kilometres, but it has a velocity of 60 kilometres towards south.

Mass: The concept of mass is something very special in Newtonian science or classical science. It is deeply involved in the mathematical aspects of Newtonian mechanics, and hence it is difficult to offer a clear definition of it. It can be considered as the quantity of material stuff of a body. The more the material stuff of the body, the larger its mass. Note that mass and weight are often taken to be identical. Although these two often have the same numerical value, conceptually they are very different. Weight is the **force** with which a body is attracted by the earth, whereas mass, as mentioned already, refers to the quantity of material stuff of a body.

Body: The term body is very often used in physics and other sciences. This is a general concept and refers to any material body. Thus a stone is considered a body in the physical sciences. The human body is also a body in so far as it is made up of matter.

THE THEORY OF RELATIVITY

In everyday language we can say that Relativity is a theory which holds that concepts like motion, length, time, mass, etc., are not absolute, but relative. They make sense only when related to a frame of reference. Thus an astronaut of mass say 80 kilograms on the surface of the earth (first frame of reference) may have a mass of 100 kilograms while inside a fast moving rocket (second frame of reference). A different technical definition is given by Eddington, when he says that Relativity is "An attitude which leads to the conclusion that we observe only relations between physical entities."

TWO DIFFERENT THEORIES OF RELATIVITY

Einstein gave us two theories of Relativity: The Special Theory of Relativity, given in 1905, and the General Theory of Relativity, given in 1915. The Special Theory of Relativity considers a special case of bodies which are moving with uniform speed in a particular direction. On the other hand, the General Theory of Relativity considers bodies moving with any kind of speed, uniform or non-uniform.

1. 3 THE SPECIAL THEORY OF RELATIVITY

The Special Theory of Relativity is less difficult to understand compared to the General Theory of Relativity. We will discuss this one in some detail.

TWO POSTULATES OF THE SPECIAL THEORY OF RELATIVITY

To develop his theory Einstein had to accept two claims as given facts which cannot be changed. He called them "Postulates." There are different ways of stating these Postulates. We will take a simple, non-technical version.

Postulate 1: This says that all frames of reference are the same as far as physics is concerned, provided they are moving with uniform speed or velocity with respect to each other. They all behave in the same way. The laws of physics are equally applicable in all frames of reference.

For instance, let us take two frames of reference: The platform of a railway station and the compartment of a train moving smoothly with the same speed all the time. Those playing cards can do so inside the train just as well as on the platform. Since all frames of reference behave in the same way, we cannot talk of a preferred frame of reference. Since there is no preferred frame of reference, Einstein concluded that there was no absolute frame of reference because an absolute frame of reference had to be a preferred frame of reference.

Postulate 2: This Postulate talks about the special, unique nature of the velocity of light. Relativity assumes that the velocity of light is something very unique. According to it, the velocity of light is absolute, i.e., same for all at all places and at all times. It is the highest velocity possible for any material body. No material body can have a velocity higher than the velocity of light. This velocity is independent of the motion of the source or of the observer.

It may be noted that Relativity is now introducing something absolute into its very core. In other words a theory which advocates the relativity of space, time, mass, etc., is built on the assumption that the velocity of light is absolute.

SOME IMPORTANT CONSEQUENCES OF THE THEORY OF RELATIVITY

Basing himself on these two Postulates and using very important mathematical tools and other principles, Einstein developed the Theory of Relativity. It has a number of very surprising, counterintuitive consequences.

Relativity of Length

According to Relativity, length (space, distance) is not absolute, but relative. It is relative to a frame of reference. Usually, when we say that a stick is 5 feet long, what we mean is that it has a length of 5 feet with respect to the earth taken as the frame of reference. What Einstein says is that if we were to take some other frame of reference, this length need not be 5 feet. For instance, suppose the same stick is put in a space-shuttle moving with a velocity comparable to the velocity of light, then the same stick will have a different length with respect to an observer standing on the surface of the earth.

Relativity goes further to say that the length of the stick inside the moving space-shuttle decreases with respect to an observer standing on the surface of the earth. That is, if an observer standing on the surface of the earth measures the length of the stick that is placed inside the moving space-shuttle, the observer will find that the length of the stick is **less than 5 feet!** This, obviously, goes against our ordinary experience. But Einstein says that this is a law of nature.

Some people may say that what is reduced is only the measured length of the stick, not the real length. To this Einstein's answer is that the actual length and the measured length are the same. There is no real length different from the measured length.

Relativity of Time

According to Relativity, time is not absolute, but relative. It is relative to a frame of reference. Here also usually we take the surface of the earth as the frame of reference and say that duration of the lecture was 45 minutes. Relativity says that for an observer in another frame of reference the duration of the same lecture need not be 45 minutes. In fact, Relativity says that time slows down in a moving frame of reference with respect to a stationary observer. Thus as in the case of relativity of length, when the same lecture takes place inside a space-shuttle moving with a velocity comparable to the velocity of light, an observer on the surface of the earth will notice that the duration of the lecture is **less than 45 minutes.**

The Clock Paradox

This slowing down of time inside a moving frame of reference with respect to an observer is often illustrated by the "Clock Paradox." Suppose we have two identical clocks in all respects. Suppose also that they have been synchronized so that both show exactly the same time. Let us say that they both show 3 pm now. We keep one on the surface of the earth and we place the other inside the super-speeding space-shuttle. After 6 hours on the surface of the earth when we look at the clock on the surface of the earth, it will show 9 pm. But if from the surface of the earth we look at the clock inside the space-shuttle, it will always show less than 9 pm! **A clock inside a moving frame of reference slows down with respect to a stationary frame of**

reference. This too goes against our ordinary experience. But Einstein says that this is a law of nature.

Relativity of Mass

Mass of a body is not absolute; it is relative; relative to a frame of reference. The mass of a moving body increases with respect to a stationary frame of reference. Thus the mass of a stone may be 250 grams on the surface of the earth. If the same stone is placed inside a fast moving space-shuttle, it will have an increased mass when measured by a scientist on the surface of the earth. This result of Relativity also goes against our ordinary experience.

Mass-Energy Equivalence – $E = mc^2$

This is the most important consequence of Relativity from the practical point of view. According to this, mass and energy are equivalent, i.e., of equal value. Mass and energy are inter-convertible. Mass can be converted into energy and energy can be converted into mass. These two are basically two aspects of the same reality. This result is expressed in the famous equation, $\mathbf{E = mc^2}$, where E stands for the energy produced when a particular body having mass m is converted into energy. c stands for the velocity of light.

Importance of this Equation

This result and the equation show that when a small quantity of matter is converted into energy, the amount of energy produced is enormous since the multiplier factor is the square of the velocity of light. Since the velocity of light itself is a very high quantity, when the multiplication is done by the square (velocity of light multiplied by velocity of light) of that velocity, the resulting quantity is incredibly large. This formula is at the basis of nuclear energy. A nuclear device like a nuclear bomb or a nuclear reactor is capable of releasing an enormous amount of energy because of this multiplier effect.

Philosophically also this equation has serious significance, particularly for Aristotelian philosophy. In Aristotelian philosophy substance and accidents are very different, and it is not possible to convert one into the other. Now energy, since it is related to motion, belongs to the world of accidents in the Aristotelian system, whereas mass belongs to the world of substance. Since, according to Mass-Energy Equivalence, mass can be converted into energy, it shows that substance can be converted into accidents and vice versa. This deals a serious blow to the Aristotelian system.

Space-Time Continuum

According to the Special Theory of Relativity, not only do space and time behave differently from what we used to believe, the relationship between space and time also has changed. Space and time are not to be looked upon as separate entities, rather they are intimately interlinked. In fact, in actuality they form a single whole. This is referred to as spacetime continuum.

1. 4 THE GENERAL THEORY OF RELATIVITY

The General Relativity Principle

General Relativity says that motion, whether uniform or non-uniform (accelerated), does not affect physical laws. The general laws of physics are the same in all moving systems whatever be their motion. In the Special Theory we found that in a uniformly moving system the laws of nature or natural phenomena take place as though the system is not moving at all. For instance, in a uniformly moving train, a person can walk, eat, play, etc., just like a person on the platform. Because of this non-influence of uniform motion on the laws of nature, we are not able to detect and measure the velocity of the moving system from within. But if the motion were to influence the laws of nature, we would be able to note the deviation produced by the motion. From this deviation the velocity could be determined.

What about accelerated or non-uniform motion? An example of an accelerated motion would be a bus taking a curve. Here centrifugal force comes into play and there is acceleration. Now we experience that when a bus takes a curve, the passengers inside are thrown to one side. This shows that those **within** the bus do experience the influence of accelerated motion. So here the situation is the opposite of what happens in the case of uniform motion. Hence the question arises whether the accelerated motion affects the general laws of physics. In other words, will the laws of physics be one thing in one accelerated world and something else in another? Einstein's answer is that the laws will be the same in both the systems.

THE NEW INTERPRETATION OF GRAVITATION

According to Newton, gravitation is a force of attraction between two bodies. Thus the sun attracts the earth, and because of this gravitational force the earth revolves round the sun. Gravitation causes the earth and other planets to describe curved paths in a straight space. In the General Theory of Relativity Einstein gives a completely different idea of gravitation. In this view gravitation is not a force, but a geometrical property. Gravitation is the distortion or curving or bending of spacetime continuum due to the presence of matter. Einstein explains that massive bodies distort the spacetime around them. This distortion or curving he calls gravitation. Since gravitation refers to change of shape, it is considered a geometrical property. This new concept of gravitation is a revolutionary conceptual change, and has transformed our whole idea of the nature of the universe.

One might ask how such a revolutionary theory can be established. How do we know that this revolutionary theory is scientifically acceptable? We will not discuss the technical aspects of this process. We only point out that when this new idea of gravitation is applied to known cases in cosmology, the results obtained are more accurate and more reliable than when we apply Newton's old concept. Today most theoretical scientists engaged in cosmological study employ Einstein's idea of gravitation with more satisfactory results.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What is Relativity? Explain the two postulates of the Special Theory of Relativity.

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2) What are some of the consequences of the Special and General Theory of Relativity?

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1. 5 SOME PHILOSOPHICAL IMPLICATIONS OF RELATIVITY

It goes without saying that so revolutionary and original a theory like Relativity leaves indelible marks on philosophy. It has been rightly observed that the making of a new philosophy follows the making of a new science. It is true that Einstein was not a philosopher by profession, but he was certainly one by attitude. Naturally this fact should show up in the master product of his intellect.

DEATH OF ABSOLUTISM

Relativity dealt a death blow to the so called absolutes: Absolute time, absolute space, absolute simultaneity, absolute mass, absolute frame of reference, absolute objectivity, etc. In doing so it has revolutionized the traditional notions of space, time, etc. According to Relativity, space and time are relative. Space is the relation between things and time the relation between events. As Jeans says, "When we question nature through our experiments, we find that she knows nothing of a space or time common to all men. When we interpret these experiments in the new light of the Theory of Relativity, we find that space means nothing apart from our perception of objects and time means nothing apart from our experience of events. Space and time fade into subjective conceptions, just as subjective as right or left hand.” Only the 4-D spacetime continuum is objective. As Minkowski says, “Space in itself and time in itself sink to mere shadows and only a kind of union of the two retains an independent existence.”

Since every moving observer has his/her own local time, no event in time can be located in an objective way, i.e., no event will be looked upon exactly in the same way by all observers at a particular time.

REFUTATION OF MONISM

The basic belief of monism is that there is only one being in the universe. This view becomes untenable in the context of Relativity since by its very definition it implies plurality since what is relative should be relative to something else.

CHALLENGE TO THE ARISTOTELIAN THEORY OF SUBSTANCE AND ACCIDENTS

This point has been already pointed out in connection with the Mass-Energy Equivalence. We have seen that mass can be converted into energy, and vice versa. Since mass is closely associated with the substance aspect and energy to the accident aspect, the Mass-Energy Equivalence allows conversion between substance and accident. This is not allowed in the Aristotelian system.

