UNIT 1 SCIENCE AND PHILOSOPHY, SCIENCE AND PHILOSOPHY OF SCIENCE

Contents

1.0 OBJECTIVES

- This unit tries to introduce philosophy of science to the students.
- It tries to study the relationship between science and philosophy.
- It undertakes to define philosophy of science and its broad areas of inquiry..

1.1 INTRODUCTION

In this unit, we want to introduce ourselves to the issues, problems, areas of philosophy of science. We first try to understand what science is and what philosophy is. Then we go to study philosophy of science and a second order discipline. Finally we see the relationship between science and philosophy and then we try to understand philosophy of science better.

1.2 SCIENCE AS SUBVERSIVE

In general science may be understood in two ways. First as “the systematic observation of natural events and conditions in order to discover facts about them and to formulate laws and principles based on these facts.” Secondly as. “the organized body of knowledge that is derived from such observations and that can be verified or tested by further investigation.” (Dictionary of Science & Technology by Academic Press). Science is in fact an intellectual activity carried on by humans that is designed to discover information about the natural world in which humans live and to discover the ways in which this information can be organized into meaningful patterns. So the primary aim of science is to collect facts (data). According to Professor Sheldon Gottlieb the “ultimate purpose of science is to discern the order that exists between and amongst the various facts.” Similarly, Robert M. Pirsig, the author of *Zen and the Art of Motorcycle Maintenance* holds: “The real purpose of the scientific method is to make sure Nature hasn't misled you into thinking you know something you don't actually know.”
So science involves more than gaining of information and knowledge. It is the systematic and organized inquiry into the natural world and its phenomena. Science is about gaining a deeper and often useful understanding of the world. So “to do science is to search for repeated patterns, not simply to accumulate facts.” (Robert H. MacArthur, *Geographical Ecology).* Therefore

science questions things and is not respector of persons. To quote Richard Feynman, Nobel-prize-winning physicist, “science alone of all the subjects contains within itself the lesson of the danger of belief in the infallibility of the greatest teachers in the preceding generation . . .As a matter of fact, I can also define science another way: Science is the belief in the ignorance of experts.” Science may be contrasted to art and poetry. A modern poet has characterized the personality of art and the impersonality of science as follows: “Art is I; Science is We.” (Claude Bernard) The famous English poet Samuel Taylor Coleridge (1772-1834), will agree: “Poetry is not the proper antithesis to prose, but to science. . . . The proper and immediate object of science is the acquirement, or communication, of truth; the proper and immediate object of poetry is the communication of immediate pleasure.” If fiction and poetry deals with the real world and takes us to the imaginary and creative dimension, science enables us to focus on the real world and to retain the doubt and criticism. So James Porter, Professor of Ecology could say: “Fiction is about the suspension of disbelief; science is about the suspension of belief.” So we can agree with Richard Feynman: “Religion is a culture of faith; science is a culture of doubt.”

The focus of science or scientific research is this empirical world. Therefore, Stephen J. Gould, one of the well-known paleontologist, evolutionary biologist would hold: “As a practicing scientist, I share the credo of my colleagues: I believe that a factual reality exists and that science, though often in an obtuse and erratic manner, can learn about it. Galileo was not shown the instruments of torture in an abstract debate about lunar motion. He had threatened the Church's conventional argument for social and doctrinal stability: the static world order with planets circling about a central earth, priests subordinate to the Pope and serfs to their lord. But the Church soon made its peace with Galileo's cosmology. They had no choice; the earth really does revolve around the sun.”

In this sense science challenges, criticizes our world-view. It subverts our understanding of ourselves. A long quote from Philip Morris Hauser, a well-known demographer and sociologist will conclude this section: “Science is the most subversive thing that has ever been devised by man. It is a discipline in which the rules of the game require the undermining of that which already exists, in the sense that new knowledge always necessarily crowds out inferior antecedent knowledge. . . . . This is what the patent system is all about. We reward a man for subverting and undermining that which is already known. . . . . Man has a tendency to resist changing his mind. The history of the physical sciences is replete with episode after episode in which the discoveries of science, subversive as they were because they undermined existing knowledge, had a hard time achieving acceptability and respectability. Galileo was forced to recant; Bruno was burned at the stake; and so forth. An interesting thing about the physical sciences is that they did achieve acceptance. Certainly in the more economically advanced areas of the Western World, it has become commonplace to do everything possible to accelerate the undermining of existent knowledge about the physical world. The underdeveloped areas of the world today still live in a pre-Newtonian universe. They are still resistant to anything subversive, anything requiring change; resistant even to the ideas that would change their basic concepts of the physical world.”

1.3 PHILOSOPHY AS RAISING THE DEEPEST AND WIDEST QUESTIONS

With philosopher Ayn Rand, we can hold that_ "Philosophy studies the fundamental nature of existence, of man, and of man's relationship to existence. … In the realm of cognition, the special sciences are the trees, but philosophy is the soil which makes the forest possible." In other words philosophy is a comprehensive system of ideas about human nature and the nature of the reality we live in. It is a guide for living, because the issues it addresses are basic and pervasive, determining the course we take in life and how we treat other people (Thomas 2011).

The topics that philosophy addresses fall into several distinct fields. Among those of fundamental concern are:

- Metaphysics (the theory of reality).
- Epistemology (the theory of knowledge)
- Ethics (the theory of moral values)
- Politics (the theory of legal rights and government)
- Aesthetics (the theory of the nature of art)

In Greek, "philosophy" means "love of wisdom." Philosophy is based on rational argument and appeal to facts. The history of the modern sciences begins with philosophical inquiries, and the scientific method of experimentation and proof remains an instance of the general approach that a philosopher tries to bring to a question: one that is logical and rigorous. However, while today the sciences focus on specialized inquiries in restricted domains, the questions addressed by philosophy remain the most general and most basic, the issues that underlie the sciences and stand at the base of a worldview. They are the more fundamental issues that human beings have to grapple with (Thomas 2011).

Philosophy raises some of the deepest and widest questions there are. Addressing the issues in each branch of philosophy requires integrating everything one knows about reality (metaphysics) or humanity (epistemology, ethics, politics, and aesthetics). Proposing reasonable positions in philosophy is therefore a difficult task. Honest philosophers have often disagreed about key issues, and dishonest ones have been able to slip their own positions into the mix as well. For this reason, there is not one philosophy worldwide, as there is one physics. Instead, there are many philosophies.

Over the course of history, philosophers have offered entire systems that pulled together positions in each of the branches of philosophy. Aristotle, the father of logic, wrote such a system in ancient times, teaching that we could know reality and achieve happiness. In more modern times, philosophers such as John Locke and Immanuel Kant have written systematic accounts of their thought (Thomas 2011). Most modern philosophers, however, have specialized in one area or another within philosophy, since philosophy itself has become very specalised today.

Check Your Progress I

Note: Use the space provided for your answers.

1) “Science is a subversive activity” Comment.

....
....
....

2) What is the primary function of philosophy?

....
....
....

1.4 PHILOSOPHY OF SCIENCE AS A SECOND ORDER DISCIPLINE

Given the two understandings of science and philosophy as discussed above, we can try to see what philosophy of science means. We may hold that the philosophy of science seeks to describe and understand how science works within a wide range of sciences. This does not have to include every kind of science. But it had better not be confined to a single branch of a single science, for such an understanding would add little to what scientists, on the whole, know. Unfortunately, philosophers and scientists are not in agreement on the nature of their own field of study. Even practising philosophers of science often disagree about the proper subject-matter of their discipline. An example of this lack of agreement is the exchange between Stephen Toulmin and Ernest Nagel on whether philosophy of science should be a study of scientific achievement, or a study of problems of explanation and confirmation through logic.

One view regarding the philosophy of science is that it the formulation of worldviews that are consistent with, and in some sense based on, important scientific theories. According to this view, it is the task of the philosopher of science to elaborate the broader implications of science (Losee 2001).

A second view is that the philosophy of science is an exposition of the presuppositions and predispositions of scientists. The philosopher of science may point out that scientists presuppose that nature is not capricious, and that there exist in nature regularities of sufficiently low complexity to be accessible to the investigator. Further, he may uncover the preferences of scientists for deterministic rather than statistical laws, or for mechanistic rather than teleological explanations. (Losee 2001).

A third view is that the philosophy of science is a discipline in which the concepts and theories of the sciences are analysed and clarified. This is not a matter of giving a semi-popular exposition of the latest theories. It is, rather, a matter of becoming clear about the meaning of such terms as ‘particle’, ‘wave’, ‘potential’, and ‘complex’ in their scientific (or physics) usage.

A fourth view is that philosophy of science is a second-order discipline. It goes more than science and critically reflects on the very discipline of science itself.The philosopher of science seeks answers to such questions as:

- What characteristics distinguish scientific inquiry from other types of investigation?
- What procedures should scientists follow in investigating nature?
- What conditions must be satisfied for a scientific explanation to be correct?
- What is the cognitive status of scientific laws and principles?

To ask these questions is to assume a vantage-point one step removed from the practice of science itself. There is a distinction to be made between doing science and thinking about how science ought to be done. The analysis of scientific method is a second-order discipline, the subject-matter of which is the procedures and structures of the various sciences. (Losee 2001)

Level	Discipline	Subject-matter
2	Philosophy of Science	Analysis of the Procedures and Logic of Scientific Explanation
2	Science	Explanation of Facts Facts

The fourth view of the philosophy of science incorporates certain aspects of the second and third views. For instance, inquiry into the predispositions of scientists may be relevant to the problem of evaluating scientific theories. In addition, analyses of the meanings of concepts may be relevant to the demarcation of scientific inquiry from other types of investigation (Losee 2001). The distinction which has been indicated between science and philosophy of science is not a sharp one.

1.5 HISTORICAL SIGNIFICANCE OF PHILOSOPHY OF SCIENCE

Philosophy of science is an old discipline. Both Plato and Aristotle wrote on the subject, and, arguably, some of the pre-Socratics did also. The Middle Ages, both in its Arabic and high Latin periods, made many commentaries and disputations touching on topics in philosophy of science. Of course, the new science of the seventeenth century brought along widespread ruminations and manifold treatises on the nature of science, scientific knowledge and method. The Enlightenment pushed this project further trying to make science and its hallmark method definitive of the rational life. With the industrial revolution, “science” became a synonym for progress. In many places in the Western world, science was venerated as being the peculiarly modern way of thinking. The nineteenth century saw another resurgence of interest when ideas of evolution melded with those of industrial progress and physics achieved a maturity that led some to believe that science was complete. By the end of the century, mathematics had found alternatives to Euclidean geometry and logic had become a newly re-admired discipline (Machmer 2002).

But just before the turn to the twentieth century, and in those decades that followed, it was physics that led the intellectual way and garnered the attention of the philosophers. Mechanics became more and more unified in form with the work of Maxwell, Hertz and discussions by Poincaré. Plank derived the black body law in 1899, in 1902 Lorenz proved Maxwell’s equations were invariant under transformation, and in 1905 Einstein published his paper on special relativity and the basis of the quantum. At the same time, Hilbert in 1899 published his foundations of geometry, and Bertrand Russell in 1903 published his principles of mathematics. The development of unified classical mechanics and alternative geometries, challenged by the new relativity and quantum theories made for period of unprecedented excitement in science (Machmer 2002).

Then came the era of computer and information technology, including artificial intelligence. But today life-sciences (biology, biotechnology) have taken over. So 21st century is rightly considered as the century of biotechnology and philosophy of science has to confront the possibilities and challenges offered by it. The emergence of postmodernity and relativity has also challenged the way philosophy of science is practiced today.

Check Your Progress II

Note: Use the space provided for your answers.

1) Describe philosophy of science as a second order activity.

....

....

....

2) Briefly elaborate the historical significance of philosophy of science?

....

....

....

1.6 RELATIONSHIP BETWEEN SCIENCE AND PHILOSOPHY

The relationship between science and philosophy has always been problematic, ever since science itself slowly evolved from “natural philosophy” during the 16th and 17th centuries. Because of the work of people who thought of themselves as philosophers but were in fact scientists, philosophy of science became a distinct disciple. Names like Francis Bacon, Galileo Galilei and Isaac Newton are examples.

It may be noted that philosophy is the mother and science is the daughter. Earlier they both existed together. But as science developed, it becomes distinct from philosophy. As in any parent-offspring relationship, things can get problematic, with the offspring claiming its territory while denying the parent’s relevance or contribution, and the latter having a difficult time letting go of the now adult and independent offspring. (Pigliucci 2008)

We believe that both scientists and philosophers can give more thought to the relationship between science and philosophy. There are many areas where meaningful bridges can be built, and where the two disciplines can operate largely independently of each other. This is neither an apology on behalf of philosophers nor an invitation to scientists to become philosophers. The first is not needed because philosophy is an autonomous area of scholarship, which certainly does not need any more justification than, say, literary criticism or quantum electrodynamics. The second would be missing the point since, scientists may benefit from a better acquaintance with philosophy. But scientists normally do not have the time to learn philosophy (Pandikattu 2003).

Now we are in a position to see what philosophy of science actually does. We may first what philosophy of science is and is not (Pigliucci 2008).

1.7 WHAT PHILOSOPHY OF SCIENCE IS AND IS NOT ABOUT

Nobel-laureate and physicist Steven Weinberg (1992) took the rather unusual step of writing a whole essay entitled "Against Philosophy." In it, he argued that not only is philosophy not useful to science, but that, in some instances, it can be positively harmful. The example he provided was the alleged slow acceptance of quantum mechanics, due to the philosophical school of positivism endorsed by so many scientists in the early 20th century, beginning with Einstein.

Positivism is a now abandoned philosophical position that takes a rather narrowly naıve view of what counts as science. Most famously, positivists thought that science had no business dealing with "unobservables," i.e., with postulating the existence of entities that cannot be subjected to experimental tests. Quantum mechanics is rife with such unobservables, including electrons and forces, and positivists were indeed highly skeptical of the whole affair, which smelled too much of metaphysics (a bad word, according to them) (Pigliucci 2008).

It is also true that some scientists, first and foremost Einstein, were rather uncomfortable with the wildest implications of quantum mechanics (as in Einstein's famous statement that "God doesn't play dice") and resisted them while searching for alternative interpretations of the theory. But Einstein himself was a philosopher.

A diametrically opposite view to Weinberg's is the one expressed by Daniel Dennett (perhaps not surprisingly, a philosopher), in his *Darwin's Dangerous Idea*: "There is no such thing as philosophy-free science; there is only science whose philosophical baggage is taken on board without examination". This will strike most scientists as preposterously arrogant, but a moment's reflection shows that Dennett, of course, is right. For example, scientific practice requires the assumption of naturalism, i.e., the idea that natural phenomena are indeed natural, and, therefore, scientists do not need to invoke the supernatural to explain them. It is interesting to note that scientists themselves invoke naturalism as a postulate of science (Pigliucci 2008).

The important thing to realize is that naturalism is not an empirically verifiable position, and, therefore, it is by definition outside of science itself (if science is about anything at all, it is about empirically verifiable statements about the world). Attitudes such as Weinberg's are largely the result of ignorance of what philosophy of science is about, and I am convinced that such ignorance hurts science. It certainly does not help to bridge between science and philosophy.

1.8 THREE BROAD AREAS OF INQUIRY

Generally speaking, philosophy of science deals with three broad areas of inquiry, which Pigliucci refers to as nature of science, conceptual and methodological analysis of science, and science criticism (Chalmers 1999).

Regarding Nature of Science: Most scientists, if they are familiar with philosophy at all, have some acquaintance with philosophical studies of the nature of science. Names such as Karl Popper and Thomas Kuhn even make it into the occasional biology textbook, and one can argue that falsificationism and paradigm shifts— the most important respective contributions of these two philosophers—are among the few concepts in modern philosophy of science that are ever mentioned in the halls of science departments. Popper and falsificationism are representative of a *prescriptive* way in philosophy of science; that is, they exemplify a tradition of philosophers seeking to tell scientists how they ought to carry out their work. Popper was motivated by the so-called demarcation problem, the difficulty in distinguishing science from pseudoscience (he included in the latter Freudian psychoanalysis and Marxist theories of history). He was also bothered by Hume's problem of induction, the idea that science is based on inductive reasoning, and yet the only reason we have to trust induction is because it worked in the past (which is itself a form of induction, making the whole thing perilously close to circular). Popper thought he solved both problems with the idea of falsification: science is really based on deductive logic, not induction. This solves Hume's difficulty, but, since deduction cannot truly establish proof of natural phenomena (although it works fine for mathematical proofs), it turns out that science can never prove anything but can only disprove (i.e., falsify) theories. (Pigliucci 2008)

It is rather ironic that many science textbooks have essentially adopted Popper's view of science as an enterprise dealing in falsificationism, with many scientists actually *defining* science in Popperian terms. Popperian falsificationism has long been superseded in philosophy of science, partly through the work of one of Popper's own students, Imre Lakatos , who argued that falsificationism does not work because it is often possible to "rescue" a given theory from demise by modifying some of the ancillary assumptions that went into building it. This is a good thing too, and indeed a reflection of how science really works. Just think of the fact that the original Copernican theory did not actually fit the data very well, and yet it was not rejected as "falsified." Rather, scientists gave it some time to develop because it seemed a promising approach. Subsequently, Kepler modified an important, though not central, assumption of the theory, thus producing results that correlated very well with the data: the sun is indeed (almost) at the center of the solar system, but the planets rotate along elliptical, not circular, orbits, of which the sun occupies not exactly the center, but one of the foci (Pigliucci 2008).

Kuhn's (1970) ideas as developed in *The Structure of Scientific Revolutions*, are an example of the *descriptivist* approach to the study of the nature of science. Kuhn did not pretend to tell scientists how to do their work but was interested in figuring out how science, as a process of discovery, actually proceeds. His idea of paradigm shifts was based on historical studies of astronomy and physics (arguably, biology has never undergone a paradigm shift after Darwin).

Regarding methodological analysis of science: The second major area of inquiry in philosophy of science the conceptual and methodological analysis. It deals largely with tracing the historical use and clarifying the meaning of fundamental ideas and practices in the sciences. Hume (1748) was among the first ones to take this approach, inquiring about what we mean when we talk about causality. (His analysis, still surprisingly challenging today, was not very encouraging.) More recently, critical work on the conceptual foundations of evolutionary theory and the practices of quantitative genetics falls into this group.

Regarding science criticism: The third major type of philosophy of science is what I term science criticism, and it directly addresses the interface between science and society. For example, philosophical issues surrounding the nature-nurture debate are relevant to the uses and, more importantly, the misuses, of genetic engineering. Here the philosopher becomes a critic not just of how the science is being conducted and its findings interpreted, but, primarily, of how such findings are understood by the public and used to guide social policies.

What is a scientist to do with all this? Scientists may largely and safely ignore what philosophers say about how science does or should work in broad terms—after all, scientists want to *do* science, not to think about how it is done (except occasionally, when they are close to retirement). They do, however, have a responsibility to update their understanding of philosophy when it comes to writing science textbooks or teaching the nature of science in the classrooms. Also, philosophers clearly have the intellectual right to pursue such inquiry into the nature of science without having to justify themselves to scientists by defending the "utility" (implicitly, to science) of what they do. (Pigliucci 2008)

When we move to the second and third areas of philosophical inquiry, we come closer to the borderland between science and philosophy, to the point where, in some cases, philosophy may be thought of as "the continuation of science by other means" (Chang 2004). Indeed, in areas from evolutionary biology to quantum mechanics, it is sometimes difficult to tell whether a theoretical paper is written by a scientist or by a philosopher without directly checking the author's institutional affiliation. Here the word "theory" takes on its original and broader meaning of formulation of concepts, not just mathematical treatment (although there are examples of philosophers engaging in the latter as well). What makes this blurred line between philosophy and science interesting is that the two disciplines bring different backgrounds and approaches to the study of the same issues—i.e., this is not just a matter of science-envy by philosophers (or the even more rare phenomenon of philosophy-envy by scientists) (Pigliucci 2008)

1.9 LET US SUM UP

This unit introduces the philosophy of science and takes up some of the basic issues related to it. We have seen how science and philosophy are related and different. Then we saw the specific role of philosophy of science.

Check Your Progress III

Note: Use the space provided for your answers.

1) What is Weinberg's idea of philosophy?

....
....
....

2) Explain philosophy of science as "science criticism"?

....
....
....

1.10 KEY WORDS

Falsificationalism: Falsifiability or refutability is the logical possibility that an assertion could be shown false by a particular observation or physical experiment. That something is "falsifiable" does not mean it is false; rather, it means that if the statement were false, then its falsehood could be demonstrated.

Natural philosophy: The study of nature and the physical universe before the advent of modern science.
Naturalism: A theory denying that an event or object has a supernatural significance. It assumes that nature can be explained by itself.

1.11 FURTHER READINGS AND REFERENCES

Chalmers A F. *What Is This Thing Called Science? An Assessment of the Nature and Status of Science and Its Methods.* Berkshire (UK): Open University, 1999.

Dennett D. *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. New York: Simon & Schuster, 1995.

Hume D. *Enquiry Concerning Human Understanding*. [1748 reprint.] Chicago (IL): Gateway Editions, 1956.

Kuhn T. *The Structure of Scientific Revolutions*. Chicago (IL): University of Chicago, 1970.

Losee, John. *A Historical Introduction to the Philosophy of Science*. 4th ed. Oxford England ; New York: Oxford University Press, 2001.

Machamer , Peter 2002 "A Brief Historical Introduction to the Philosophy of Science" in Peter Machamer and Michael Silberstein The Blackwell Guide to the Philosophy of Science, Oxford: Blackwell Pub, 2002. 1-17.

Okasha, Samir. *Philosophy of Science: A Very Short Introduction.* Oxford; New York: Oxford University Press, 2002.

Pandikattu, K. "Dialogue between Science and Religion for Preserving and Fostering Life." In *Science, Technology and Values: Science-Religion Dialogue in a Multi-Religious World*, edited by Job Kozhamthadam, 35-48. Pune: ASSR, 2003.

Pigliucci M. *Denying Evolution: Creationism, Scientism, and the Nature of Science*. Sunderland (MA): Sinauer. Weinberg S. 1992.

Pigliucci, Massimo. "The Borderlands Between Science and Philosophy: An Introduction" *The Quarterly Review of Biology*, 83/1 March 2008, 7-15.