1.6 LET US SUM UP

In the past many schools of philosophy held that scientific concepts, once established as scientific, could not undergo any serious change. For instance, Newton in 1687 gave the Law of Universal Gravitation, according to which gravitation was an attractive force between material bodies. This theory was scientifically established. The claim was that this was a fact that could not be changed. But the General Theory of Relativity shows that Newton’s theory, though very valuable and served science admirably for centuries, is not the last word on the nature of gravitation; a better idea can be given, and this idea differs significantly from the Newtonian one. Thus scientific ideas, laws, theories, etc., are not for ever. They can and do undergo change.

Check Your Progress III

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

What are some of the important philosophical implications of Relativity?

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1.7 KEY WORDS

Special relativity is a theory of the structure of space-time. Special relativity is based on two postulates which are contradictory in classical mechanics:

1. The laws of physics are the same for all observers in uniform motion relative to one another (principle of relativity);
2. The speed of light in a vacuum is the same for all observers, regardless of their relative motion or of the motion of the source of the light.

General relativity is a theory of gravitation developed by Einstein in the years 1907–1915. The development of general relativity began with the equivalence principle, under which the states of accelerated motion and being at rest in a gravitational field (for example when standing on the surface of the Earth) are physically identical.

1.8 FURTHER READINGS AND REFERENCES

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1.9 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1. It is often thought that philosophy and science are radically different, and there is no close relationship between the two. A serious discussion of the Theory of Relativity shows that this belief is not correct. There is a close relationship between the two. Many great scientists were very deeply philosophically-minded, and many great philosophers were scientifically-minded. This discussion of Relativity shows that there can be and there should be a discipline called Philosophy of Science.

2. The historical background of Relativity is the search for the medium of ether and the famous experiment performed by Michaelson and Morley. See the details in the text. This historical study shows that scientific theories, especially very creative ones, have a context, and a knowledge of this context can be very valuable in understanding the meaning and significance of the theory. It also throws valuable light on the philosophical aspects of the theory.

Answers to Check Your Progress II

1. Relativity is a theory which says that concepts like length, time, mass, etc., are not absolute, but relative; relative to a frame of reference. Einstein gave two theories: The

Special Theory of Relativity and the General Theory of Relativity. The Special Theory of Relativity has two Postulates. The first says that all frames of reference which are moving with uniform velocity with respect to each other behave in the same way. That is, the laws of physics are equally applicable in all these frames of reference. The second Postulate talks about the special, unique nature of the velocity of light. It says that the velocity of light is a constant and absolute quantity. It is the highest velocity any material body can have. It can neither be increased nor decreased.

The Special Theory of Relativity has many important consequences. Some of them are: Relativity of length, relativity of time, relativity of mass, and the Mass-Energy Equivalence. For details see the discussion above. The General Theory of Relativity also has several important consequences. We have discussed only one: The new understanding of gravitation. Newton had said that gravitation was an attractive force between material bodies. According to Einstein in the General Theory of Relativity, gravitation is a geometrical property. It is the distortion or curving of spacetime continuum in the presence of matter.

Answers to Check Your Progress III

1. Some of the important philosophical implications of the Theory of Relativity are the following. It went against the belief in absolutism. For details see the text. It showed that Monism could not be accepted. It exposed the weakness of the Aristotelian theory of substance and accidents. It also showed that scientific concepts were not fixed, but underwent change, even very serious change.

UNIT 2 QUANTUM MECHANICS AND ITS PHILOSOPHICAL IMPLICATIONS

Contents

2.0 OBJECTIVES

The world of physical science has two important parts: the Mega-world – the world of large bodies and large velocities – and the Micro-world – the world of the minute bodies. Relativity deals mostly with the mega-world, whereas Quantum Mechanics deals with the micro-world. This unit attempts to give the students some of the fundamental ideas of the world of Quantum Mechanics and to help them reflect on some of the deeper philosophical aspects of this world. Just as in the case of the Theory of Relativity, in the case of Quantum Mechanics also we will see that there is a close linkage between science and philosophy. It will emphasize the fact that when science advances more and more, its philosophical dimension also grows.

2.1. INTRODUCTION

In quantum physics we find humans at their best as 'seekers.' Here we find them grappling with the eternal problem of the ultimate nature of reality. This problem has been haunting scientists ever since science was born. Each new development in science has been giving fresh and more accurate insights into the ultimate nature of matter. Thus in 1805, Dalton using the theories then existing came to the conclusion that the ultimate part of matter was the atom. However subsequent researches by Rutherford and others showed that Dalton's atoms were anything but atoms (indivisibles). From the beginning of the 20th century on, millions and millions of atoms were broken into still smaller elementary particles like electrons, protons, neutrons, mesons, positrons, neutrinos, etc. Thus arose the idea that the ultimate entity of reality was not atoms but sub-atomic particles. The human search for the ultimate nature of material reality did not stop here. It went further to investigate the structure of the elementary particles, and found that the ultimate stuff of matter was quarks. Again science wanted to find out the ultimate nature of this fundamental stuff of material reality. Two possibilities were offered: Wave nature and particle nature. To the great surprise and dismay of scientists, it was found that light had both these natures. Later it was found that not only light, but electrons, atoms and molecules also had two natures. How can one and the same entity have two distinct and incompatible natures? What are some of the consequences of this dual nature of light and matter? All these and related considerations gave rise to serious scientific and philosophical questions. This unit will discuss these points.

2.2 HISTORICAL BACKGROUND: MAX PLANK'S DISCOVERY AND THE ORIGIN OF QUANTUM THEORY

In 1900 the German physicist, Max Planck, made a great discovery which became the foundation of Quantum Theory. The chain of developments that led him to the discovery can be put as follows: It was known for a long time that material reality could exist in two different forms – as matter and as radiation or as mass and energy. Matter refers to material bodies like atoms and molecules. On the other hand, light is a form of radiation. Now it has been found that matter can be divided into smaller and smaller bits. But, as far as our present knowledge goes, when we reach quarks, matter cannot be divided any more. So there is a limit to the divisibility of matter. The question Max Planck had to tackle was with regard to radiation or energy. It is known that energy can be reduced. But is there a limit to the reducibility of energy? Initially it was thought that there was no such limit - energy could be reduced endlessly. But this belief gave Max Plank and others serious problems, particularly when they were studying the Blackbody Radiation. At the end Max Planck took the drastic step of assuming that there was a limit to the reducibility of energy or radiation. In other words, he said that we could go on reducing energy, but when we reach a certain limit, we had to stop the process of reducing. Max Planck called this quantity of energy at the limit 'h,' which is today called the Planck's Constant. 'h' is the smallest bit or quantum of energy that can exist in the universe. Nothing smaller than h is possible. This discovery led science to the conclusion that energy is emitted, propagated and absorbed not continuously, but discretely, in small bits. Quantum Theory gets its name from this idea of quantum or packet of energy.

2.3 WHAT IS QUANTUM THEORY?

Quantum Theory is the physics of molecules, atoms and elementary particles. To date, it is considered the most successful theory in science since it has been successfully applied to many intricate phenomena. Relativity was mainly the work of one scientific genius, Albert Einstein. However, Quantum Theory needed the contribution of many scientific geniuses to develop and reach the stage it is in today.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What is Quantum Theory? Why is it important in philosophy of science?

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2) What was the main contribution of Max Planck? Why is it important in the history of science and philosophy?

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2.4 THE FUNDAMENTAL BUILDING BLOCKS OF MATTER

Since Quantum Theory deals with the ultimate nature of matter, it talks about the ultimate building blocks of matter. We will try to explain this point with a simple example. Suppose we have a piece of common salt, the chemical name of which is sodium chloride. We can break it into smaller pieces. At the end we come to one single molecule of sodium chloride. This is the smallest bit that shows the basic properties of common salt. But we can break the molecule into its individual atoms, and we are left with one atom of sodium and one atom of chlorine. These atoms also can be further broken up, and we get a number of protons, neutrons, electrons, etc. Although protons and electrons are still called elementary particles, they can be broken up into smaller bits known as quarks. According to the scientific view today, quarks are the rock-bottom of material reality since a quark cannot be broken up further. Thus here we reach the ultimate building block of material reality.

2.5. THE ULTIMATE NATURE OF MATERIAL REALITY

We have seen what the ultimate building block of matter is. Now the question is: what is its nature? How does it look like? Usually two possibilities are considered: Wave nature and particle nature. So the question now is whether material reality is ultimately wave-like or particle-like, whether it behaves like waves or particles. In the first quarter of the 29th century a lot of hard research was done by scientists on this issue. Historically, this investigation started with the nature of light. Here it was found that light had not just one nature, but two distinct natures – wave nature and particle nature. This discovery of the dual nature of light was a shocking result for scientists and philosophers who were committed to the belief that one being could have only one nature. For instance, a human being has human nature, no other nature. To add to this perplexity, later investigation showed that material particles like electrons, protons, atoms and molecules also had dual nature. We will now discuss these developments step by step.

Dual Nature of Light

Serious and careful investigation on the nature of light showed that light had wave nature. This view was supported by eminent scientists. It had very reliable empirical evidence in its favour. At the same time it was found that there was equally strong evidence to show that light was made of tiny particles. This view also was supported by many eminent scientists. First we will take up the discussion of the wave nature of light. A number of well-known phenomena supported this view.

Evidence for the Wave Nature of Light

The well-known phenomena that support the wave nature of light are:

a. Interference
b. Diffraction
c. Polarization

We will discuss only the second one of diffraction since it is relatively non-technical and easy to understand.

Diffraction

It has been observed that light bends round a corner or around sharp edges. This phenomenon is referred to as diffraction. When a sharp edge, like a knife-edge, is placed in the path of light, it bends around to go to the other side. It was argued that since light was expected to travel along a straight line, this bending could not be explained if light was made up of tiny particles. Hence, it was concluded from the phenomenon of diffraction that light had wave nature.

Evidence for the Particle Theory of Light

There were well-known and well-supported phenomena to show that light had particle nature. Some of these phenomena are:

a. Photoelectric Effect

b. Compton Effect

We will discuss only the first one of Photoelectric Effect.

Photoelectric Effect

Photoelectric Effect basically involves the production of an electric current by the action of light. It has been found that when light falls on certain special metallic surfaces, electrons are ejected from those surfaces, and an electric current is produced through the flow of these electrons. This phenomenon is called Photoelectric Effect.

Einstein in 1905 gave an explanation for this phenomenon. He assumed that light was made up of a stream of tiny particles called photons. Also the special surfaces mentioned above had free electrons on the outermost layer, which could be easily dislodged. When light falls on the surface, the photons collide with the free electrons, and dislodge them. These electrons are collected, and they give rise to the electric current. It has been shown that this phenomenon cannot be satisfactorily explained if we consider that light is made up of waves. Thus this Photoelectric Effect has become a strong evidence for the particle theory of light. Einstein received his Nobel Prize for his explanation of this effect.

2.6 THE DILEMMA WITH REGARD TO THE NATURE OF LIGHT

These scientific findings gave rise to a dilemma in science in the first quarter of the 20th century: On the one hand there was strong and reliable scientific evidence that light showed two different and distinct natures. On the other hand, the accepted belief was that one and the same thing could have only one nature. Science finally settled for the uncomfortable conclusion that light had not one but two natures.

The Contribution of Louis de Broglie

In 1923 Louis de Broglie proposed that a moving particle, whatever its nature, had wave properties associated with it. He even gave a formula for the wavelength of such a particle. If the mass of the particle is ‘m,’ velocity ‘v,’ and wavelength ‘wl,’ then we have:

wl = h/mv.

This relation shows that a wave is associated with the material particle, although the wavelength is very small. The wavelength depends on the mass of the body. The larger the mass, the smaller the wavelength. This explains why we do not notice wave-like behaviour among ordinary things since they have a significant mass and so their wavelength is imperceptibly small. On the other hand, the mass of electrons, atoms and molecules is very small, and so their wave properties become significant and noticeable.