Press. Lakatos I. *The Methodology of Scientific Research Programmes*. Cambridge (UK): Cambridge University Press, 1977.

Thomas, William R. "What is Philosophy" The Atlas Society. Available at http://www.atlassociety.org/what_is_philosophy. Retrieved on July 2, 2011.

Wilson E O. *Consilience: The Unity of Knowledge*. New York: Alfred A. Knopf/Random House, 1998.

UNIT 2 PHILOSOPHY OF SCIENCE AND OTHER DISCIPLINES

Contents

2.0 OBJECTIVES

As philosophy seems to be the foundation of every discipline, a deeper inquiry into any discipline takes us to the philosophical basics of that discipline. Sciences (natural and social) also have their own philosophical basics. This discipline philosophy of science is not an isolated inquiry, rather it is related to many other domains of inquiry. This short essay seeks to discuss some important aspects of the interactions of Philosophy of Science with *Epistemology* and *Metaphysics*. It also has a cursory look at its relationship with *Values* (Ethics) and *Feminism*, just to give an idea of the vastness and depth of the impact of philosophy of science upon various disciplines.

2.1 INTRODUCTION

Like any other human inquiry and knowledge enterprise, science also involves philosophical issues, like the goals of science, the nature of scientific knowledge and the foundations of science; 'What is Science?', itself is a philosophical question. Though science emerged from philosophy and philosophy is said to be the *mother* of all the disciplines, in course of time all disciplines came of age, and got separated from the mother. For instance, by the 3rd BC, Euclid's work made geometry a 'science of space', though philosophers taught this in Plato's Academy; till 17th century science was known as 'natural philosophy' and scientists were 'natural philosophers'. In fact, the term scientist was coined only 1833, by William Whewell, an English Philosopher and Historian of Science. With Darwin's *The Origin of Species* (1859) biology was cut off from philosophy; the beginning of 20th century saw the separation of psychology from philosophy. By the middle of the same century computer science hijacked logic that has been with philosophy for more than two thousand years. Science and philosophy, therefore, are not strangers to each other. In the ancient times, Aristotle and many other philosophers were also scientists. Significant philosophers, like Bacon, Descartes, Leibniz and Locke, were influenced by science and their contributions to science were also very significant. Great scientists of the 19th century, Maxwell, Hertz and Helmholz, gave serious thought to the above mentioned philosophical issues. Poincare, a prominent mathematical physicist, came up with insights into the nature of theories and hypotheses, the notions of explanation and probability.

Some philosophical Issues in Science: i) To understand certain concepts adequately, science has to go beyond to the realm of philosophy. For instance, the concept of time cannot be defined in terms of hours / minutes of duration, as all these presuppose the notion of time; ii) The relation between the scientific theory and the world out there – realistic or instrumental relationship?; iii) How do the scientists switch over to the new theories? Is it completely based on logic and observations? Or is it through a social process, like Kuhn and other historicists would propose? iv) Evidence is generally based on the assumption that there are 'pure' observations. But there seems to no 'theory-free' observation in science. Even to see the time now as 12 noon, assumes that the clock and observer exist independently of each other and not deluded by a Cartesian demon, and to accept all the theories with which the clock has been manufactured. This raises further questions: Is there any real epistemic distinction between observational and theoretical assertions? Is there any safe and sound basis for science? v) What is the meaning of 'systematically basing' the theories on the evidence? Any theory, with its universal applicability, goes beyond the observable data at hand. Same observational data can yield too many theories, even contradicting ones (notion of Under-determination); vi) What are the extra factors to be considered to decide upon the 'correct' theory? If simplicity and predictive power of theories are considered, are they only pragmatic considerations or some sort of truth-revealing indicators? vii) Philosophical analyses of the aims, methods, assumptions, foundations, practices and achievements of science, are to be undertaken as specific sciences will not have time for such aspects; viii) The study of the very language of science, the methods and the structures of explanation used in science; it checks the validity of arguments used in science; ix) Exploration of the worldviews based on important scientific theories to uncover the preferences of scientists for deterministic rather than statistical laws, or for mechanistic rather than teleological explanations; x) The investigations into the broader implication of science and to see how the socio-cultural factors affect the growth and the subject matter of science.

2.2 PHILOSOPHY OF SCIENCE AND EPISTEMOLOGY

Science aims at acquiring more knowledge about the world, by specific methods of observation and experimentation and it makes conclusions based on evidence. In philosophy also there is a branch, 'Epistemology', which deals with domains of knowledge. 'What is the difference between knowledge and mere beliefs?' 'Can one be sure that one can know at all? 'What are the things that one can know?' "What are the requirements for a proposition to be a piece of knowledge?' - are some of the questions that are crucial to both the disciplines. Science justifies its knowledge through specific method(s). However Hume already pointed out that the inductive reasoning, widely used in science, cannot be completely justified, as its conclusion involves claims about unknown elements. The ampliative inference – where the inference contains some factual content which has not been present in the premises – decides on something about the unexperienced, basing on the experienced. Science functions on many axioms, like the fundamental uniformity of nature, the future will resemble the past etc., which are known, *a posterori*, nor *a apriori*. Philosophy of science critiques the method used in science.

Scientific Methodology

The term 'Method' means 'a way to achieve an end' and the scientific method is way to achieve 'scientific ends', i.e. scientific knowledge [Greek terms, *meta* = after and *hodos* = way]. The basic steps of scientific methodology: i) *Stating the Problem* (success and progress of science greatly depends on the clear understanding of problem at hand); ii) *Framing a Hypothesis* (a tentative solution to the problem, based on one's creative and original imagination); iii) *Observing and Experimenting* (studying an event/phenomenon under varied conditions, controlled by the investigator, with or without instruments); iv) *Interpreting the Data* (making the resulting data – figures, pointer readings, graphical representations etc. – intelligible and useful, by means of analysis, synthesis, comparisons, analogies, models etc.); and v) *Drawing Conclusions and Inferences* (the aim of the whole process).

There are *Mental Devices* used in scientific methodology: i) Logic (the use of *induction*, to arrive at causal connections between events, and *deduction*, to arrive certain conclusion from the given premises; induction gives new information, but need not be certain, while deduction gives certain conclusion, but not new one); ii) *Classification* (to bring order into the multitude of complicated data); iii) Comparison and Analogy (especially useful in forming the hypothesis and in interpreting the data); iv) *Models* (a basic representation, from the known to the unknown); and v) *Mathematics* (a powerful device to make complicated concepts understandable).

Scientific Methods in the Modern Times: Though Aristotle in his *Prior Analytics* and *Posterior Analytics* used both the inductive and deductive reasoning, Francis Bacon, in his *Novum Organum* (1620) emphasized only the method of induction for scientific inquiry. But with the emergence of modern science (17^{th} – 19^{th} centuries) the need was felt to look for a new understanding of method of science and two predominant methods of science emerged: Inductivism and Hypotheism.

Inductivism	**Hypotheism**
i) The method of science is the method of induction. ii) Founder: Francis Bacon. iii) Rooted in Empiricism – (only those ideas that are traceable to sense experiences are to be treated as knowledge). iv) Important features of science: Certainty and breadth. Science has to look for definite knowledge and more encompassing knowledge about reality. v) Since science has to be certain, it has to limit itself only to the observable phenomena; then proceeds from particulars to general conclusions through induction. Science must remain from the beginning till the end at the level of observation; so there is no reference to unobservables. vi) The aim of science: to arrive at laws, (i.e. established inductive generalizations).	i) The method of science is the method of hypothesis. ii) Rene Descartes iii) Based on Rationalism – (At least some portion of human knowledge cannot be traced to, and thus, independent of sense experiences). iv) Novelty and Depth. Science has to go beyond the observational; it has to reach the depth of reality of unobservables, behind the observed. v) Mere generalization in terms of observations is not enough; science has to explain the observable in terms of the unobservables. vi) To generate hypotheses to explain what we observe. [Hypothesis meant 'a statement regarding unobservable entities & process.

vii) Inductivists are antirealists; they hold that the theoretical terms don't refer to anything real; as empiricists for them only observed reality is real and nothing outside exists; they are only useful tools.	Today it means 'a tentative solution to a problem']. vii) Hypothesists are realists; theoretical terms (like electrons, protons etc.) refer to really existing entities, though they are not given to us in observations.

By the middle of the 19th century science had to deal with many unobservable entities or process (e.g. Franklin's fluid theory of electricity, Vibratory theory of heat, Phlogiston theory of burning and neurophysiological theories of David Hartley etc.), which took science beyond observational methods of inductivism. Within philosophy too there were objections to show that there was no rational justification for induction.

Problems of inductive reasoning

Inductive reasoning is common-sensical and highly successful in sciences and practical lives. However, Hume astutely argued in his *Treatise of Human Nature* (1739) that there is no logical justification for the principle of induction. N.R. Hanson points out the actual problem with the inductive thinking: "It is the problem of showing how 'The Inductive Principle'… can at once be synthetic (in that its negation is not demonstrably self-contradictory), yet necessary (in that its negation describes no intelligible state of affairs at all)" (1971, 248). *The decisive problem* with induction is that to justify induction we need to involve inductive reasoning itself; it can be illustrated as follows: The principle of induction worked successfully on occasion n_1, n_2, n_3….n_x. Therefore the principle of induction always works.

In the past few decades a number of solutions have been propose in order to defend the inductive reasoning: Reichenbach (*Experience and Prediction*, 1938 and *The Theory of Probability*, 1945) is satisfied with a pragmatic justification; Nelson Goodman replaced Hume's old problem of induction with the new problem of induction; Kant offered a transcendental deduction of a principle of universal causation; P. F. Strawson offered an ordinary language dissolution, and thereby making Hume's problem is only a pseudo-problem; Carnap appealed to 'inductive intuition'. (For analyses of all these proposed solutions, see: Wesley Salmon, 1967). Popper (1935, *Logic of Scientific Discovery*) did away with the need for induction in science, because science adopts hypothetico-deductive method. [*Note*: For explanation of this method, kindly see: Block 2, Unit 2: *Historicism*].

Bayesian Theory of Probability - A Reasonable Solution: Bayesian theorem, proposed by Thomas Bayes (an English non-conformist clergyman, a renowned mathematician, a fellow of the Royal Society, lived between 1702-61) is an attempt to supply rational basis for inductive reasoning in science. The degree of certainty of the conclusion of an experiment is measured by the probability of the conclusion. By probability Bayes meant "a rational acceptance: The probability of any event is the ratio between the value at which an expectation depending on the happening of an event ought to be computed, and the value of the thing expected upon it's happening" (1763, 376, as quoted by Barry Gower, 1997, 96). Salmon lists five leading philosophers, Carnap, Reichenbach, L. J. Salvage, Nelson Goodman and Popper, who show inclinations towards the Bayesian theorem, directly or indirectly (Wesley Salmon, 2002, 397-99). Howson and Urbach explain the Bayseian confirmation in simple terms. The relationship between the empirical data (evidence) and the hypothesis is crucial, because it helps in accepting or rejecting a hypothesis. A piece of evidence can be confirming or undermining or neutral to the hypothesis under the test: Say, h – hypothesis; e – evidence, $P(h)$ – the prior probability, and $P(h|e)$ – the posterior probability; e confirms h, if $P(h|e) > P(h)$; and e disconfirms h, if $P(h|e) < P(h)$; i.e. if the posterior probability is more the evidence confirms the hypothesis and vice versa. When the confirmation is at maximum, $P(e|h) = 1$ and then h logically entails e. When the disconfirmation is at maximum, $P(e|h) = 0$ and then h is refuted. No further evidence will confirm it, unless the refuting evidence or part of background knowledge is revoked. Posterior probability depends on prior probability but this dependence is related to the scientists' attitude towards *ad hoc* hypothesis; their preferences with regard to simpler hypotheses and their decision with regard to the credibility of the hypothesis. The authors are, in fact, very optimistic that "Bayesian approach is the only one capable of representing faithfully the basic principles of scientific reasoning" (Colin Howson and Peter Urbach, 1993, 2).

The *most basic objection* to the Bayesian approach is that it gives importance to subjective factors in the scientific appraisal. For instance, Lakatos claims that the states of mind, like one's beliefs, commitments, understanding etc. of the psychological approaches don't affect the cognitive value of a scientific value of a theory, which is actually "independent of the human mind, which creates it or understands it, its scientific value depends only on what objective support these conjectures have in facts" (Lakatos, 1978, 1). But the admirers of Bayesian reasoning seem to suggest that the so-called 'objectivists' of scientific methodologies deliberately close their eyes towards the indispensable subjectivist elements in the scientific reasoning. That is why a leading proponent I.J. Good argued persuasively that "the subjectivist (i.e. Bayesian) states his judgments, whereas the objectivist sweeps them under the carpet by calling assumptions knowledge, and he basks in the glorious objectivity of science" (http://www.cs.ubc.ca/~murphyk/Bayes/bayesrule.html). Given the scenario, Howson is confident that "Eventually we shall all be subjective Bayesians" (Howson, 1991, 82). [For more on the objections against probabilists and Bayesians, kindly see: Karl Popper and D. Miller, 1984, 434].

Finally, conclusiveness always escapes us in inductive reasoning. Nevertheless, it need not make us nervous or skeptic towards the whole enterprise of inductive reasoning. Though we can always reject what has been inductively arrived at, we can still consider it as valid reasoning, "since they have as little chance in fact of going wrong" (Mellor, 1989, 7.). It seems to be reasonable to accept inductive reasoning as a species by itself.

Check Your Progress I

Note: Use the space provided for your answers.

1) Comment on the need and relevance of Philosophy of Science for other intellectual inquiries?

....
....
....
....
....

2) What is a scientific method? Discuss the methods of modern science.

....
....
....
....
....

3. What is the problem with the inductive reasoning? Can it be convincingly solved or conveniently ignored?

....
....
....
....
....

2.3 PHILOSOPHY OF SCIENCE AND METAPHYSICS

When science comes out with theories, especially about the unobservables, a crucial question can be raised: Do they portray the world as it is or are they only a convenient tool to understand the natural phenomena? Science not only describes, but also explains how and why a phenomenon takes place. By explaining the fundamental nature of things, about its existence, about its causation etc, science enters the domain of metaphysics. We focus only on these two aspects of *realism* and *causality* here.

Scientific Realism and Anti-realism

The question of realism and anti-realism arises in the context of the unobservable entities, like, viruses, radio waves, electrons, quarks, genes, atoms and sub-atomic particles, blackholes, etc. Though they are not observable science is able to acquire knowledge about their nature, behaviour, constituents etc. 20th century physics gives a picture of reality that is more abstract and far-removed from common sense. At this juncture, the question of justifying the ontological status of these unobservable entities arises very strongly. There are two opposing trends in philosophy of science with regard to the existence of unobservable entities: *Scientific Realism* and *Scientific Anti-realism*, where the former claims that the unobservables really exist, and the latter denies it.

The Basic Claims of Scientific Realism

i) Unobservable entities exist; ii) They exist independent of our minds; iii) We do make statements about them, with truth-value; iv) These statements are true or false, depending on how the world is, and v) We must believe in their existence and consider much of them as knowledge. For instance, the kinetic theory of gases speaks about the molecules in random motion, because that is what happens in a gas. Thus, they demand three kinds of philosophical commitments: *metaphysical* (mind-independent existence), *semantic* (literal interpretation of the theories and the correspondence theory of truth) and *epistemological* (the unobservable entities do exist and they count as knowledge).

The Basic Claims of Scientific Antirealism

i) Only what is empirically observed does exist, and all the other so-called unobservable entities don't. [*Note*: Most of the antirealists, though they deny the real existence of such entities, yet they agree that science is the most rational enterprise, because of its practical success and growth in accumulation of knowledge. So the issues of 'rationality in science' and 'realistic view of science' are different]; ii) The unobservable entities are only useful instruments to make calculations simpler or predictions more feasible, and the description about them are not true reflections of the state of affairs in the world. There are *different types of anti-realists* in science. To be an anti-realist it is sufficient to disagree with anyone of the above-mentioned five claims of the realists. [Sceptics deny (i), reductive empiricists deny (iii), Social constructivists, like Kuhn, deny (ii), constructive empiricists, like Bas van Fraassen, deny (v) and they are also unsure of (i)].

The major groups among the anti-realists

Instrumentalism: i) Scientific theories don't describe the world, rather they are tools to approach the world and to relate a set of observable states of affairs with other sets; ii) Theories about the unobservable entities are not to be taken literally as they are only logical constructs used as useful instruments to relate with the external world; iii) Theories are judged in terms of their efficiency and usefulness, and not in terms of truth / falsity; iv) Since theories are only instruments they don't have predictive powers; b) *Conventionalism*: i) Scientific theories are only conventions; ii) The theoretical entities don't exist as nothing beyond observational reality exists; iii) The concepts used in a theory, say, 'force' and 'mass' in the Newtonian theories, are mere conventions; however they are empirically significant and useful to explain the world of facts. c**)** *Descriptionism*: The theoretical claims of the unobservable entities are only convenient descriptions of reality, as they don't refer to anything that actually exists.

Remarks

The debates between realists and antirealists seem to go for ever; For, antirealists have to explain how scientific theories, if they are just convenient tools to deal with reality, produce practical successes; on the other hand, realists have to deal with the problems with the theory-ladennes of observation and the fact the whole enterprise of science is increasingly seen as a product of psycho-social and cultural milieu of a given time. [More arguments against 'pure' observations will be given in *Historicism* (Unit 2 of Black 2]. ii) All observational terms are theoretical constructs to a certain extent. Stars, planets, light rays, gases etc. acquire their meaning, to some extent, only from the theoretical contexts in which they occur. For example, instrumentalists argue that only the billiard balls are observable and real, while the force and friction that exist among them are only tools, invented by physicists to understand certain physical phenomena. But one needs to realize that the concept of a billiard ball also involves some theoretical constructs like individuality, rigidity, made of a particular substance etc., without which we cannot speak of those balls. iii) Realists argue that unless we assume the unobservables really exist, how can one justify the efforts of the contemporary scientists to unify various kinds of theories and to arrive at one theory of everything (TOE)? However, instrumentalists would reply that the efforts to unify theories are still worth the trouble, because the scientific community will arrive at one 'big' and 'unified' instrument to deal with nature. Some of them may deny the very effort of unifying as baseless, as science is only a assortment of various tools to deal with variety of problems (Nancy Cartwright,1983). iv) Further, the predictive feature of science gives science a distinguishing characteristic for science and this feature is possible only when science treats theories as true descriptions of reality. v) Given these circumstances, there are authors coming up with nuanced understanding of realism, as instrumentalism seems to have more problems than realism. [e.g. *'Unrepresentative Realism'* by A. F. Chalmers, in *What is This Thing Called Science?*, 1992): It is realism, because we need to assume the independent existence of reality and acknowledge the practical and predictive power of scientific theories. It is *unrepresentative*, because it does not involve correspondence theory of truth between theories and the reality out there].

Causality and Science

One of the significant aims of science is to explain events or phenomena in terms of natural laws or cause-effect relationships. A natural law is expected to have authenticity, a measure of certainty and it must be universal (i.e. reliable in all situations, at all the times). For example, Newton's theory of gravitation is true at all times. Accidents (unlike laws) don't have predictive power.

Cause-Effect Relationship

How causes are related to effects is of philosophical interest: *a) Logical Necessity:* Causes necessitate some events that are effects. As causes are sufficient for their effects, the relation of causal necessity between particular events makes one *an inevitable consequence* of another. Due to the inherent connection between the cause and its effect, the effect must happen whenever and wherever the cause exists. If laws are universally valid there must be necessary relationship between the phenomena; thus, when one heats the water, it not only normally evaporates but it must evaporate. *b) Constant Conjunction* (Hume): There is no logical justification for any necessary connection but only "constant conjunctions" (exceptionless regularities) between cause and effect. As we are conditioned by these regularities in our experiences, we form an idea of causal necessity and mistakenly think that second billiard ball not only *will*, but also *must,* move when the first ball strikes it. The idea of necessary connection between them is only a psychological expectation and nothing is based on sense impression. Since any cause is perfectly separable in our mind from their effects, we can imagine any cause (without any absurdity) without its accustomed effect or even with effect with which never accompanies. Only from my experience I learn that when water is heated it boils, instead of freezing; but there is nothing tells me that the latter *cannot* happen. Therefore, since anything might cause anything, an effect cannot be inferred from a cause; both are conjoined, and not connected. *c) Empirical Necessity:* The cause-effect relationship is only *a hypothetical or conditional* necessity, given a set of natural laws. Boiling of water on heating is just a consequence of the law of nature. If there were different sets of laws the effects could have been very different. Such an empirical analysis looks at causation**,** *not in terms of what can and cannot happen, not in terms of what is and what is not possible, but solely in terms of what does happen.*

Remarks

a) Problems with the Hume's notion of *constant conjunction*: i) Basing on this one cannot distinguish *genuine causal* relations and *accidental conjunctions*. Not all constant conjunctions can be taken as causal relationships. (E.g. "Whenever the Minister visits my town it rains". Even if this statement is always true, the visit of the Minister cannot be the cause for the rain. ii) In the Humean understanding the direction of causation cannot be figured out, since constant conjunction has only a relationship of symmetry, whereas the causation is the one of asymmetry.

iii) Does the constant conjunction mean that sometimes the causes don't result in the effects? It is only a probablisitic causation?

b) Problem with Hume's notion *similarity*: Events similar to *A* are always followed by things similar to *B*. The idea of 'similarity' is not clear - Is it exactly similar? If so, the only thing exactly similar to an event is that event itself, and it cannot be reproduced exactly, because at least the space-time factors will differ; or is it 'more-or-less' similar? Humeans claimed that the similarity must be in certain crucial and relevant respects. But what is the basis to decide upon the relevance? If they claim that only those changes which are similar in relevant respects are always followed by other changes which are similar relevant respects, then their analysis of the causal relationship becomes tautological; for it just says that *those changes that are similar in the respects that causally connect them with their effects have similar effects*.

c) Since the concept cause is indispensable not only in our practical lives but also in sciences, there are efforts by philosophers, like D.M. Armstrong, Fred Dretske, Tooley in the late 1970s, to propose some sort of clear notion of necessitation in causal relationships; for *necessitation implies constant conjunction but not conversely*. This necessitation, of course, is not known *a priori*, rather what necessitates is an empirical matter, known by *a posteriori* inspection.