Experimental Confirmation of de Broglie’s Proposal – Wave Nature of Matter

The theory of de Broglie was confirmed in 1927 by Davisson and Germer through their electron diffraction experiment. They obtained a diffraction pattern using a beam of electrons. This showed that electrons behaved like waves. Again, in 1928 Thomson confirmed this result with a more refined experiment. Still more, in 1932 Stern experimentally showed that atoms and molecules showed wave-like properties. Thus it seemed that the wave-property was not the monopoly of light or minute electrons, but was the characteristic property of all matter.

2.7 DUAL NATURE OF MATTER

The theory of Louis de Broglie and the epoch-making experimental work following it showed that matter had a dual nature. The old view of “one thing, one nature” was challenged, and shown to be incorrect when it came to the quantum world. Science had to admit that light as well as matter shows sometimes wavelike properties and sometimes particle-like properties. Both natures are correct and have to be taken seriously. Thus it seemed that the ultimate nature of reality is not particles or waves but rather ‘wavicles’ (waves and particles) Describing this situation, de Broglie says, “It is one of those stages where the human is forced to realize, with some bitterness, that the complexity of reality refuses to allow itself to be cast in too simple a mould, and that a new and painful effort will be required for a fresh definition of what, after all, is perhaps indefinable.” This shows a certain indefiniteness or indeterminacy with regard to the nature of material reality. This empirically-established indeterminacy is at the foundation of Quantum Mechanics.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Explain the fundamental building blocks of matter.

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2) What does Quantum Mechanics say about the ultimate nature of material reality?

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2.8 THE UNCERTAINTY PRINCIPLE

The Uncertainty Principle or the Principle of Indeterminacy is often considered *the* principle in Quantum Mechanics. As Hutton puts it: “The new Principle of Uncertainty or Indeterminacy is regarded as fundamental in the description of microscopic process.” Since it was developed by

Werner Heisenberg, it is also called the Heisenberg's Principle. Philosophically it is of the highest significance since it raises many philosophically sensitive issues. Its importance in philosophy of science is enormous because it reveals many striking facts about the nature, capability and limitedness of science. Some of its consequences are so novel and unexpected that great scientific stalwarts like Einstein, de Broglie, Bohm, etc, did not accept it, but the vast majority of scientists made it part of their credo, and still do.

Some Basic Assumptions

To understand adequately the meaning and significance of the Uncertainty Principle, it is important to keep in mind two basic assumptions made in science, particularly in the science of Mechanics.

The Idea of Complete Knowledge: In Mechanics one can talk of complete knowledge of the state of a body if one can determine exactly both the position and the momentum (mass x velocity) of that body at the same time.

Neutrality of the Act of Observation: In any experiment it is assumed that the act of observation does not influence the result of the observation, and does not alter the object under observation. In other words, the object under observation remains the same both before and after the act of observation.

2.9 THE STATEMENT OF THE UNCERTAINTY PRINCIPLE

It is in principle impossible to determine exactly both the position (location) and momentum (dynamical state) of a particle at the same time. No matter how much we try, no matter how sophisticated the instruments we use, there will always be a certain amount of inexactness or uncertainty with regard to the exact state of the particle under consideration. Mathematically this Principle can be put as follows: Suppose 'p' stands for the momentum of the particle and 'dp' stands for the inexactness or uncertainty with regard to the determination of the momentum of the particle. Similarly suppose 'q' stand for the position or location of the particle and 'dq' for the inaccuracy or uncertainty with regard to the determination of the position. Then the Uncertainty Principle can be given as: **dp x dq is greater than or equal to 'h,'** where 'h' is Planck's Constant.

This relation shows that the uncertainty can never be eliminated fully. If we try to reduce the uncertainty of position to zero, then the uncertainty of momentum becomes infinite, meaning that we will not know anything about the momentum of the particle. The same happens if we try to reduce the uncertainty of momentum to zero. Uncertainty or inexactness in the quantum world is inescapable.

The Uncertainty Principle puts a natural limit to the exactness attainable in science or the certainty obtainable in science. Under no condition can one get 100% exactness or 100% certainty in science. Thus this principle exposes the limitedness of science. It may be noted that this finding has come from science itself.

2.10 THE CAUSES OF THE UNCERTAINTY OR INDETERMINACY

A number of reasons can be given to account for the source of this indeterminacy.

The Indeterminate Nature of the Elementary Particles

We have already seen that when it comes to the ultimate nature of light and elementary particles, there is a certain indeterminateness – they can show wave properties or particle properties. Their nature is such that they do not allow measurement of exact position and exact velocity at the same time.

An Analysis of Observation in Science for Gathering Information

Interaction is necessary for observation and measurement. In this connection it is helpful to reflect on how information is obtained through observation in science. Any observation for gathering information needs communication between the observer making the observation and the object being observed. Without such a communication no genuine observation is possible. Now for this communication a messenger is needed to go from the observer to the observed, and then to come back to the observer with information of the observed. For instance, take the case of a king in olden times gathering information about another king. He will send his messenger to the other king. The messenger gets in touch with the other king, gets the information, and then comes back to the king with the information. Basically the same happens in the case of observation in the quantum world. From the observer (from his/her observational equipment) a messenger radiation will have to go to the object under investigation. This radiation will have to interact with the object, and then come back to the observer with the information. Hence here two items are necessary: The messenger radiation and the interaction. Both these items have serious consequences for the information or knowledge obtained from the observation. Both these put serious limits to the kind of information or knowledge obtained.

Limit to the Smallness of the Radiation

A messenger radiation is necessary for gathering information through an observation. Electromagnetic radiation is the fastest and most accurate candidate for this messenger since it moves with the velocity of light, the highest any material entity can have. Also we know that in any measurement in general the smaller the unit used, the more accurate the result of the measurement. Now according to Quantum Theory, the smallest unit that can be used for making observation is h. So the smallest messenger radiation available to us is a packet of radiation of a single h. Nothing smaller than h is possible. This brings in a certain coarseness in our measurement and observation, and the information coming therefrom. Thus naturally a limit is put on the extent of accuracy we can get in science.

The Need for Interaction

As we have seen, interaction is necessary to get information through observation. No interaction, no information! This requirement also leads to uncertainty because this interaction involves spending of energy and disturbance of the object under observation. This disturbance prevents us from getting exact information, thereby leading to a certain uncertainty.

Uncertainty Unavoidable

The uncertainty or indeterminateness coming from the Uncertainty Principle is an "in principle" uncertainty, not just a practical uncertainty. Everyone knows that because of our human frailty and fallibility in practice absolute certainty and accuracy are beyond our capability. But the Uncertainty Principle goes further to declare that this uncertainty is far deeply rooted in the very nature of the material world. The nature and structure of our material world simply does not lend itself to absolute accuracy and absolute certainty. There will always be a certain amount of uncertainty no matter how hard we try, how accurate our instruments. As Heisenberg says in the context of our attempt to get accurate information about an electron, "The indeterminateness is to be considered as an essential characteristic of the electron and not as evidence of the inapplicability of the wave picture." So long as we accept the quantum nature of material reality, i.e., energy is produced, propagated and absorbed only in discrete quantities of multiples of h, this uncertainty remains unavoidable.

Some Important Consequences of the Uncertainty Principle

Few scientific principles attracted such wide variety of schools of thought as did this principle. It was like a magician's wand! People, could, it seemed, deduce almost anything from this principle! Thus in the Uncertainty Principle certain theologians could see the "scientific proof" for the possibility of miracles. For the empiricists and materialists it seemed to give the "theoretical backing" for discarding the age old principle of causality. For the defenders of free will, it gave a "scientific theory" for showing the existence of free will. But it does not take much reflection to show that all these hasty conclusions arise from a partial or incorrect understanding of the principle itself. However there are a number of consequences which arise straight from the theory itself, and which have serious scientific and philosophical importance.

Indeterminate Nature of the Elementary Particles

We have seen that material reality in the quantum world shows duality of nature – they have wave properties as well as particle properties. The Uncertainty Principle is closely linked to this scientific finding. This means that the clear-cut corpuscles of classical physics no longer represent the real state, but only the idealized state.

Information in the Pure State Impossible

In scientific observations and other forms of investigation it is assumed that the act of investigation leaves the object under investigation intact, i.e., the object remains the same both before and after the investigation. Hence the claim was that the "purity" of the state is unaffected. However, we have seen that interaction is necessary to get information, and this interaction involves energy exchange and related changes. Hence the "pure" state is disturbed. We cannot get information in the pure, undisturbed state.

Intrusion of Subjectivity

Another claim made by Classical Science was that there could be complete objectivity in science. Objectivity can be defined as independence from person, place and time. An objective statement is one that does not depend on who says it, at which place it is said, and at what time it is said. Two plus two is four is considered an objective statement, because it does not depend on who says it, where it is said and when it is said. In the light of the developments in Quantum Theory, particularly in the context of the Uncertainty Principle, this claim to complete objectivity cannot be accepted. We have seen that disturbance is unavoidable in investigations involving observation. Hence the object under investigation does not remain the same both before and after the observation. Since this is the case, claims arising from such an investigation cannot be independent of person, place and time. This leads science to rule out complete objectivity from its claims, at least in the quantum world. Some subjectivity comes into science. Louis de Broglie says, "Quantum Physics shows that a description of physical reality which is wholly independent of the means by which we observe it is strictly an impossibility."

Please note that the subjectivity involved here is very small, it is of the order of h which is the smallest bit of energy possible. In the practical world, this subjectivity is negligibly small.

Exact Predictability not Possible

Closely linked to what has gone before is the impossibility of exact prediction in the quantum world and for that matter in the scientific world itself. Exact prediction requires exact knowledge of the prior situation. Since, according to the Uncertainty Principle, such an exact knowledge is not possible, no exact prediction is possible in the quantum world.

Statistical Nature of Scientific Laws

Given all the limitations above, it follows that in science we cannot talk of exact laws which can yield exact information, and which enable us to make exact predictions. Hence science cannot give us information with absolute certainty; it can give us only information that is highly probable. Scientific laws and claims are probabilistic or statistical.

2.11 SOME PHILOSOPHICAL REFLECTIONS ON QUANTUM MECHANICS

Quantum Mechanics is considered to be the most successful theory ever proposed by humans. It is considered also as one of the most revolutionary theories in the history of humankind. Obviously, it has many deep-level, serious philosophical implications.

Insights Concerning the Fundamental Nature of Material Reality

Thinking and reflective humans have always asked the question: What is our universe made up of? What is the fundamental stuff out of which our amazing universe has been formed? Many answers were given to this question down through the ages. For instance, Thales of Miletus in ancient Greece said that the element water was the fundamental stuff. In the Indian tradition, particularly in the Buddhist tradition, very interesting answers have been given to this perennial question. The merit of Quantum Theory is that it has attempted to give a serious and responsible answer to this question based on serious, solid and sustained scientific investigation. Traditionally the quest for the fundamental nature of reality has been a part of metaphysics in philosophy. Quantum Theory is, in a way, engaged in this metaphysical inquiry concerning the ultimate nature of material reality, and has shed very valuable light on the issue. This case shows that metaphysics need not be confined to the abstract, speculative realm of philosophy.

Exposing the Limitedness of Scientific Knowledge

The findings of Quantum Mechanics have revealed the serious limitedness of science. We have seen that, thanks mainly to the conclusions arising from the Uncertainty Principle, scientific knowledge is not absolute, cannot claim absolute certainty, cannot claim absolute exactness, cannot give exact prediction, etc. All these go against the claims of classical or Newtonian science. Most scientists and many schools of Philosophy, particularly the Positivists, had subscribed to this view of science and scientific knowledge.

2.12 LET US SUM UP

The exposing of the limitedness of science should not mislead us to conclude that Quantum Mechanics or science has been a failure. Not at all. As has been mentioned already, Quantum Mechanics is the most successful theory ever proposed by humans. It has so many laurels to its credit. It continues to be successful in various fields. So many brilliant minds all over the globe are engaged in serious and productive research in the field of Quantum Mechanics. There is good reason to believe that this state of affairs will continue for years to come. All that these developments in the science of Quantum Mechanics have shown is that we need to have a realistic view of science, not an elitist view. Science has achieved a lot, and will continue to do so. But it is not a panacea or answer for every problem. It has its own domain, its own area of competence. It has its own strengths and limitations.