Check Your Progress II

Note: Use the space provided for your answers.

1) Discuss some of the areas where Metaphysics and scientific inquiries come together?
....
....
....
....
....
2) What is more appealing and reasonable: Scientific realism or Scientific anti-relism? Substantiate your position.
....
....
....
....
....

2.4 FEMINIST ACCOUNTS OF SCIENCE

In the recent years, Feminists, Sociologists of Knowledge and Postmodernists criticize science from various angles. From the early 1970s feminism began critiquing science. The research on the gender bias in the fields of science is highly complex and multi-faceted; it includes issues like the research on the presence of women doing hard-core science, the ill-treatments done to them in the scientific circles, the gender partiality exhibited in the content, methodology and epistemology of science, the selection of the problem for scientific investigations, especially in the fields of biology and health sciences, the decisions and policies drafted by the males, and so on. Feminists point out that scientific researches are gender-biased, for instance medical researches use only the males of any species for their study.

Feminist accounts of science, not only reveal the gender bias in theories, practices and assumptions of science, but also most of them go further to show how this androcentric prejudices shape the very notion of rationality, objectivity and scientificity. They substantiate their claims with case studies that there have been systematic omissions or distortions of women / gender issues, which have resulted in faulty conclusions. Case studies show that even contradicting claims are given in order to claim the superiority of the males, in terms of smartness, intelligence and physical robustness. To argue for the natural tendency for women to have subordinate role in the society and family, as Fausto-Sterling maintains, some evidence is consistently not considered, some questions are never raised, some hypotheses are ignored and some experimental controls are never instituted (Okruhlik, 2001). Feminist critiques point out the gender bias of Darwin in his theory that evolutionary development exclusively belongs to males, the hunter-gatherers'. This androcentric bias serves as an auxiliary theory in other disciplines, like Anthropology, to justify the behaviours and social roles of the males. Similarly, Francis Bacon made use of gender metaphors to refer to nature. He saw nature as female, as a wild and uncontrollable female to be restrained and controlled. Feminists argue that a dualistic and detached pursuit of science to study nature should be removed in order to save women from male domination. Even the scientific revolution of the modern science is seen as the reflection of gender ideology, whereby the mechanistic world view looked at the earth and nature as something to be dominated and controlled by humans.
Women's experience and women's epistemology must be taken into consideration in order to have a holistic picture of science. In a reconstructed feminist epistemology of science, according to Anne M. Clifford, "the scientist is not an impersonal authority standing above nature and human concerns, but a person whose thought and feelings, logical capacitates and institutions are all relevant and involved in the process of enquiry" (Clifford, 1992, 77). They argue that the gender does influence the investigations and the conclusions arrived thereupon; they even that feminists can point out the bias in the masculinist science and even produce better science (Harding, 1986, and 1991). Wendey Kohli points out that reason and reasoning need to be addressed historically within the context of gender differences; for centuries down the history masculinity and reason have been treated as synonyms, making feminine inferior, and even subservient to masculine rationality (Fleming, 1992 and Lloyd, 1995).

All are not ready to buy the arguments of the feminists. Some don't see even theoretical possibility of feminist critique, while Ronald Giere (1998) argues for such possibility. Feminists' convictions that women can produce better science and 'feminist epistemology' is privileged are challenged by many critiques. Cassandra Pinnick (1999) for instance does not find any evidence to support such convictions. Though the feminists may exaggerate, there must be, I think, some grains of truth in their claims. For, the traditional understanding of rationality seems to have not paid attention to non-cognitive elements of thoughts and feelings. The rational mind of men and the intuitive mind of women need to be in collaboration with each other for the betterment of humanity; this distinction reveals the complementary nature, not superiority-inferiority divide, between men and women. If women are also involved in the important decisions and policy-making we can certainly expect a better 'human touch' in all those policies. For instance, it is a painful irony to see in India that while we produce millions of surplus food-grains, there are thousands of starvation deaths every year. If women are involved more and more in the administration and decision-making process, I strongly believe, that, with their intuitive and maternal touch, they will not easily tolerate the wastage of food-grains and the starvation deaths. With their in-born quality of dividing the stuff among the children lovingly and equally, they will certainly bring down, if not totally eradicate, the hunger deaths on the streets.

2.5 VALUES AND SCIENCE

For the Greeks, the pioneers of the Western thought and culture, there was no significant distinction between science (knowledge) and values (good), science and philosophy, objective and subjective and factual (descriptive) and normative (evaluative). The problem arises with the mechanical view of nature (or Newtonian science). The epistemological and methodological revolution in science and philosophy, initiated by Descartes, insisted upon a sharp distinction between objective and subjective dimensions in the knowledge-seeking enterprise. Since science is said to be rational and objective, factual and experimental, values are beyond the purview of science. However, such value-neutral approach of science is strongly challenged today by philosophers of science, sociologists, historicists, humanists, and even by scientists themselves. For instance, the very fact that there are goals in science shows the need of value- consideration. Science involves several types of goals: i) *Epistemic goals* (e.g. advancing human knowledge with explanations and predictions; teaching science to next generations ...); ii) *practical goals* (e.g. increasing technological power, improving standards of life ...); iii) *Goals of scientists* (their personal interests for name, fame, money ...); Personal goals *at their personal level* (openness, freedom, readiness to take risks, social responsibility, mutual respect, efficiency ...), *at the level of scientific publications* (objectivity in publication, intellectual properties...), *at the level of personal relations among those involved in science* (mentor-mentee relationship, harassment, reporting misconduct in science, sharing & preserving resources) and so on. Thus, the need to discuss the role of value judgments and ethical considerations in science has become more crucial and urgent with the uncontrollable explosion of war technology, ecological degradation and the bio-ethical issues arising from bio-sciences of the 20^{th} century.

Value-neutrality of Science is usually based on two factors: a) *Fact-value dichotomy*: Science is for what 'is', not what 'ought to be'; science can only describe, not prescribe (Perera, 2005). But now it is realized that both facts and values are thoroughly interdependent. There does not seem to be any significant difference between the so-called scientific values, like justification, coherence, truth etc., and moral or aesthetic values (Putnam, 1982). Truth is considered as a scientific value, but relevance, interests and significance of such truths in the social contexts are also equally important scientific values. The latter may be called as extra-scientific values, but they are also equally important. To remove these value-considerations from a scientist is to remove his / her humanity as well. One cannot suppress his/her value judgment unless one is ready to destroy him/her as a human being and as a scientist. Scientists are not seeking for merely objective truths, knowledge, but truths that are interesting, useful and valuable to humanity as a whole. Therefore, knowledge, truth, objectivity and so on are rooted in values and human purposes; b) *Skeptical attitude*: Skepticism abhors authoritarianism and orthodoxy, subjecting everything to a severe scrutiny. It demands openness to check whether one is misguided or not. It is a part of rationality in science. However, consistent and absolute skepticism is not possible, even in science. One needs to be reasonable in being skeptic. Riniold and Nisbet argue that *no one is consistently skeptic but only selectively skeptic*, due to our built-in biases. Even hard core sceptics, therefore, become the *victims* of i) *Confirmation bias* (the tendency to look for evidence that is consistent with our beliefs); ii) *Biased assimilation* (bias in assimilating information that suits our belief system); and iii) *Belief perseverance* (the tendency not to give up a long-cherished belief, though there is pressing evidence against them). (Riniolo and Nisbet, 2007, 50-51).

Moral considerations of science and the social responsibilities of science and scientists are no more at the periphery of philosophy of science but they take the centre-stage. Science does not develop in a void. Technological revolution is not a non-social concept. Therefore, "It would be highly irrational to overestimate the powers at the disposal of science and the scientists in the humanization of advances in science and technology. It is still less rational, in fact, irresponsible, to ignore the active socio-ethical humanistic stand taken by the scientific community" (Froov and Yudin, 1989, 352-3). As long as scientists are humans, who are part and parcel of human society, scientists are bound by, at least, certain final values. One such value demands science to enhance and enrich humanity and alleviate its sufferings and the damage to the environment.

Check Your Progress III

Note: Use the space provided for your answers.

1) "Gender-issues in science is a pseudo problem; it is a waste of time to engage in such meaningless quibbles" – Do you agree with this claim? Substantiate your position.

....
....
....
....
....

2) "Science cannot, and should not, be confused with moral issues, as it is objective and rational" - Give your comments.

....
....
....
....
....

2.6 LET US SUM UP

Philosophy of Science deals with the philosophical issues of science. It critiques, among many other tasks, the methods and assumptions of science. Philosophy of science as a discipline is related with many other disciplines. We have focused in this essay a few of them: i) since science aims at acquiring knowledge, it is related with *Epistemology*, a branch of philosophy that deals with the nature and validity of knowledge enterprise; ii) since science is particular about revealing the *true* nature of reality it is related with *Metaphysics*, a branch of philosophy that focuses on the issues of reality; iii) since science is *by* humans and *for* humans and it is essentially a social enterprise, all that affects human society becomes a serious concern for science, including moral and environmental issues.

2.7 KEY WORDS

Inductive Reasoning: It is a process of inferring conclusions about unknown phenomena based on the known individual instances. It assumes "the uniformity of nature", and that "the future will resemble the past".
Scientific Realism and Anti-realism: Trends in of philosophy of science that deals with issues of actual existence of the theoretical entities and that of the reality independent of the observers as postulated by scientific theories.

The Principle of Causality: It demonstrates the relation between causes and effect. This philosophical concept has serious implications for science.

2.8 FURTHER READINGS AND REFERENCES

Armstrong, D. *What is a Law of Nature?* Cambridge: Cambridge University Press, 1983.

Boyd, Richard, Philip Gasper and J.D. Trout. Eds. *The Philosophy of Science.* USA: The MIT Press, 1991.

Cartwright, Nancy. *How the Laws of Physics Lie.* Oxford: Oxford University Press, 1983.

Clifford, Anne M. "Feminist Perspective on Science: Implications for an Ecological Theology of Creation." *Journal of Feminist Studies in Religion.* Vol.8, 2 (1992).

Fleming, Marie. "Women's Place in Communicative Reason." in *Women and Reason.* Ed. by Elizabeth Harvey and Kathleen Okruhlik. Ann Arbor: University of Michigan Press, 1992. 245-62.

Frolov, Ivan and Boris Yudin, *The Ethics of Science: Issues and Controversies.* Moscow: Progress Publishers, 1989.

Giere Ronald. "The Feminist Question in the Philosophy of Science." in Klemke. Et.al. 1998. 550-564.

Gower, Barry. *Scientific Method.* London & NY: Routledge, 1997.

Hanson, N.R. *Patterns of Discovery.* Cambridge: Cambridge University Press, 1958.

Harding, Sandra. *The Science Question in Feminism.* Ithaca, NY: Cornell University Press, 1986).

-----------. *Whose Science? Whose Knowledge?* Ithaca, NY: Cornell University Press, 1991.

Hempel, C. G. *Aspects of Scientific Explanation.* New York: free Press, 1965.

----------. “Science Unlimited?” in *The Philosophy of Carl G. Hempel – Studies in Science, Explanation and Rationality.* Ed. James H. Fetzer. Oxford: Oxford University Press, 2001.

Howson, Colin.“The Last Word on Induction.” in *Erkenntnis - An International Journal of Analytic Philosophy*. 34(1991), 73-82.

---------- and Peter Urbach. Eds. *Scientific Reasoning: The Bayesian Approach.* Chicago and La Salle, Illinois: Open Court, 1993.

Jardine, N. *Birth of History and Philosophy of Science: Kepler’s ‘Defence of Tycho against Ursus’, with Essays on Its Provenance and Significance.* Cambridge: Cambridge University Press, 1984.

Kitcher, Philip. *The Advancement of science: Science without Legend, Objectivity without Illusions.* NY: Oxford University Press, 1993.

Klemeke, E. D. & Robert Hollinger. Ed. *Introductory Readings in the Philosophy of Science.* New York: Prometheus Books, 1998.

Kuhn, T. *Structure of Scientific Revolutions.* Chicago, IL: University of Chicago Press, 1970.

Lakatos, Imre. *The Methodology of Scientific Research Programmes: Philosophical Papers,* Two Vols., J. Worral and G. Currie. Ed. Cambridge: Cambridge University Press, 1978.

Lloyd, Elizabeth. “Objectivity and the Double Standard for Feminist Epistemologies.” *Synthese* 104(1995). 351-381.

Longino, H. *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry.* Princeton: Princeton University Press, 1990.

Mellor, D. H. “Induction Is Warranted.” *Analysis* 49 (1989).

Okruhlk, Katheleen. “Feminist Accounts of Science.” in W. H. Newton-Smith. 2001. 134-142.

Perera, Ariyapala. *Science and Human Values.* New Delhi: Global Vision Publishing House, 2005.

Pinnick, Cassendra. “Problems with Feminist Epistemology.” in *Scientific Inquiry – Readings in the Philosophy of Science.* Ed. by Robert Klee. New York: Oxford University Press, 1999. 295-305.

Popper, Karl. *Logic of Scientific Discovery*. London: Hutchinson; New York: Basic Books, 1959).

Putnam, Hilary. “Beyond Fact / Value Dichotomy.” *Critica* 14. 3 -12. [Reprinted in *Realism with a Human Face.* Ed. Conant. Cambridge: Harvard University Press, 1990].

Riniolo, Todd C and Lee Nisbet. “The Myth of Consistent Skepticism – The Cautionary Case of Albert Einstein.” *Sceptical Inquirer.* May/June 2007. 49-53.

Ruben, D. H. Ed. *Explanation.* Oxford: Oxford University Press, 1993.

Salmon, Wesley. *The Foundations of Scientific Inference.* Pittsburgh: University of Pittsburgh, 1967.

----------- “Bayes’s Theorem and the History of Science.” in *Philosophy of Science – Contemporary Readings.* Ed. Yuri Balashov and Alex Rosenberg. London & New York: Routledge, 2002. 385-401.

UNIT 3 INTRODUCTION TO COSMOLOGY

Contents

3.0 OBJECTIVES

- To introduce the students to the basic notions of physical cosmology.
- To make them aware of the early (religious) history of cosmology
- To familiarise them with some of the complex issues related to the origin, nature and end of the universe.

3.1 INTRODUCTION

This unit tries to introduce the topic of cosmology. After studying the origin, nature and destiny of the universe, it looks into the Indian and Greek cosmologies. Then it takes up some important issues in contemporary scientific cosmology. Our aim is to show the religious beginnings of today's scientific cosmology.

3.2 ORIGIN, NATURE AND DESTINY

Cosmology ("study of universe" from Greek "*kosmos*" meaning "universe"; and "logia, "study"), in strict usage, refers to the study of the Universe in its totality as it is now (or at least as it can be observed now). Though the word cosmology is recent (first used in 1730 by the rationalist philosopher, Christian Wolff), the study of the universe has a long history involving science, philosophy, esotericism, and religion.

In recent times, physics and astrophysics have played a central role in shaping the understanding of the universe through scientific observation and experiment. The physical cosmology is primarily shaped through both mathematics and astronomical observation by the analysis of the whole universe. This discipline focuses on the universe as it exists on the largest scale and at the earliest moments. It is generally understood to begin with the Big Bang that is thought to have emerged roughly 13.5-13.9 billion years ago (Cosmology 2011).

From its beginnings scientific cosmologists propose that the history of the universe has been governed entirely by physical laws. Theories of an objective universe governed by physical laws were first proposed by Roger Bacon. Contemporary cosmologist Steven Weinberg echoes the same sentiment: “The universe itself acts on us as a random, inefficient, and yet in the long run effective, teaching machine.… our way of looking at the universe has gradually evolved through a natural selection of ideas."

Philosophical Cosmology, as distinct from physical cosmology, draws data from physical cosmology and focuses on critical reflection as to the origin, nature and destiny of the universe. Metaphysical assumptions and implications are also brought into it. Between the domains of religion and science, stands the philosophical perspective of metaphysical cosmology. This ancient field of study seeks to draw intuitive conclusions about the nature of the universe, man, the Divine and their relationships based on the extension of some set of presumed facts borrowed from spiritual experience and observation (Cosmology 2011).

But metaphysical cosmology has also been observed as the placing of man in the universe in relationship to all other entities. This is demonstrated by the observation made by Marcus Aurelius of a man's place in that relationship: "He who does not know what the world is does not know where he is, and he who does not know for what purpose the world exists, does not know who he is, nor what the world is." This is the purpose of the ancient metaphysical cosmology. Cosmology is often an important aspect of the creation myths of religions that seek to explain the existence and nature of reality. In some cases, views about the creation (cosmogony) and the end (eschatology) of the universe play a central role in shaping a framework of religious cosmology for understanding humanity's role in the universe.

3.3 INDIAN COSMOLOGY

In India science and religion are not opposed fundamentally are seen as parts of the same great search for truth that inspired the sages of Hinduism, Buddhism, and Jainism. Thus, in the Hindu scientific approach, understanding of external reality depends on also understanding the godhead. In all Hindu traditions the Universe is said to precede from the gods. Fundamental to Hindu concepts of time and space is the notion that the external world is a product of the creative play of *maya (illusion).* Accordingly the world as we know it is not really real but illusionary. The universe is in constant flux with many levels of reality; the task of the saint is find release (*moksha*) from the bonds of time and space (Hindu Cosmology 2006).

Therefore, one of the ancient Hindu books describes thus: "After a cycle of universal dissolution, the Supreme Being decides to recreate the cosmos so that we souls can experience worlds of shape and solidity. Very subtle atoms begin to combine, eventually generating a cosmic wind that blows heavier and heavier atoms together. Souls depending on their karma earned in previous world systems, spontaneously draw to themselves atoms that coalesce into an appropriate body." Hindu cosmology envisaged the universe as having a cyclical nature. The end of each *kalpa* brought about by Shiva's dance is also the beginning of the next. Rebirth follows destruction and the cycle goes on. Thus in Hindu cosmology the universe is, according to mythology and Vedic cosmology, cyclically created and destroyed. The following symbolic

representation of the creation of the world by Brahma is insightful. The life span of Lord Brahma, the creator, is 100 'Brahma-Years'. One day in the life of Brahma is called a *Kalpa* , which is calculated to be 4.32 billion years. Every *Kalpa* Brahma creates 14 Manus one after the other, who in turn manifest and regulate this world. Thus, there are fourteen generations of Manu in each *Kalpa* (one day of Brahma). Each Manu's life consists of 71 *Chaturyugas* (quartets of *Yugas* or eras) which in turn is is composed of four eras or Yugas: *Satya*, *Treta*, *Dwapara* and *Kali*.
The span of the *Satya Yuga* is 1,728,000 human years, *Treta Yuga* is 1,296,000 human years long, the *Dwapara Yuga* 864,000 human years and the *Kali Yuga* 432,000 human years. When Manu perishes at the end of his life, Brahma creates the next Manu and the cycle continues until all fourteen Manus and the Universe perish by the end of Bramhma's day. When 'night' falls, Brahma goes to sleep for a period of 4.32 billion years, which is a period of time equal one day (of Brahma) and the lives of fourteen Manus. The next 'morning', Brahma creates fourteen additional Manus in sequence just as he has done on the previous 'day'. The cycle goes on for 100 'divine years' at the end of which Brahma perishes and is regenerated. Bramha's entire life equals 311 trillion, 40 billion years. Once Bramha dies there is an equal period of unmanifestation for 311 trillion, 40 billion years, until the next Bramha is created (HC 2011).

The present period is the *Kali Yuga* or last era in one of the 71 *Chaturyugis* (set of four Yugas/eras) in the life one of the fourteen Manus. The current Manu is said to be the seventh Manu. As such the Kali Yuga began in 3102 BC, at the end of the *Dvapara Yuga* that was marked by the disappearance of Vishnu's Krishna avatar. The beginning of the new Yuga (era) is known as "*Yugadi*/*Ugadi*", and is celebrated every year on the first day (*Paadyami*) of the first month (*Chaitramu*) of the 12-month annual cycle. The *Ugadi* of 1999 begins the year 1921 of the *Shalivahana* era (5101 *Kali Yuga*, 1999 AD). The end of the Kali Yuga is 426,899 years from 1921.

Overview of Yugas

1. *Satya Yuga* (*Krita Yuga*):- 1,728,000 Human years
2. *Treta Yuga*:- 1,296,000 Human years
3. *Dwapara Yuga*:- 864,000 Human years
4. *Kali Yuga*:- 432,000 Human years (5,111 years have passed; 426,889 years remain). *Kaliyuga* started in 3102 B.C.; CE 2009 corresponds to *Kaliyuga* year 5,111

The *Nasadiya Sukta* of the Rig Veda describes the origin of the universe. The Rig Veda's view of the cosmos also sees one true divine principle self-projecting as the divine word, *Vaak*, 'birthing' the cosmos that we know, from the monistic Hiranyagarbha or Golden Egg. The Hiranyagarbha is alternatively viewed as Brahma, the creator who was in turn created by God, or as God (Brahman) Himself. The Universe is preserved by Vishnu (The God of Preservation) and destroyed by Shiva (The God of Destruction). These three constitute the holy Trinity (*Trimurti*) of the Hindu religion. Once the Universe has been destroyed by Shiva, Brahma starts the creation once again. This creation-destruction cycle repeats itself almost endlessly as described in the section above on Brahma, Manu and the *Yugas* (HC 2011).

The Puranic View

The later Puranic view asserts that the Universe is created, destroyed, and re-created in an eternally repetitive series of cycles. In Hindu cosmology, a universe endures for about 4,320,000 years—one day/*Kalpa* of Brahma, the creator) and is then destroyed by fire or water elements. At this point, Brahma rests for one night, just as long as the day. This process, named *Pralaya* (Cataclysm), repeats for 100 Brahma years (311 trillion, 40 billion human years) that represents Brahma's lifespan. It must be noted that Brahma is the creator but not necessarily regarded as God in Hinduism because there are said to be many creations. Instead, he is regarded as a creation of the Supreme God or Brahman.

We are currently believed to be in the 51st year of the present Brahma's life and so about 158.7 trillion years have elapsed since the birth of Brahma. After Brahma's "death", it is necessary that another 100 Brahma years pass until he is reborn and the whole creation begins anew. This process is repeated again and again, forever (HC 2011 and Raman 2004).