Check Your Progress I

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Explain the Uncertainty Principle. Give some of its important philosophical consequences.

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2) What are some of the important philosophical implications of Quantum Theory?

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2.13 KEY WORDS

Compton Effect: Einstein's photoelectric discussion of 1905 and his other work including Special Relativity led physicists to speculate on the momentum of these packets of light which became known as "photons." Arthur Compton and Debye both provided in 1922 a very simple mathematical framework for the momentum of these photons with Compton having experimental evidence from firing X-Rays of known frequency into graphite and looking at recoil electrons.

Momentum: In classical mechanics, momentum is the product of the mass and velocity of an object ($p = mv$). In relativistic mechanics, momentum is sometimes referred to as linear momentum to distinguish it from the related subject of angular momentum. Momentum is a conserved quantity, meaning that the total momentum of any closed system (one not affected by external forces) cannot change.

2.14 FURTHER READINGS AND REFERENCES

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2.15 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress I

1. Quantum Mechanics is the science of the micro-world, the world of minute material beings. It studies the ultimate nature of material reality. In doing so it investigates the breakup of matter into molecules, atoms, elementary particles, and quarks.

Quantum Mechanics is important in philosophy of science because it helps us develop a metaphysics of material reality.

2. Max Planck was a German physicist. His primary concern was to find out how energy or radiation was emitted, propagated and absorbed by different bodies. He found that just as there was a limit to the divisibility of matter or material bodies, there was also a limit to the reducibility of energy or radiation. We cannot go on reducing energy indefinitely. We reach a point where we cannot reduce energy any further. This limit is h, which is called the Planck's Constant.

Planck's discovery was very important since it put an end to the old belief that energy could be reduced ad infinitum. Planck's discovery of h is fundamental to Quantum Mechanics. The philosophically most important Uncertainty Principle is closely linked to h.

Check Your Progress II

1. The fundamental building blocks of matter are quarks, according to the current science. We can arrive at it as follows. Suppose we have a piece of chalk. We can break it up into smaller pieces. At last we reach a molecule of chalk. This is the smallest bit that shows all the basic

properties of chalk. We can break the molecule into its atoms. Then the atoms into elementary particles like Protons, Neutrons and Electrons. Protons and Neutrons can be further broken up into Quarks. With Quarks we reach the rock-bottom of matter.

2. Concerning the ultimate nature of material reality Quantum Mechanics says that material reality is indeterminate. That is, it shows two distinct natures – wave nature and particle nature. Historically, the study went through two steps: First it studied the nature of light, and found that light had two natures. Certain well-known phenomena of light showed that light had wave nature. Certain others showed that light had particle nature. Hence light showed a dual nature.

Similarly it was found that matter also had two natures. Electrons, Protons, atoms, etc., showed wave nature in certain situations and particle nature in certain other situations. Hence matter also has a dual nature. Although some scientists found this duality of nature unacceptable, most scientists accepted it, and the Quantum Theory was based on this finding of science.

Check Your Progress III

1. The Uncertainty Principal is the most philosophically significant aspect of the Quantum Theory. It says that it is in principle impossible to determine exactly both the position and momentum of a particle at the same time. Since, according to the science of mechanics, knowledge of both the position and momentum of a body is necessary for getting complete knowledge of a scientific system, this principle says that we cannot get complete knowledge of a scientific system. Since it is an "in principle" impossibility, not merely a practical impossibility, this principle says that we can never get complete knowledge, no matter how hard we try, how highly sophisticated instruments and methods we use.

Some of the important consequences of this principle are: The indeterminate nature of material reality, impossibility of getting information of system in its "pure" state, intrusion of subjectivity into scientific claims, impossibility of exact prediction in science, and the impossibility of exact laws in science.

2. Our study of Quantum Theory has important philosophical implications. First of all, it helps us to develop a metaphysics of material reality. Here we find that material reality is

indefinite and indeterminate at its foundational level. This study also has exposed the limitedness of science. Scientific knowledge has serious limits. At the same time our study of Quantum Theory shows the tremendous strength of science since it is accepted as the most successful theory proposed by humans.

UNIT 3 FINITE / INFINITE NATURE OF THE UNIVERSE

Contents

3.0 OBJECTIVES

The question whether our universe is finite or infinite can only be answered by a subject that incorporates a bundle of disciplines namely, philosophy, physics, mathematics and geometry. From the very beginning of human history, the immensity of the universe, fascinated as well as frightened humanity. Though the Ziggurats, Stonehenge, Machu Picchu, sundials, observatories and satellites all probed the vast nature through millenniums, yet a clear and distinct answer on the question always eluded us. Each probe though unraveled many mysteries, still pushed us into deeper mysteries. Thus this course on the finite/infinite universe, tries to unravel the question from four different perspectives, namely the mythical, the philosophical, the religious and the scientific. Thus, cosmogony explains the answer given by the ancient civilizations while cosmosophy elucidates how Aristotle answered the question from a philosophical outlook. The medieval scholastic thought enumerates the number of spheres and the limits of the universe through a religious interpretation of the cosmosophy. The inadequacies of the medieval cosmotheology paved the way for a paradigm shift in modern astronomy through the earth shaking contributions of Copernicus and Galileo. The heliocentrism thus emerged led to the classical mechanics which in turn generated the theory of relativity and quantum mechanics which together elucidate the big bang expanding evolutionary cosmology. However, a distinct and clear answer on the question of the finiteness/infiniteness of the universe still eludes us because of the proposals of dark matter and infinite universes by scientists. As Einstein claimed, our universe is bound; yet unbound, an answer that spreads a shroud of mystery still over the universe.

So by undergoing this course you will be able to understand

- the immensity of our Universe
- the gradual development of our knowledge about the universe
- the scientific descriptions about the universe
- unknown parameters that govern the bounderies of our universe

3.1 INTRODUCTION

By looking up into the vast immensity of the night sky, the primitive humanity created myths about the universe as a means to comprehend it. Thus all civilizations created stories based on their experience and their environment. The Babylonians developed the Zodiac based on sexadecimal system, six as the base, 60, 360 for defining both time and space. Thus they created the Zodiac, the first comprehensive model of the universe. For them the universe was like a closed box in the midst of which was the source of river Euphrates and beyond it stood the celestial mountains which supported the sky. The Egyptians believed that the Sky Goddess Nut gives birth to the Sun God Ra creating a myth of the divine origin of the Pharaohs fusing the calendar development and the divinity of royalty. They developed geometry by measuring the land. For them, the universe was like a box whose ceiling was the sky kept hung by cosmic cables. Greeks created the pantheon of Gods as Zeus head and the mount Olympus as the haven of Gods and they developed notions of circles to describe the macro universe and elements to define micro universe. The Indian civilization developed a cyclic universe, the creation annihilation as a continuous chain reaction. The Chinese based their universe on harmony and the harmony of the heavens and that of the earth as yin and yang, complimentary. Thus all these civilizations defined the universe as finite, but described based on their experience in an entirely different way.

3.2 BABYLONIAN COSMOGONY

The most ancient description of the universe, as far as we know, is found in the *Enuma Elish* creation epic of the Babylonians. It is a long poem that took a definitive form by 1500 BC, describing how god Marduk created the universe, the births of the gods and how Marduk achieved supremacy among these gods. This cosmogonic epic narrates how Marduk "set up constellations corresponding to the stars, designated the year and marked out its divisions and apportioned three stars to each to the twelve months". These lines of the epic, thus, denote the division of the Zodiac into twelve equal parts, assigning stellar constellations to them and the ordering of the year into twelve lunar months in addition to the description of the phases of the moon and the naming of the thirty six stars used to notify the time of the year. Thus, this epic exposes the supremacy of the Babylonian culture in the observation of the sky and the conceptual structuring the universe, for the first time, through computation.

The ancient Babylonian culture was a fusion of the Mesopotamian, Sumerian, Assyrian, Chaldean and Persian cultures. It seems that there were also interaction between the Mesopotamian and Indian culture because of the similarities on the division of the zodiac into twelve equal parts and assigning signs to them. The Alexandrian conquest speeded the interaction among the cultures and as a result an integrated description of the world also gradually emerged.

The identification of the human existence and the prediction of the future events with the heavenly phenomena led the Babylonians to observe the sky and record meticulously the celestial events. Social mechanisms were established by the authorities in order to meticulously record, store and preserve the astronomical data like the positions of the moon and the other planets, weather etc. This duty was entrusted to the priests of the temple of Esanglia in Babylon and thus the scientific documentation of the astronomical data started for the first time. For this purpose, the Babylonians developed the sexagesimal algorithm which was so useful in ordering time and space which spread to all other cultures and continue even in the twenty first century. The time, one hour, has been divided into 60 and the space in a circle into 360 degrees. It has been speculated that the ease of calculation without the use of fractions might be the reason for the development of this base 60 number system. This introduction of mathematical techniques to describe the heavenly phenomena quantitatively which became the hallmark of arriving at a model for the universe.

3.3 GREEK COSMOGONY

In the early Greek culture like many other cultures, a qualitative description of the universe can only be found. Homer's *Iliad* and *Odyssey* were written around the eight century BC. They give glimpses of the early Greek concepts on the universe. The Olympian gods and their leader Zeus created and governed the universe according to their whims and fancies. Many stars and their constellations like Pleiades, Hyades, Orion and the Bear are mentioned in the book. Homer considered the earth as flat just like a shield, surrounded by Ocean while the sky was similar to a solid like iron or bronze. Hesiod's *Works and Days* is a more systematic attempt to connect the lives of humanity with the heavenly phenomena. The celestial phenomena guides the human activities through an agricultural calendar based on the phases of the moon, solar cycle and the motion of the stars. However, a popular practical astronomical knowledge that was connected to the lives of the ordinary people developed in the early Greek period. Compared to the Babylonians, the qualitative astronomical knowledge developed by the Greeks was thus far inferior without any accurate predictions and descriptions of the heavenly phenomena.

3.4 INDIAN COSMOLOGY

The Vedas, Upanishads and the Bhagavatas describe the universe as cyclic and thus infinite. The Vedic splitting of the Brhamanda cosmic egg as Purusha and Prakriti and the various evolutes describe another form of the cosmic evolution and the underpinning rhythm of the universe. The description of the life of the Brhama for a yuga and the end of it the pralaya creating a brand new Brhma denotes the cyclic concept of the universe and thus the prospects of an infinite universe.

3.5 MATHEMATIZATION OF NATURE

However, soon the Greek mind took a philosophical bent. The Ionian and Eliatic thinkers tried to interpret the nature rationally and materially in an all-comprehensive way, proposing elements like water, air, fire and earth as constituents in an imaginative and experiential way. *Apeiron* like abstraction was also introduced in order to describe nature in an abstract way. It is the Pythagoreans who introduced the revolutionary concept that mathematics as the key to unlock the mysteries of the universe in terms of patters, forms, ratios and regularities. Thus music was reduced into a ratio; octave as 2:1, fifth as 3:2, and fourth as 4:3. A pattern is also generated from the addition of successive odd numbers generating square numbers. As an example 1+3 = 4 +5 = 9+7 = 16+9 = 25 . .etc. Thus philosophy is the highest form of music that itself reducible to numbers. The celestial bodies are considered as spheres each having its own musical rhythm, depending on the ratios of their respective orbits giving rise to a musical harmony. Thus, the Pythagoreans blended the academic intellectual life and the societal spiritual life into a harmonious and complimentary approach. Philolaus, another Pythagorean introduced the concept of fire at the centre of the universe from where the universe drew its warmth, energy and breath. Thus, the Pythagorean cosmology was the harmony of the spheres, where at the centre there is fire, providing heat and light. Beyond the fire is the spherical earth which is surrounded by the sun, moon and other planets in concentric circles. It is generally assumed that the introduction of the sphericity of the Earth and the idea of a spherical cosmos are proposed for the first time by the Pythagoreans.

The Pythagorean abstract mathematical doctrines influenced Plato very much leading him to speculate a perfect, ideal world where the numbers have a real and independent existence. He expressed the reality of the ideal world and the shadowy nature of the sensual world through the metaphor of the cave. The dialogues of Plato, namely, *Republic*, *Thaetetus* and *Timaeus* describe the celestial phenomena. The Platonic doctrines on the creation of the universe and the constitution of matter are to be found in *Timaeus*. Plato held the concept of a geocentric universe surrounded by Moon, Sun, Venus, Mercury, Mars, Jupiter and the fixed stars. Plato credited the creation of octahedron and icosahedron, to Thaetetus, two of the total five Platonic symmetrical solids which have the property that all the faces and all the vertices are identical. Thaetetus was a mathematician in Plato's academy and Plato immortalized him by giving his name as title to one of his dialogue. The other three solids, namely, the tetrahedron, cube and dodecahedron were already discovered by the Pythagoreans. Plato identified these solids with that of the five elements, namely, fire, air, water, earth and ether. In Plato's attempt to integrate the form of the solids with a constituent physical matter - fire on account of its shape of a flame with tetrahedron, water the heaviest with the icosahedron, air with the intermediary density with octahedron and earth with the stable cube. Dodecahedron was identified with ether and constituted the celestial bodies that are moving in circular motion around the earth.

3.6 GEOMETRIZATION OF THE UNIVERSE

A fusion of the Babylonian, Greek and Egyptian astronomical and mathematical knowledge led to the first comprehensive geometrical model of the universe by Eudoxus of Cnidus. We get the information on Eudoxus from his contemporary and the influential sixth century Aristotelian commentator Simplicius. Aristotle's works such as *Metaphysics* and *On the Heavens* quote and refine Eudoxus' geometrical model from a philosophical perspective. Relying more on other authors, Simplicius gave details on Eudoxus. It seems that Eudoxus estimated accurately the duration of a year as 365 days and 6 hours, developed a star calendar, discovered the circumference of the Earth and proposed a treatise on the eight year lunar-solar cycle. Eudoxus' works, namely, *Phenomena, On Speeds* and *Mirror* contain the systematic description of the universe and they all seem to be lost forever. However, Aratus of Soli was inspired a century later by Eudoxus' *Phenomena* and wrote a poem *Phenomena* which became famous and was translated into Latin; many commentaries were written on it. Hipparchus, another Greek mathematician and astronomer commented on Euoxus' and Aratus' *Phenomena* and highlighted the astronomical errors he encountered in these books. The Italian astronomer Schiaparelli reconstructed the Eudoxian structure of the universe, basing it on Callippus and Aristotle and most of the modern accounts are based on this book. Eudoxus initiated and influenced Euclid and his *Elements*, which became the flowering of Geometry in the Greek culture. The astronomical and mathematical discoveries of Eudoxus were thus of fundamental significance to Greek geometry.

3.7 ARISTOTELIAN COSMOSOPHY

Aristotle superimposed the imaginative-experiential, abstract mathematical and metaphysical analysis of the Pre-Socratic investigation into the structure of the universe with his conclusive metaphysical cosmology. Thus Aristotelian cosmology can be better interpreted as a cosmosophy than a cosmology. Aristotle did not focus his writings on astronomy and science in one volume but one can find them scattered in different volumes. The main three treatises in which he concentrated his cosmological views are *Physics, Meteorology, On the Heavens, Metaphysics* and *On Generation and Corruption*. In these books, Aristotle summarized and gathered all the ancient wisdom on science and cosmology in an orderly manner. When we critically examine today, this vision seems to be a common sense approach.

Aristotle's *Physics* containing eight books deals with the first causes and the natural movement in general. Examining the already given proposals of the Pre-Socratic philosophers on the questions of the basic building block of the universe, Aristotle sums them up with his own critical reflections and draws from them a few common elements and a structural principle. The second chapter of *Physics* deals with the philosophy of nature of Aristotle. Chapter I describes the meaning of nature and chapter II differentiates between physics and mathematics. Chapters III-IX deal with the causes behind physical phenomena. Aristotle brings out the general difficulty in differentiating physics from mathematics by pointing out the overlapping of the disciplines in studying planes, solids, lines and points. Aristotle clarifies that mathematics describes the world by abstraction while physics examines the physical body as matter. Mathematics in terms of arithmetic and geometry through quantitative analysis studies on pure discreteness and extension as abstraction. Physics on the other hand studies the universal matter than individual discrete entity. Aristotle being aware about the interrelationship between mathematics and physics and forms a discipline named applied mathematics where he employs the disciplines like astronomy, harmonics, optics and mechanics as physical parts of mathematics. The role of physics is to study nature both in terms of matter and form. Nature as form is the end while nature as matter is the means to the end and thus, Aristotle's teleological orientation is evident even in the study of nature as physics. Philosophy, physics, mathematics are all according to Aristotle, inextricably intertwined and thus he narrates them as philosophy of nature.

According to Aristotle, the underpinning philosophy of the study of nature is to discover the causes that are at work in nature. For Aristotle, to know is to know by means of the causes. So physics invariably looks out for the causes of physical changes and distinguishes four kinds of causes. The term cause is first applied to “that out of which a thing comes to be and which is present as a constituent in the product” as a statue made out of wood and has wood in it and termed as material cause. This material cause is applied to the form or pattern of a statue, according to which the matter is manipulated and termed as the formal cause. The technical gadgets as well as the manipulator or means that transform the matter in to a statue are known as the efficient cause. The end of the whole process is termed as final cause which may be expressed as the goal of making the statue for fame or money. All these four causes together are the conditions of necessity for any effect. Aristotle thus emphasized end over means and introduced a finality, order and purposiveness in the hierarchy of causes and hence applied philosophy into the analysis of physics. Thus it is evident that Aristotelian physics is absolutely driven by philosophy.

This meta-physics is culminated in the book VIII of *Physics* elaborated through the introduction of the prime mover. Gradually Aristotle develops the concept of the prime mover through an analysis of motion. Motion is defined as always existing and there are things at rest as well as in motion. Whatever is in motion is moved by something and there must be a prime mover that moves everything but yet unmoved and eternal. The first mover has no parts or magnitude, and is at the circumference of the world. Thus, the movement originates from the circumference, is the fastest of all movements and it imparts this motion to the heavenly spheres and hence they are the fastest of all bodies. However, Aristotle leaves us in the dark about how the unextended and incorporeal prime mover be at the circumference of the universe and how can it impart movement. These questions are answered in his *Metaphysics*.

Through an analysis of sensation, memory and experience, Aristotle arrives at the primordial desire of man to know the pure knowledge of causes which he defines as wisdom. It is the knowledge of causes as first, foremost and universal and the most comprehensive of all knowledge. Philosophy springs forth from wonder and moves towards understanding of the universe through the discovery of the first and universal causes. Thus *Metaphysics* compliments *Physics*.

Physics studies the substantial existence that are subject to change while mathematics studies entities that are free from change but exist as distinguishable aspects of concrete reality. *Metaphysics* studies entities that unchangeable, substantial and distinguishable. Physics deals with the terrestrial bodies - perishable sensible and the eternal sensible – the celestial bodies.

Metaphysics examines with the unchangeable God who is the prime mover or the unmoved mover and the intelligences that move the planetary spheres. The climax of Aristotle's *Metaphysics* is in his *Book A*, termed as theology that deals with the substantial, self dependent existence free from all kinds of changes. It starts with the observation of the existence of the best over better and identifying it with the divine. Time and change are imperishable and Aristotle comes up with the explanation for eternal circular motion of the celestial bodies which is proved by experience.

Then Aristotle examines the cause for an eternal circular motion whose essence is pure activity and postulates the existence of the unmoved mover which is eternal, substantial and purely actual being. In order to avoid a physical causation on the mover by the moved, Aristotle postulated that the unmoved mover must be a non-physical entity, by being an object of desire existing outside of space.

The nature of the causation of motion is dealt by Aristotle as the unmoved mover as the efficient cause by being the final cause through love and desire. Physical activity is denied for the unmoved mover and defined as form, actuality, life, mind and ultimately the term God has been applied to it by Aristotle. Thus God knows itself and his knowledge is itself. This God who exists immanently and transcendentally, according to Aristotle is not a creator because mater and universe existed eternally and ungenerated. Thus, Aristotle introduced a through going divine teleology in his description and explanation of the whole dynamics of this universe.

On the Heavens describes the order and movement of the stars and the number and nature of the elements and their transformation into one another. As we know, Aristotle maintained in his Dialogue on Philosophy that the planets and stars, and the rotating spheres which carry them, are composed of an element named ether, which can not be destroyed or transformed into other substances and is, in general, contrasted with the elements understandable to our senses. *On Generation and Corruption* deals with the nature of things and how they are inferior to the celestial bodies.

Aristotle teaches the division of the Universe into two essentially distinct parts - sublunary or terrestrial and superlunary or celestial, on a variety of grounds: tradition, experience, and philosophical. It is quite sure that he is very much influenced by the earlier tradition and the collected experience of the past astronomers. It is a general criticism against Aristotle that he never looked for empirical evidence for the knowledge he received from posterity. He proceeded to prove axiomatically that the celestial and the terrestrial are different worlds and the substances with which they are made up of are also different giving a limit to the universe and thus described the universe as finite.

3.8 ARISTOTELIAN-PTOLEMAIC-THOMISTIC COSMOTHEOLOGY

The Aristotelian philosophical cosmology and its mathematical rendering by Ptolemy is superposed with the Christian doctrine into a holistic synthesis by Aquinas. Each planet including the sun is embedded in a sphere which is termed as orb. The daily motion, sidereal motion and motion in latitude are explained by additions orbs and hence Aristotle technically used fifty five orbs while Ptolemy forty one. However, the number is reduced to eight to eleven by the medieval theologians. The seven planets including the sun and the moon and the fixed stars altogether embedded in eight concentric orbs which are in perpetual motion. The spheres are inscribed within each other. The sun is kept in the middle as "heart in the middle of the body". The ninth orb is a purely theological construction which is immobile imparting motion to all other orbs and the holy place of the unmoved mover or the prime mover, the ultimate container of the universe. This last crystalline orb is "the dwelling place of God and the saints" and termed as Empyrean orb.

The motion of the orbs where thought to be first pushed by the angels and later assigned an immaterial, spiritual intelligence who are endowed with inexhaustible powers to move their respective orbs with uniform circular motion. The question of whether the orbs are transparent or opaque is also entertained by the medieval scholars. Thus Aquinas also described the universe as limited and finite. This medieval finite cosmotheology was drilled into the popular consciousness by the works of poets like Dante.

Check Your Progress 1

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) How did the Babylonian, Indian and Greek civilizations describe the universe??

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2) How did Aristotle give a philosophical description of the universe?

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3.9 COPERNICAN REVOLUTION

The book one of the *De Revolutionibus Orbium Celestium* starts with praising the splendour, glory, beauty, elegance, purity and majesty of the universe, reminding that some have already called it god, an extraordinary excellence. The spirituality inundated in Copernicus induced him to write that the study of nature was the highest form of contemplation about God quoting both the psalmist as well as Plato. Copernicus thus emphasizes that this study of the universe is indeed spirituality, transporting the human mind into God and contemplation about him and submits himself to the benevolence of the Almighty. Relaying on God's help for the exposition of his new theory, Copernicus gives also a warning that the book might expound a theory entirely different from the one narrated by his predecessors. The sphericity of the world and of the earth were ascertained and explained how the land and water mass together behave as a single whole. It was during Copernicus studies in Krakow, the discovery of America took place and he mentioned specifically the name of America along with Spain and Portugal and asserted the sphericity of the earth. The circular movement and the rotation of the earth, the immensity of the universe in comparison with the earth, an explanation for why the ancients considered earth as the centre of the universe and at rest, the rise of the evening and morning stars, retrogressions and progressions of the planets, the order of the planets were explained and 14 supporting geometrical theorems and corresponding trigonometrical values were enumerated by Copernicus in the first book. From a wide variety of literature written by the great ancient philosophers such as Plutarch, Cicero, Sophocles, Plato and Aristotle were quoted by Copernicus exhibiting his interest and knowledge in the world literature in addition to his proficiency in astronomy, mathematics and physics. Copernicus also quotes profusely from various Islamic astronomers especially, Al-Battani the Syrian throughout the book.