Both the Rig Veda and Brahmanda Purana describe a universe that is cyclical or oscillating and infinite in time. The universe is described as a cosmic egg that cycles between expansion and total collapse. It expanded from a concentrated form — a point called a Bindu. The universe, as a living entity, is bound to the perpetual cycle of birth, death, and rebirth. The *Padma Purana* discusses about the number of different types of life-forms in the universe. According to the *Padma Purana*, there are 8,400,400 life-form species, 900,000 of which are aquatic ones; 2,000,000 are trees and plants; 1,100,000 are small living species, insects and reptiles; 1,000,000 are birds; 3,000,000 are beasts and 400,000 are human species (HC 2011).

Unlike the West, which lives in a historical world, India is rooted in a timeless universe of eternal return: everything which happens has already done so many times before, though in different guises. Hinduism arose from the discoveries of people who felt that they had gained an insight into the nature of reality through deep meditation and ascetic practices. Science uses a heuristic method that requires objective proof of mathematical theories. Yet both have proposed similar scenarios for the creation of the universe. (Hindu Cosmology 2006).

Check Your Progress I

Note: Use the space provided for your answers.

1) How is cosmology related to cosmogony and eschatology?

……
……
……

2) Give a brief account of the *Puranic* view of the universe.

……
……
……

3.4 GREEK BEGINNING

The Greek worldview gave us the basis for scientific cosmology. Closely tied to the pseudo-science of astrology, it continued from ancient Greece through medieval Islamic civilization to seventeenth-century Europe (CHP 2011).

Plato and Aristotle

Underlying the Greek worldview was the philosophy of Plato. He sought a deeper level of reality than that accessible to the senses. He also pursued a simple theory about the universe which had incredible explanatory power. The result was a belief in uniform, circular motion. This belief dominated the thinking of many Western astronomers and cosmologists for two thousand years.

The task for astronomers was to ascertain the motions of the planets. Sky-watchers in the ancient Middle East, Central America, and China made many observations. From their tables of numbers, they devised schemes to predict future movements in the heavens, unlike the colorful myths proposed by the Babylonians, Mayans, and early Chinese sky-watchers. It is no exaggeration to claim that scientific cosmology — the search for a picture of the universe that would make sense with no mention of divine beings — began with the Greeks. They sought to look beyond the patterns of numbers to something fundamental. Under Plato's influence, Greek thinkers attempted to devise combinations of uniform circular motions that would reproduce the observed motions, which were far from regular.

Greek philosopher-scientists set themselves the task of envisioning the universe as a set of physical objects. Plato's pupil Aristotle came to dominate thinking in this field. Where Platonists thought in terms of the idealized mathematics of two-dimensional circles, the Aristotelians envisioned actual three-dimensional spheres (CHP 2011)

Aristotle taught that rotating spheres carried the Moon, Sun, planets, and stars around a stationary Earth. The Earth was unique because of its central position and its material composition. All generation and corruption occurred in the "sublunar" region, below the Moon and above the Earth. This region was composed of the four elements: earth, water, air, and fire. Beyond the Moon was the unchanging and perfect celestial region. It was composed of a mysterious fifth element. Greek philosophers estimated the distance to the Moon, and even tried to calculate the size of the entire universe, which believed to be finite. The outer sphere of the stars carried them on their nightly course around the Earth. The natural place for earthy material was down at the center of the universe. Earthy material tended to move to its natural place, toward the center of the world. Flames moved upward to reach their natural place at the top of the sublunar region. There could be no other worlds scattered throughout this universe, because their earthy nature would have forced them to move toward their natural place at the center. With the Earth at its center and the sphere of the stars its outer boundary, the Aristotelian cosmos consisted of little more than our solar system.

Claudius Ptolemy

Continuation of the Greek tradition of Plato and Aristotle is exemplified in the work of Claudius Ptolemy. He systematized hundreds of years of Greek geometrical cosmology with rigorous demonstrations and proofs (CHP 2011). Ptolemy wrote his mathematical treatise, later named the Almagest, in about 150 A.D. He worked out geometrical systems of compound motions on two-dimensional circles to match the observed motions. The heavens were not made of rocks, metal, or other earthy material, but of some divine celestial material. This offered no obstruction to the passage of one part through another. In his later book, Planetary Hypotheses, Ptolemy used three-dimensional hollow spheres, arranged one within another and surrounding the Earth. There was no empty space between the spheres. The thickness of each shell accommodated small motions in and out from the Earth. The rotating sphere itself carried the planet or Sun or Moon in its orbit around the Earth. According to him, the spheres rotated because that was their natural motion. It was proper, Ptolemy believed, to attribute uniform circular motion to the planets because disorder and nonuniformity were alien to divine things. The study of astronomy, dealing with divine things, was especially useful for elevating the human soul.

3.5 THE ARAB CONTRIBUTION

As the Roman Empire fell and civilization in Europe collapsed, the rising Islamic civilization rescued Ptolemy's cosmology — and improved upon it. The entire system was transmitted back to the West as learning revived there toward the end of the Middle Ages. Translations reveal the transitions. Ptolemy's mathematical treatise came to be called "greatest." (CHP 2011) This was transliterated into Arabic and prefaced with the definite article *al* ("the," also seen in words like algebra and star names like Aldebaran). Translated from Arabic into medieval Latin, Ptolemy's book became "The Almagest." The Arabs also taught the West "Arabic" numerals, the place-value system of calculating using zero (which was invented in India), and many trigonometric techniques, all originally from India, and made important mathematical advances of their own.

Islamic civilization enjoyed a high level of scientific work. Astronomy was important for giving times of prayer (from the altitude of the Sun or stars), and the qibla, or sacred orientation: worshippers anywhere in the world needed to know the direction of Mecca so they could face it while praying, and mosques were oriented toward the holy city. The astrolabe was the fundamental astronomical instrument, serving as a clock and navigational tool. Islamic princes also constructed giant instruments to measure the positions of planets and stars for astrological purposes. Among the Arabs and Persians were great calculators and mathematicians who worked to improve the cosmological explanation of astronomical measurements. For example, Nasir al-din al-Tusi at Maragha produced a particularly innovative addition to Ptolemy's circular motions. The "Tusi couple" calculates a linear motion from a combination of uniform circular motions (CHP 2011).

In his revolutionary work on the solar system published in 1543, Copernicus used a strikingly similar device. Also, Copernicus used a model for the Moon's motion identical to one devised two centuries earlier by the astronomer Ibn al-Shatir in Damascus. Copernicus cited the works of Islamic astronomers and certainly learned from them. Historians are still trying to determine the full extent of his intellectual debt. More on the history of cosmology will be taken up in the next unit. Since this is an introduction, we want to focus on some important themes of contemporary scientific cosmology.

Check Your Progress II

Note: Use the space provided for your answers.

1) Where was the natural place for earthly material for Aristotle? Why?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………
2) Give a brief account of the Arab contribution to cosmology.
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

3.6 SOME IMPORTANT THEMES OF SCIENTIFIC COSMOLOGY

Cosmologists study the universe as a whole: its birth, growth, shape, size and eventual fate. Contemporary cosmology began last century. The vast scale of the universe became clear in the 1920s when Edwin Hubble proved that "spiral nebulae" are actually other galaxies like ours, millions to billions of light years away (Battersby 2006). We take up some important concepts and themes to initiate ourselves into contemporary cosmology.

The Big Bang

Hubble found that most galaxies are red shifted, i.e., the spectrum of their light is moved to longer, redder wavelengths. This can be explained as a doppler shift if the galaxies are moving away from us. Fainter, more distant galaxies have higher red shift, implying that they are receding faster, in a relationship set by the hubble constant. The discovery that the whole universe is expanding led to the big bang theory. This states that if everything is flying apart now, it was once presumably packed much closer together, in a hot dense state. A rival idea, the steady-state theory, holds that new matter is constantly being created to fill the gaps generated by expansion. But the big bang largely triumphed in 1965 when Arno Penzias and Robert Wilson discovered cosmic microwave background radiation (Battersby 2006). This is relic heat radiation emitted by hot matter in the very early universe, 380,000 years after the first instant of the big bang.

Space-time Curve

The growth of the universe can be modelled with Albert Einstein's general theory of relativity, which describes how matter and energy make space-time curve. We feel that curvature as the force of gravity. Assuming the cosmological principle (that on the largest scales the universe is uniform), general relativity produces fairly simple equations to describe how space curves and expands. According to these models, the shape of the universe could be like the surface of a sphere, or curved like the surface of a saddle. But in fact, observations suggest that it is poised between the two, almost exactly flat. One explanation is the theory of inflation. This states that during the first split second of existence, space expanded at terrifying speed, flattening out any original curvature. Then today's observable universe, grew from a microscopic patch of the original fireball. This would also explain the horizon problem - why it is that one side of the universe is almost the same density and temperature as the other (Battersby 2006).

The universe is not totally smooth, however, and in 1990 the COBE satellite detected ripples in the cosmic microwave background, the signature of primordial density fluctuations. These slight ripples in the early universe may have been generated by random quantum fluctuations in the energy field that drove inflation. Topological defects in space could also have caused the fluctuations, but they do not fit the pattern well. Those density fluctuations form the seeds of galaxies and galaxy clusters, which are scattered throughout the universe with a foamy large-scale structure on scales of up to about a billion light years. All these structures form because gravity amplifies the original fluctuations, pulling denser patches of matter together (Battersby 2006).

Dark Matter

In experimental simulations of big bang it is found visible matter does not supply enough gravity to create the structure we see: it has to be helped out by some form of dark matter. More evidence for the dark stuff comes from galaxies that are rotating too fast to hold together without extra gravitational glue. Dark matter can't be like ordinary matter, because it would have made too much deuterium in big-bang nucleosynthesis. When the universe was less than 3 minutes old, some protons and neutrons fused to make light elements, and cosmologists calculate that if there had been much more ordinary matter than we see, then the dense cauldron would have brewed up a lot more deuterium than is observed. Instead, dark matter must be something exotic, probably generated in the hot early moments of the big bang - maybe particles such as WIMPs (weakly interacting massive particles) or, less likely, primordial black holes.

Dark Energy

Another dark mystery emerged in the 1990s, when astronomers found that distant supernovae are surprisingly faint - suggesting that the expansion of the universe is not slowing down as everyone expected, but accelerating. The universe seems to be dominated by some repulsive force, or antigravity, which has been dubbed dark energy. It may be a cosmological constant (or vacuum energy) or a changing energy field such as quintessence. It could stem from the strange properties of neutrinos, or it could be another modification of gravity. The WMAP spacecraft put the standard picture of cosmology on a firm footing by precisely measuring the spectrum of fluctuations in the microwave background, which fits a universe 13.7 billion years old, containing 4% ordinary matter, 22% dark matter, and 74% dark energy. WMAP's picture also fits inflationary theory. However, a sterner test of inflation awaits the detection of cosmic gravitational waves, which the rapid motions of inflation ought to create, and which would leave subtle marks on the microwave background (Battersby 2006).

The density of dark energy is far smaller than the vacuum energy predicted by quantum theory. That is seen as an extreme example of cosmological fine tuning, in that a much larger value would have torn apart gathering gas clouds and prevented any stars from forming. That has led some cosmologists to adopt the anthropic principle - that the properties of our universe have to be suited for life, otherwise we would not be here to observe it.