In book two, the rotation of the earth is given a special emphasis with supporting geometrical theorems, table of the declination of the ecliptic, the rise and set of stars, the size difference of the shadows, description of an astrolabe and catalogue of the stars. In book three, the precession of the solstices and equinoxes with supporting geometrical theorems, a table describing the precession corresponding to the years, the movement of the sun in sixty years collected from Egyptian astronomy etc., are described. In book four, the movements of the moon is illustrated. A table is given with the movement of the moon in periods of sixty years, the irregularities in the movements of the moon, computation of the lunar latitudes, instruments to observe the parallaxes of the sun and the moon and its determination, calculation of the distance of the moon from the earth, calculation of the moon's diameter and the calculation of the eclipses of the sun and the moon and its duration are also given in the fourth book. Book number five illustrates the movements as well as the irregularities of the five planets. A table containing the parallaxes of Saturn, Jupiter, Mars, Venus and Mercury is given in terms of sixty years and sixty days. Some of the astronomical observations made by Bernhard Walther, Johann Schoener were also given in this book. Calculation of the longitudes and the retrogressions of these planets are also given in the book. In the last book of *De Revolutionibus*, Copernicus included the calculation of the orbits and latitudes and a table of latitudes of the five planets, thus concluding the complete description of the movements of the earth and other planets around the sun with supporting geometrical theorems and a number of astronomical observations from the past history elucidating the heliocentrism in a most detailed, systematic and technical manner. Thus Copernicus revolutionized the finite universe of the philosophy and theology into the scientific cosmology.

3.10 THE NEWTONIAN INFINITE UNIVERSE

Newton, put all the physical laws under the philosophical vision of the absolute space and time and developed the cosmos as infinite. According to him, the space was without beginning and an end and hence infinite. The time has a beginning but it has no end, eternally moving forward. The matter is governed by the three laws of motion and the macroscopic universe was governed by the law of gravitation. Thus the three laws of motion and the law of gravitation of Newton and the three laws of Kepler unified the universe and described it as governed by the physical laws, everywhere the same. Thus the Aristotelian-Aquinian finite universe was transformed into an infinite universe, without boundaries and governed by the same physical laws and everybody in the universe observing the same event which he called as simultaneity.

3.11 THE EINSTEINIAN BOUND YET UNBOUND UNIVERSE

The advent of the theory of relativity proposed a cosmic beginning which was supported by the discovery of the cosmic back ground radiation of the universe. The interpretation of gravity as the property of space-time and matter – space- time a continuum brought forth the integration of finiteness and the infiniteness of the universe. The matter curves the space time and hence it is bound; yet the matter moves in the space-time, expanding it to unknown horizons and hence unbound. In 1927 George Lamaitre proposed that the cosmic beginning by a big bang. The Friedmann solutions to the relativistic field equations gave an impetus to the Big Bang proposal because it also shown the expanding universe from a cosmic zero point. Gamow and Hubble shown the expansion of the universe as a reality and in 1965 the Cosmic background radiation was also discovered giving evidence to the Big Bang hypothesis as a reality. Thus the Big Bang and the theory of relativity had shown that there was beginning for the universe. However the universe is expanding and whether it would have a limit is questionable.

The discrepancy between the calculated amount of matter in this universe and the observed matter gave rise to the proposal of Dark Matter. Dark matter constitutes 95% of the matter in this universe since it is unobservable. Depending upon the amount of the Dark matter, the future of the universe is defined. Thus, at present the scientists are skeptical about the finiteness or the infiniteness of the universe. However, the universe is expanding and to where it is expanding is a big question, baffling us with the infiniteness of the Universe.

3.12 MULTIPLE UNIVERSES

Lisa Randall, a Harvard physics professor proposed the theory of multi-universes and the particle's possibility of travelling between them, describes the infiniteness of the universe. Banes are lower dimensional surfaces that can house forces and particles, and they can be the

boundaries of higher dimensional space. When particles and energies reach the boundaries they encounter a brane, and this brane forms the boundaries of the full higher-dimensional space known as bulk. It was in 1995 that the physicist Joe Polichinski of the Kavli Instiitute for Theoretical physics in Santa Barbara established that Branes were essential to string theory. many ideas of branes like p-brane and the mechanism for confining particles in a brane like surface suggested by scientists of particle physics. Btu string theory branes were the first known types of brane that would trap forces as well as particles. Branes have introduced mathematical notions into physics. The three dimensional space that we encountered could be a slice of higher dimensional world. A brane is a distinct region of space time that extend through only a (possibly multi dimensional) slice of space. The word 'membrane' motivated the choice of the word 'brane' because membranes like brane are layers that either surround or run through a substance. Some branes are '"slices' inside the space, but others are 'slices that bound space, like slices of bread in a sandwich. Branes can have any number of dimensions. We use 3-branes to refer to branes with three dimensions, 4 branes to refer to those with four dimensions and so on.
Particles confined to branes are truly trapped on branes by physical laws. Brane bound objects never venture into extra dimensions that extend off the brane. But not all particles are blocked by branes. They move through the brane to higher dimensions. The distinguishing facto that separates brane theory form other multi dimensional theories is the particle on branes that doesn't move into other dimensions.

Gravity is never confined to the brane. As general relativity, gravity is woven into the frame work of space time. This would mean that gravity must be exerted through out the space time in every dimension. If we are in a three dimensional brane, we will be able to travel freely only along its dimension. Even though other dimension would exist adjacent to the brane. What exists beyond the brane is the bulk. Gravity will be felt everywhere on and off the brane. Brane can interact with bulk with the help of gravity. There could also be the particles and forces in bulk which would interact with brane. The term universe may not stand the test of time; the new concept is that of 'multi' verse. Multiverse is a name that is some times attached to theories with more than one brane. People often use the word to describe a cosmos with non-interacting or only weakly interacting pieces. This Multiverse is full of possibilities. Even if we know the basic ingredients, in a Multiverse populated by more than one brane, exotic new scenarios for the geometry of space are conceivable as well as myriad possibilities for how the particles we know and don't know are distributed among them.

There is also a possibility that those branes parallel to us may house parallel worlds. Brane world introduce newly physical scenarios that might describe both the world we think we know and to other worlds we don't know on other branes that we have no idea about, separated form our world in unseen dimension. Gravity is the only interaction that we know for sure is shared between the stuff on our brane and this tuff on any other brane, and gravity is extremely weak force. Without direct evidence, other branes will remain cloistered in the realm of theory and conjecture.

Thus, the question of the finite/infinite universe, move us from the three dimensions of space to the four dimensions of the space-time fused by Einstein, Minkowsky and Poincre is further led into the multiple dimensions proposed by Brian Greene, Michio Kaku and Lisa Randall. According to these physicists, the world is made up of more than four dimensions, some proposing even ten or eleven and except the four dimensions the rest are scrolled up somewhere in the universe, catapulting us to wonder and dismay at the boundaries and extent of the universe.

3.13 FINITE/INFINITE UNIVERSE – A MULTI-DISCIPLINARY SUBJECT

Philosophy plays a key role in the analysis of the finiteness and infiniteness of the universe. It is philosophy that defined the finiteness of the universe in the Aristotelian as well as Aquinian universe. The Newtonian infinite universe was based upon the Euclidean geometry. The infinite space described by Euclidian geometry and time as infinite, with a beginning but moves like an arrow eternally to infinity. So everything is being acted in the frame of these absolute space and time and motion too is absolute, giving rise to an infinite universe. However, the development of Non-Eucledean geometry paved the way for combining the space and time into space-time. Riemann geometry was used by Minkowsky to develop spacetime as a membrane which was used by Einstein in generalizing the relativity by equating the effects of acceleration and gravitation. This led to the definition of the universe as bound yet unbound, namely finite yet infinite. Thus, philosophy, physics, astronomy, geometry and mathematics together explain the finiteness and the infiniteness of the universe.

3.14 SCOPE AND IMPORTANCE OF INFINITE/FINITE UNIVERSE

The question about the finiteness and infiniteness about the universe, lead us to the beginning, evolution and the ultimate ending of the universe and the probability of further beginnings. Thus the concept of the linear or non-linear or cyclic origin of the universe is underpinning the question of the finiteness and the infiniteness of the universe. The Eastern philosophical traditions propose a cyclic concept of the universe while the western traditions propose a linear process for the universe. So the finiteness and the infiniteness question of the universe has a profound philosophical bearing that has wide connotations.

3.15 LET US SUM UP

The questions of the finiteness and the infiniteness of the universe is a perennial question, probed by the contemporary as well as the ancient man. From time immemorial man was baffled by the immensity of the universe and tried to grapple with the question in terms of myths, philosophy and physics. As the knowledge grew and technology developed from the naked eyes to the sophisticated satellite telescopes, the question about the finiteness and infiniteness became shrouded in mystery rather than leading us into a clear picture. The cosmogonies and philosophies of the ancient civilizations and the science and technology of the modern civilizations could not give a clear answer to the question. Initially, the civilizations thought about the unlimited universe which paved the way for a limited universe which again catapulted to an infinite universe. Thus, the sciences and the philosophy is indeed oscillating between a finite and an infinite universe.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) How does the theory of Relativity describe a bound and unbound universe?

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2) How the infinite, parallel, and multiple universes are described by the advanced cosmologies?

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3.16 KEY WORDS

Cosmogony: Cosmogony is any theory concerning the coming into existence or origin of the universe.

Cosmology: Cosmology is the study of the universe in its totality. Though the word *cosmology* is of recent use (first used in 1730 in Christian Wolff's *Cosmologia Generalis*), study of the universe has a long history involving science, philosophy, esotericism, and religion.

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3.18 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1) Babylonian Universe – sexagesimal, finite universe, the zodiac signs; Greek Universe – sun, moon as Gods – as burning objects; search for the ultimate building block of the universe, air, fire, water, earth, and structural principles; human urge for comprehending the universe; from many to one;

2) Celestial and terrestrial worlds; eather constituting the celestial, hence perfect and circular, no corruptibility; fire, air, water, earth and the dynamic opposites constitutes terrestrial universe, comes to rest, heavy will fall faster compared to the light; geocentric limited universe; Ptolemy employed mathematical tools, made a comprehensive predictable model universe.

Answers to Check Your Progress II

1) Matter, space, time a continuum; gravity as curvature, property of the space-time; gravity and acceleration producing the same effects; infinite, yet finite universe.

2) Multiple and parallel universe, time wrap, ten dimensions.

UNIT 4 SCIENTIFIC THEORIES ON THE ORIGIN AND END OF THE UNIVERSE

Contents

4.0. OBJECTIVES

In this unit we introduce the different theories on the origin, evolution, and future of the Universe. The most prominent theories in this field are the Big Bang Theory and the Steady State theory. Among them the Big Bang theory is the widely accepted one. Hence it is given prominent place in the discussion. By the end of this discussion you should be able to form a scientific view on

- The structure of the universe
- Evidences for the Big Bang Origin and Evolution of the Universe
- The future of the Universe
- And develop a scientific mind regarding the world you live in.

4.1. INTRODUCTION

Ever since human being has started to think, the question about the origin and end of the world in which he lives loomed in his mind. How did this universe begin? How exactly is it structured? What does it contain? How will it end? What is our place in this universe? These are the questions humans have been asking for thousands of years. The answers found over the ages are expressed in art, myths, and religions. This unit seeks answers to the above questions by turning to modern science. In particular we shall seek answers in this chapter to questions about the origin of the Universe and about its eventual fate.

Our search for the past and future, that is, the origin and end, of the universe must begin from the present since it is from the present that we can build up its past and future. Hence our study must begin with the present structure of the universe.

4.2. THE STRUCTURE OF THE UNIVERSE

The best way to see the structure of the universe is to have a journey through the distant galaxies and have a direct look at it. Since the universe is unimaginably large in size we have to go through it at an unimaginable speed. The speed with which we travel on earth (certain kilometers, per hour) will reach us nowhere in this regard. Hence we have to take an imaginary journey from earth to the distant galaxies on a rocket that will travel at the speed of light. Traveling at that speed allows us to tell how far we have come just by looking at a clock. Every second of time we will cover a distance of light-second, which is 300,000 kilometers. At that speed if we are going around the earth we can make seven and a half trips around it in one second. Our imaginary journey will last billions of years of time and it will take us across billions of light-years of space.

The Milky Way Galaxy

Within four minutes of lift-off from Earth we are already crossing the orbit of Mars and ten minutes later we are passing through the Asteroid belt, between Mars and Jupiter. Soon the giant outer planets – Jupiter, Saturn, Uranus, and Neptune – briefly fill our viewing window. And in just a little over five hours we have left all of the Sun's nine planets behind. All along, the Sun has been growing fainter and is now just one of many bright stars in the sky.

It will be four years before we encounter the first stars beyond the Sun. Every few years we pass another star. They brighten up as we approach them and then fade in the distance. After just 50 years we lose sight of the Sun.

The centuries and millennia of our journey tick away. We are passing thousands upon thousands of stars. Many are alone; others are double and triple star systems. Eventually the concentration of stars lessens and we break out of the obscuring layer of gas and dust associated with them. Looking back we see an enormous number of stars, star clusters, and clouds, arranged in a huge but very flat disk-like distribution. What we are seeing is the **Milky Way galaxy –** our home galaxy measuring about 100,000 LYs across and combines about 150 billion stars. Apart from its central bulge or nucleus, its most distinctive feature is the pattern of spiral arms. In fact, our journey began from an inconspicuous spot at the inner edge of one of them, roughly 30000 light-years from the center of the Galaxy.

The Local Group

Ahead of us lies the Universe filled with many billions of galaxies. Each is like an island universe, separated from the others by many light-years of emptiness. On our way we come across spiral, elliptical and irregular galaxies. They appear in small and large clusters of galaxies. The small clusters contain up to a few dozen galaxies, while the large clusters have thousands of them.

The Milky Way belongs to a small cluster of galaxies, known as the **Local Group**, that contains some thirty members. Andromeda is one of the most spectacular galaxies (spiral) in the local group.

The Virgo Super Cluster

After we have inspected at close range the Andromeda galaxy and several other galaxies in the same vicinity, we change course once again and leave the Local group. Each of them contains one or two large galaxies about which other smaller one are gathered.

If we leave the local group the nearest large cluster of galaxies is Virgo Cluster. This cluster is some 50 million LYs distant, and on the way we come across small clusters similar to local group.

As we travel on past the Virgo Cluster the concentration of galaxies begins to thin and we encounter now and then a small cluster of galaxies.

About 100 million LYs after leaving the Milky Way the frequency of galaxies diminishes still further and we find ourselves in mostly empty space. We have left our local cosmic neighborhood. Looking back we see we have come from a huge super cluster of galaxies measuring more than 100 million LYs across.

Virgo Super cluster is not alone in this universe. There are many of them coming across in whichever direction we travel. On the average we cross another Super cluster every 100-200 million years.

4.3. THE BIG BANG THEORY

The **Big Bang** is the cosmological model of the initial conditions and subsequent development of the universe that is supported by the most comprehensive and accurate explanations from current scientific evidence and observation. As used by cosmologists, the term *Big Bang* generally refers to the idea that the universe has expanded from a primordial hot and dense initial condition at some finite time in the past, and continues to expand to this day. The theory bases itself on three evidences: the expansion of the universe, the cosmic microwave background radiation, and the primordial abundance of elements.

The Expansion Of The Universe

Up to 500 years ago most humans believed in a Geo-centric universe with earth at the centre, and the Sun, Moon, and stars circling around it. The Polish astronomer Nicolaus Copernicus (1473-

1543) revolutionized that point of view by placing the Sun at the centre of the universe and making Earth one of its planets. In the following centuries, astronomers gradually realized that the Sun is just one star among many millions in the Milky Way and that it is far from the centre of the Galaxy. The prevailing view was that the Milky Way galaxy comprised the entire universe. By 18th century people predicted the existence of separate galactic systems. Now with the help of the modern equipment we understand that the universe is much bigger than anyone had imagined and is in a process of expansion.

The Hubble Constant

Our understanding of the expansion of the universe is based on the phenomenon known as the Hubble constant.

Among the pioneers who participated in the discoveries regarding the universe was the great American astronomer Edwin P. Hubble (1889-1953). After the true nature of the galaxies has been established, he turned his attention to their motions. He was motivated to do this by a puzzling report by Vesto M. Slipher (1875-1969) of the Lowell Observatory of Arisona that many of the faint nebulae are moving away from us with velocities of hundreds and thousands of kilometers per second. That seemed peculiar, for the stars in the Milky Way have velocities much smaller than that and some move away while others move towards us. In contrast, the velocities of nearly all galaxies are always directed away from us. Slipher had made his observations during the 1910s, before anyone was certain that these nebulae were really galaxies far beyond the Milky Way. In 1920s Hubble and his colleague Humason who knew that the faint nebulae were separate galactic systems, began a systematic study of the relation between their velocities and their distances.

They let the faint light of the distant galaxies pass through a spectrograph, an instrument that splits electromagnetic radiation into its spectoral components. In almost every case they found that the light was shifted towards red colour. This meant the galaxies are receding from us. This confirmed Slipher's earlier observation.

Furthermore, they noticed that the recession velocities vary regularly with distances. Galaxies that have 2, 3, 10 times recession velocities than nearby ones are approximately 2,3,10 times farther away. A calculation of recession velocity verses distance shows that on an average for every increase in distance by 1 million light years there exists a corresponding increase in velocity by 15 km/se. This rate of increase of recession velocity with distance is referred to as Hubble constant.

The Big Bang

The relation between recession velocities of galaxies and their distances has powerful implications for the origin and evolution of the Universe. It suggests that the entire universe be in a state of expansion. This in turn implies that in the past the Universe was much more compact than it is today and that, possibly, at some long-ago time it came into existence in one gigantic explosion. The explosion sent matter flying in all directions. Matter that initially acquired large velocities relative to us is consequently very distant from us today, and matter that acquired a small velocity is comparatively still quite close. The situation may be compared with the explosion of a grenade. The energy of the explosion breaks the grenade into many fragments, some of which acquire high velocities and others low velocities. As the fragments fly apart, the ones with high velocities fly farther than those with smaller velocities. This analogy should, however, not be taken too literally, for there exists a definite centre in the case of the explosion of the grenade. There is no such centre in the case of the Universe.

Observers from other galaxies, if there are any, see the expansion of the Universe as we do, except from their vantage point it is our galaxy that is moving away from them. And the more distant we are from them, the faster they see the Milky Way receding. Hence, they share our impression that the Universe was born in a gigantic explosion – the Big Bang.

Cosmic Microwave Background Radiation

We came to the conclusion that the universe started with a Big Bang by extrapolating from the present expansion of the Universe. If the universe started with a Big Bang then there should be additional evidences in its support. One such support now available is the Cosmic Background Radiation.

If we extrapolate the present structure and expansion of the Universe back in time, we find that the galaxies were closer together. Eight billion years ago they were approximately twice as close as they are today and 10 billion years ago they were three times as close. At the time of the Big Bang the matter must have been compressed to exceedingly high densities and heated to enormous temperatures. If the Universe started from such extreme conditions, some remnant of the early, intense heat might still be around today in the form of electromagnetic radiation and perhaps it can be detected.

This was the kind of reasoning that in the 1940s led George Gamow (1904-1968) to calculate what the cosmic radiation left over from the Big bang should be like today. He assumed that the radiation, if it existed at all, should be very faint, fill the entire universe, and come from all directions. Unfortunately at that time no one took Gamow's bold predictions seriously, and no efforts were made to search for cosmic background radiation. Since 1964 the cosmic background radiation as it is now known, has been observed by radio –astronomers around the world, as was predicted by Gamow 20 year earlier.

The discovery of the cosmic background radiation is one of the great achievements of the 20^{th} century. The discovery made it possible to obtain information about cosmic process that took place a very long time ago. The background radiation comes from all regions of the sky at a low level and is the *weak remnant of the radiation of the Big Bang.*

There are, in the universe, objects that are natural emitters of radio waves, which is the source of background radiation. These objects were the most distant yet found. The optical counterparts of these radio-sources were at large distances yet appeared star-like. Because of this they were called quasi-stellar objects or Quasars. In Quasars the energy of thousands of normal galaxies is concentrated in a region of space not much larger than our solar system.

Quasars have the largest amount of red shift (that is, five times longer than the normal). The red shift suggests that they are receding at more than 90% of the speed of light. Some remain at a distance of 13 billion years.

What is important is that we are seeing such objects not as they are now but as they were in the distant past. This is because of what astronomers call look back time. Because these radio waves, which are a form of light has the finite velocity of light and it takes time to traverse the enormous distances of space. Hence the radio waves we receive from a radio wave source set off on its journey at some time in the past. The effect of look back time is severe when we consider the quasars. When we look at them we see the waves that set off when the universe was only a tenth of its present size and age. Hence by looking deeper and deeper into space we can look further and further back in time and are able to determine what the universe was like in its youth and how it has since developed. Quasars hence are a phenomenon of early universe.

Primordial Abundance of Elements

Since the discovery that the Universe is expanding Big-Bang theory had a number of rivals, such as the steady state Theory. The steady State Theory of the Universe proposes that the Universe is expanding forever, yet it never changes. Matter is created continuously and new galaxies are formed just at the rate at which old galaxies recede due to the expansion of the universe. A steady Universe has neither a beginning nor an end.

However none of the other theories is able to explain both the expansion of the universe and cosmic background radiation. Nor are they able to explain the primordial abundance of elements which is a third evidence for the Big Bang origin of the universe.

The primordial abundance of the elements refers to the composition matter acquired when it was created by the Big-Bang. Astronomers have estimated this abundance by examining the spectrum of light emitted by the stars on our and other galaxies. They found that out of every 100 atoms, approximately 93 are Hydrogen and seven are Helium. By mass this amounts to approximately 76% Hydrogen and 24% Helium. This ratio of helium to Hydrogen in the stars is consistent with the Big-Bang model of creation. The universe started out explosively from a very hot and dense state and quickly cooled as it expanded. This hot and dense conditions lasted long enough for some hydrogen to fuse into helium, but not so long as to allow the production of significant amounts of the heavier elements. They were made in the interiors of massive stars.

Check Your Progress 1

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) What do you understand by Local Group?

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2) Write a short note on Big Bang Theory.

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Age of the Universe: Based on Hubble Constant

The relation between the recession velocity and distance allows us to estimate the age of the Universe by the following reasoning. From the Hubble constant we know that on the average, galaxies at a distance of 100 million light years move away from us with 15000 km/se. If, for example we assume that galaxies at 100 million light-years have been receding from us with a velocity of 1500 km/se since the Big Bang, we can compute how long it took them to reach that distance:

$$\text{Time} = \frac{\text{distance}}{\text{Velocity}} = \frac{100 \text{ million LY}}{1500 \text{ km/se}} = 20 \text{ billion years}$$

Thus we conclude that the Universe was born approximately 20 billion years ago.

Later we will see that this simple arithmetic leads to overestimating the age of the Universe. Gravity is continuously slowing down the expansion of the universe; hence, the value of the Hubble constant – that is the rate of the Universe's expansion – must have been greater in the past than it is today. Consequently, the Universe probably reached its present size in less than 20 billion years.

The Birth and Evolution of the Universe

We have seen that the Universe came into existence in one gigantic explosion some 13-15 billion years ago. During the earliest phase of this explosion, the temperatures and densities were so extreme that neither space and time, nor matter and energy, nor the laws of physics were as we know them today.

In order to obtain some knowledge about the early conditions of the universe we need to start from the known conditions today and extrapolate back in time. Our extrapolation will tell us that the initial extreme conditions passed in rapid succession through a number of transitions during which the universe acquired the characteristics that still distinguish it today. A single super-force which ruled in the beginning, split into the four forces we are accustomed to. Matter was spontaneously created and acquired the enormous expansion velocities that we still observe. There occurred a brief burst of primordial nucleosynthesis during which Hydrogen was converted into Helium. One by one the lightest of the elementary particles – gravitions, neutrinos, and photons – decoupled from the rest of the particles and began to evolve independently. The photons decoupled subsequently evolved into today's cosmic background radiation. Matter (Hydrogen and Helium) evolved on an independent course as well and began to condense into the lumpy distributions of clusters of galaxies, galaxies, stars and planets that we find in the universe today.

The first structures in the Universe

When matter set out on its independent evolution it consisted approximately 76% hydrogen and 24% Helium by Mass. It was in gaseous form and smoothly distributed. However this smoothness was not quite perfect; it contained weak, random fluctuations in density.

Formation of Primordial Clouds: Wherever there existed small enhancements in density, the attractive force of gravity counteracted and tended to slow the expanding matter. As a result the initial largest fluctuations extending over approximately 10^{15}- 10^{16} solar mass of matter extended more and more slowly and eventually began to contract. This led to the formation of huge primordial clouds of hydrogen and helium – the first large scale structures in the evolving universe.

Breakup of the primordial clouds: In many regions where the density within the clouds was greater than the average, gravity managed to contract the gas further and to intensify the concentration of matter. This led to the break-up of the primordial clouds into large numbers of cloud fragments.

The break up of the primordial clouds was chaotic and violent. The gravitational forces, which were weak at first, as the matter became clumped, increased in strength. And gaseous material fell together faster and faster. Eventually it reached large velocities relative to each other. This violent activity occurred in the first few hundred million years.

Birth of the first stars: Since there was little "elbow room" in the dense universe fragments of gas containing masses equal to millions of suns were ploughing into each other at thousands of km per hour. The shock waves created by the collisions compressed the gas of the fragments. This happened to such a degree that huge regions became gravitationally unstable and collapsed into compact clouds within which the first generations of stars began to form.

The birth of the first stars had two far-reaching consequences: 1. The newly formed stars began to pour forth their radiant energy and illuminate the gaseous matter surviving in their vicinity; 2. The gas that collapsed into stars became concentrated into relatively small volumes.

Birth of Galaxies and Cluster of Galaxies: As this sequence of collisions and mergers of fragments and of conversion of gas into stars progressed, the surviving systems looked more and more like star clusters and galaxies. The fragments that were most successful in capturing and assimilating others grew into large galaxies. Those that managed to retain their gaseous material became spiral galaxies like our Milky Way. Fragments that lost their gas or converted most of it into stars evolved into giant ellipticals. Fragments that grew less successfully became dwarf ellipticals and globular star clusters. Finally fragments that collided with another more massive galaxy experienced strong tidal perturbations and ended up with rather distorted shapes.

Most of the newly formed galaxies found themselves in the vicinity of others and were bound to each other by the force of gravity. This clustering was particularly pronounced near the central regions of what used to be the primordial clouds. Today that is where the rich clusters of galaxies with thousands of members are found, as Virgo cluster. Farther out the galaxies clustered into sparser groupings with only a handful to a few dozen members. Our Local Group is an example of such a small cluster. The Future of the Universe

So far we have been largely concerned with observational information about the Universe: the distribution of galaxies, the expansion of the universe, the cosmic background radiation, and the primordial abundance of elements. These observations led us to the conclusion that the Universe was created some 20 billion years ago by a gigantic explosion – the Big Bang – and has been expanding for ever since.

The Future of the Universe

We now face the obvious question: will the universe go on expanding for ever or will it eventually fall back onto itself?

The eventual fate of the universe depends on how much matter it contains, its size, and how fast the matter is expanding (that is, its mass, size and expansion velocity).

- The more matter there is, greater is the gravitational force holding the universe together, and the more likely it is that the Universe is finite and will eventually collapse back on itself.
- Greater the present size of the universe, the further are the galaxies separated from each other, and the weaker will be the gravitational pull. This increases the likelihood that the universe is infinite and will expand forever.
- Greater the velocity of expansion, the harder it is for gravity to slow the expansion to zero and to reverse it. This contributes toward making the universe infinite and expanding.

Friedmann's Three Models of the Universe

Alexander Fiedmann a Russian mathematician obtained three models of the Universe basing on Einstein's equation. Each solution predicts that the universe began with an explosion, but they differ on the subsequent evolution for the future.

1. The universe expands for some time, reaches a maximum size, then contracts. This predicts a *finite and closed universe*.
2. The universe expands forever making it infinite, expanding even after all galaxies and the rest of its content have become infinitely dispersed. This will result in an *infinite and open universe.*
3. The universe expands, but its expansion velocity slowing to zero in the process. This is in border with the other two: and is called the *flat universe*.

The Age of the Universe: Revised Estimate

The models derived by Friedmann allow us to estimate the age of the Universe more accurately than we did earlier. The estimate of 20 million years was based on the assumption that the Universe has always been expanding at its current rate of 15 km/sec per million light years. This rate must have been greater in the past. Hence, it took the Universe less time to reach its present scale than we estimated. It turns out to be 13 to15 billion years

Critique:

1. The Big Bang Origin of the universe is the widely accepted theory regarding the origin of the universe. With the present scientific know how and with the best available information obtained regarding the universe based on observation with sophisticated instruments, this is what we can say regarding the origin and the subsequent evolution of the universe.
2. Any theory to be widely accepted needs to have different evidences in support of it. The Big Bang Theory satisfies this condition. The extrapolation from the present expansion of the universe towards the Big Bang origin is further corroborated by the existence of *cosmic microwave background radiation* and *the primordial abundance of elements.*
3. Although the theory points to the origin of the universe through a big explosion, the question remains regarding the source of that matter which exploded.
4. It is to be also noted that the description of the origin of galaxies merely represents some of the current thinking of astronomers. It is far from the final word on the subject. The description is largely based on theoretical deductions from observations of cloud collisions, on observations of collisions and near-encounters among some nearby galaxies, and on computer simulations. It is not based on observations of the actual events that produced the galaxies and galaxy clusters.

4.4. STEADY STATE THEORY

In cosmology, the **Steady State theory** (also known as the **Infinite Universe theory** or **continuous creation**) is a model developed in 1948 by Fred Hoyle, Thomas Gold, Hermann Bondi and others as an alternative to the Big Bang theory (known, usually, as the standard cosmological model). In steady state views, new matter is continuously created as the universe expands, so that the perfect cosmological principle is adhered to. Although the model had a large number of supporters among cosmologists in the 1950s and 1960s, the number of supporters decreased markedly in the late 1960s with the discovery of the cosmic microwave background radiation, and today only a very small number of supporters remain. The key importance of the steady-state model is that as a competitor to the Big Bang, it was an impetus in generating some of the most important research in astrophysics, much of which ultimately ended up supporting the Big Bang theory.

Theoretical calculations showed that a static universe was impossible under general relativity and observations by Edwin Hubble had shown that the universe was expanding. The steady state theory asserts that although the universe is expanding, it nevertheless does not change its look over time (the perfect cosmological principle); it has no beginning and no end.

The theory requires that new matter must be continuously created (mostly as hydrogen) to keep the average density of matter equal over time. Such a creation rate, however, would cause observable effects on cosmological scales.

An aesthetically unattractive feature of the theory is that the postulated spontaneous new matter formation would presumably need to include deuterium, helium, and a small amount of lithium, as well as regular hydrogen, since no mechanism of nucleosynthesis in stars or by other processes accounts for the observed abundance of deuterium and helium-3. (In the Big Bang model, primordial deuterium is made directly after the "bang," before the existence of the first stars).

Problems with the steady-state theory began to emerge in the late 1960s, when observations apparently supported the idea that the universe was in fact changing: quasars and radio galaxies were found only at large distances (therefore existing only in the distant past), not in closer galaxies. Whereas the Big Bang theory predicted as much, Steady State predicted that such objects would be found everywhere, including close to our own galaxy.

For most cosmologists, the refutation of the steady-state theory came with the discovery of the cosmic microwave background radiation in 1965, which was predicted by the Big Bang theory. Stephen Hawking said that the fact that microwave radiation had been found, and that it was thought to be left over from the Big Bang, was "the final nail in the coffin of the steady-state theory." Within the steady state theory this background radiation is the result of light from ancient stars which has been scattered by galactic dust. However, this explanation has been unconvincing to most cosmologists as the cosmic microwave background is very smooth, making it difficult to explain how it arose from point sources, and the microwave background shows no evidence of features such as polarization which are normally associated with scattering. Furthermore, its spectrum is so close to that of an ideal black body that it could hardly be formed by the superposition of contributions from dust clumps at different temperatures as well as at different redshifts

Hence, the Big Bang theory has been considered to be the best description of the origin of the universe. In most astrophysical publications, the Big Bang is implicitly accepted and is used as the basis of more complete theories.

4.5. LET US SUM UP

We have been discussing the theories regarding the origin of the universe. Though there are many scientific attempts to explain the origin of the universe the Big Bang theory remains to be the widely accepted one at present.

Check Your Progress II

Note: a) Use the space provided for your answer

b) Check your answers with those provided at the end of the unit

1) Explain briefly the formation of primordial clouds?

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2) What will be the eventual fate of the universe?

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4.6 KEY WORDS

Astrophysics: Astrophysics (Greek: *Astro* - meaning “star”) is the branch of astronomy that deals with the physics of the universe, including the physical properties (luminosity, density, temperature, and chemical composition) of celestial objects such as galaxies, stars, and the interstellar medium, as well as their interactions. Because astrophysics is a very broad subject, *astrophysicists* apply many disciplines of physics, including mechanics, electromagnetism, statistical mechanics, thermodynamics, quantum mechanics, relativity, nuclear and particle physics, and atomic and molecular physics.

Gravitons: Graviton is a hypothetical elementary particle that mediates the force of gravity in the framework of quantum field theory. To prove the existence of the graviton, physicists must be able to link the particle to the curvature of the space-time continuum and calculate the gravitational force exerted.

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4.8 ANSWERS TO CHECK YOUR PROGRESS

Answers to Check Your Progress I

1. Ahead of us lies the Universe filled with many billions of galaxies. Each is like an island universe, separated from the others by many light-years of emptiness. On our way we come across spiral, elliptical and irregular galaxies. They appear in small and large clusters of galaxies. The small clusters contain up to a few dozen galaxies, while the large clusters have thousands of them. The Milky Way belongs to a small cluster of galaxies, known as the 'Local Group' that contains some thirty members. Andromeda is one of the most spectacular galaxies (spiral) in the local group.

2. The 'Big Bang' is the cosmological model of the initial conditions and subsequent development of the universe that is supported by the most comprehensive and accurate explanations from current scientific evidence and observation. As used by cosmologists, the term *Big Bang* generally refers to the idea that the universe has expanded from a primordial hot and dense initial condition at some finite time in the past, and continues to expand to this day. The theory bases itself on three evidences: the expansion of the universe, the cosmic microwave background radiation, and the primordial abundance of elements.

Answers to Check Your Progress II

1. *Formation of Primordial Clouds:* Wherever there existed small enhancements in density, the attractive force of gravity counteracted and tended to slow the expanding matter. As a result the initial largest fluctuations extending over approximately 10^{15}- 10^{16} solar mass of matter extended more and more slowly and eventually began to contract. This led to the formation of huge primordial clouds of hydrogen and helium – the first large scale structures in the evolving universe.

2. The eventual fate of the universe depends on how much matter it contains, its size, and how fast the matter is expanding (that is, its mass, size and expansion velocity).

- The more matter there is, greater is the gravitational force holding the universe together, and the more likely it is that the Universe is finite and will eventually collapse back on itself.
- Greater the present size of the universe, the further are the galaxies separated from each other, and the weaker will be the gravitational pull. This increases the likelihood that the universe is infinite and will expand forever.
- Greater the velocity of expansion, the harder it is for gravity to slow the expansion to zero and to reverse it. This contributes toward making the universe infinite and expanding.