3.7 SOME UNANSWERED QUESTIONS

In the current cosmology, the biggest questions are still unanswered. We do not know the true size of the universe, even whether it is infinite or not. Nor do we know its topology - whether space wraps around on itself. We do not know what caused inflation, or whether it has created a plethora of parallel universes far from our own, as many inflationary theories imply.

And it is not clear why the universe favours matter over antimatter. Early in the big bang, when particles were being created, there must have been a strong bias towards matter, which the standard model of particle physics cannot explain. Otherwise matter and antimatter would have annihilated each other and there would be almost nothing left but radiation. (Battersby 2006)

The fate of the universe depends on the unknown nature of dark energy and how it behaves in the future: galaxies might become isolated by acceleration, or all matter could be destroyed in a big rip, or the universe might collapse in a big crunch - perhaps re-expanding as a cyclic universe. The universe could even be swallowed by a giant wormhole. And the true beginning, if there was one, is still unknown, because at the initial singularity all known physical theories break down. To understand the origin of the universe we will probably need a theory of quantum gravity. (Battersby 2006)

3.8 LET US SUM UP

This unit was an introductory one on cosmology. Here we dealt with the religious cosmologies and some of the important notions of today's scientific cosmology.

Check Your Progress III

Note: Use the space provided for your answers.

1) What is dark energy?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

2) What are some of the unanswered questions still remaining in contemporary cosmology?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

3.9 KEY WORDS

Cosmological Constant: The cosmological constant is a constant term in field equations of general relativity, represented by the Greek symbol Lambda, which allowed for a static universe. Later evidence supported the fact that the universe was indeed expanding and the cosmological constant was believed to be zero. Evidence in the late 1990s has begun supporting the idea that the universe is not only expanding, but that the expansion rate is actually accelerating due to the presence of dark energy. This meant that the cosmological constant wasn't just zero, as Einstein thought, but had to have a very slight positive value. Einstein quickly accepted the new evidence and told physicist George Gamow that the cosmological constant idea was the "biggest blunder" of his life.

Cosmological Principle: The assumption that on a very large scale all the matter in the universe is distributed evenly, so that hypothetical astronomers a long way from the Earth would see the same universe, on the biggest scale, as we do. The problem with testing the cosmological principle is that it operates on a scale so vast that even galaxies and clusters of galaxies are merely local clumps of material by its standards.

Doppler Shift: change in the apparent frequency of a wave as observer and source move toward or away from each other. Also called Doppler effect, it was named after Austrian physicist Christian Doppler who proposed it in 1842 in Prague, is the change in frequency of a wave for an observer moving relative to the source of the wave.

Horizon Problem: The horizon problem is a problem with the standard cosmological model of the Big Bang which was identified in the 1970s. It points out that different regions of the universe have not "contacted" each other because of the great distances between them, but nevertheless they have the same temperature and other physical properties. This should not be possible, given that the exchange of information (or energy, heat, etc.) can only take place at the speed of light. The horizon problem may have been answered by inflationary theory, and is one of the reasons for that theory's formation. Another proposed, though less accepted, theory is that the speed of light has changed over time,

Hubble Constant: is the ratio of the speed of recession of a galaxy (due to the expansion of the universe) to its distance from the observer; the Hubble constant is not actually a constant, but is regarded as measuring the expansion rate today

Nucleosynthesis: The process by which heavier chemical elements are synthesized from hydrogen nuclei in the interiors of stars.

Spiral Nebulae: a galaxy having a spiral structure; arms containing younger stars spiral out from old stars at the center.

WIMP: A subatomic particle that has a large mass and interacts with other matter primarily through gravitation. [W(eakly) I(nteracting) M(assive) P(article).

WMAP: The Wilkinson Microwave Anisotropy Probe (WMAP) — also known as the Microwave Anisotropy Probe (MAP), and Explorer 80 — is a spacecraft which measures differences in the temperature of the Big Bang's remnant radiant heat — the Cosmic Microwave Background Radiation — across the full sky.

3.10 FURTHER READINGS AND REFERENCES

Battersby, Stephen (2006) “Introduction: Cosmology” New Scientist September 2006, *http://www.newscientist.com/article/dn9988-introduction-cosmology.html?full=true*

Bernstein, J. *An Introduction to Cosmology*. Englewood Cliffs: Prentice Hall, 1995.

Bhattacharjee, SS. *The Hindu Theory of Cosmology : An Introduction to the Hindu View of Man and His Universe*. Calcutta: Bani Prakashani, 1978.

Bondi, H. *Cosmology*. Mineola: Dover Publications, 2010.

Brun, RB. *Creation and Cosmology: Attempt at Sketching a Modern Christian Theology of Nature : A Collection of Essays Contributing to the Discussion between Christianity and Modern Science*. United States: Xlibris Corp., 2009.

Carmeli, M (2002) *Cosmological Special Relativity: The Large Scale Structure of Space, Time and Velocity*. N.J: World Scientific, 2002.

Carroll, BW, Ostlie. *An Introduction to Modern Galactic Astrophysics and Cosmology*. San Francisco: Pearson Addison Education, 2006.

Chow, TL. *Gravity, Black Holes, and the Very Early Universe: An Introduction to General Relativity and Cosmology*. New York: Springer, 2008.

CHP "Center for History of Physics" (2011) "The Greek Worldview" http://www.aip.org/history/cosmology/ideas/greekworldview.htm.

Cosmology (2011, May 5). In Wikipedia, The Free Encyclopedia. Retrieved 07:08, May 29, 2011, from http://en.wikipedia.org/w/index.php?title=Cosmology&oldid=427511242

Eberhardt, N (1998) *From the Big Bang to the Human Predicament : Outline of an Ultimate Evolutionary Synthesis*. Raleigh, N.C.: Pentland Press, 1998.

HC (Hindu cosmology). (2011, April 22). In Wikipedia, The Free Encyclopedia. Retrieved 07:16, May 29, 2011, from http://en.wikipedia.org/w/index.php?title=Hindu_cosmology&oldid=425293454

Hess, PMJ, Allen PL (2008) *Catholicism and Science*. Greenwood Press, Westport, Conn.

Hindu Cosmology (2006) "Hindu Cosmology," http://www.hinduwisdom.info/Hindu_Cosmology.htm

Jones, MH, Lambourne RJ, Adams DJ. *An Introduction to Galaxies and Cosmology*. New York: Cambridge University Press, 2004.

Miller, JB. *Cosmic Questions*. New York: New York Academy of Sciences, 2001.

Morison, I. *Introduction to Astronomy and Cosmology*. Chichester: Wiley, 2008.

Narlikar, JV. *An Introduction to Cosmology*. New York: Cambridge University Press, Cambridge, 2002.

Utukuru, Paul (2003)"Ancient Hindu Cosmology and Modern Cosmology." Available on-line from "Metanexus: The Online Forum on Religion and Science" at http://www.metanexus.net/metanexus_online/show_article.asp?8021. 13 March 2003.

Raman, Varadaraja V. (2004), "Indic Visions in an Age of Science, III: Theories of Mind & Consciousness," Available on-line from "Metanexus: The Online Forum on Religion and Science" at http://www.metanexus.net/metanexus_online/show_article.asp?9193. 8 December 2004.

Raman, Varadaraja V. "Indic Visions in an Age of Science, VI: Discussions and Debates on Indic Science," Available on-line from "Metanexus: The Online Forum on Religion and Science" at http://www.metanexus.net/metanexus_online/show_article.asp?9288. 5 May 2005.

UNIT 4 HISTORY OF COSMOLOGY

Contents

4.0 OBJECTIVES

- To give a historical basis for scientific cosmology.
- To know the key contributions of some of the famous cosmologists of the previous centuries.
- To appreciate the origin of scientific or physical cosmology, as distinct from religious one.

4.1 INTRODUCTION

In the previous unit, we have traced the history of pre-scientific cosmology and gone into some of the important themes of contemporary scientific cosmology. In this unit, we shall primarily focus on the history of scientific cosmology.

4.2 BEGINNING OF SCIENTIFIC COSMOLOGY

Revolutions in science, as in politics, often go beyond the limited changes that the people who started the revolution had in mind. Let us see some great minds who have contributed to the emergence and growth of scientific cosmology.

Nicholas Copernicus (1473-1543)

In 1543 Nicholas Copernicus proposed to switch the places of the Earth and the Sun. He put the Sun in the center of the universe and placed the Earth in revolution around the Sun. To account for the daily motion of the heavens, he set the Earth rotating about its own axis. (CHP 2011) To calculate the positions of planets, Copernicus used elaborate geometrical schemes, much like his Greek and Islamic predecessors (historians are still trying to decide just what sources contributed to his ideas). Ptolemy's system was reasonably satisfactory in matching the observations. Copernicus did not have new and more accurate observations demanding the overthrow of the old theory. It was a yearning for greater mathematical harmony that made him seek something different. In Copernicus's opinion, when Ptolemy had violated the principle of uniform circular motion. Furthermore, from Copernicus's "heliocentric" (sun-centered) theory, several observed phenomena followed automatically, rather than needing to be adjusted as they were in the Ptolemaic theory (Coles 2001).

A heliocentric system was counter to long-established belief and seemed unimaginable to many. This is why Copernicus wrote in the preface to his book that he had "hesitated long whether I should give to the light these my Commentaries written to prove the Earth's motion." His friends, though, had "often urged and even importuned me to publish this work." Copernicus hoped that "my labors contribute somewhat even to the Commonwealth of the Church... For not long since the question of correcting the ecclesiastical calendar was debated." It was true for centuries, the difficult question of calculating the dates of future Easters had been a main motive of astronomical observations and calculations. (CHP 2011)
Further, he admitted: "To ascribe movement to the Earth must indeed seem an absurd performance on my part to those who know that many centuries have consented to the establishment of the contrary judgment, namely that the Earth is placed immovably as the central point in the middle of the Universe." Yet this logical consequence of Copernicus's innovation was not immediately realized, by Copernicus or by others. It was finally recognized by Thomas Digges, an English Mathematician and astronomer, who translated and paraphrased the key parts of Copernicus's work, he said, "to the end such noble English minds might not be altogether defrauded of so noble a part of Philosophie."
Copernican revolution led to the conclusion that the Earth was no longer unique. It was merely one of many similar objects in the solar system. If the Earth were but one of many similar planets, other planets might also have similar inhabitants (Coles 2001). The principle of "plenitude," which interpreted any unrealized potential in nature as a restriction of the Creator's power, further encouraged belief in a plurality of worlds. This conclusion was most dramatically emphasized by Galileo and his new telescopic observations.

Galileo Galilei (1564-1642)

Galileo's father wanted him to study medicine, and he did so briefly at the University of Pisa. But Galileo preferred mathematics. He studied with private tutors in Pisa and then at home, in Florence. Soon he was giving private lessons in mathematics and was later appointed to the vacant mathematics chair at the University of Pisa. Here he is said to have dropped iron balls from the leaning tower, as a public challenge to Aristotelian philosophers, who said that heavier balls should fall faster. They don't. While Galileo probably never acted as this legend tells, it is true to his spirit — challenging authority, thinking clearly, and relying upon actual observation.

Aristotelian professors were certainly not friendly to Galileo, and he soon moved to the University of Padua. Galileo built a telescope and was the first to use this new instrument to systematically explore the heavens, making astonishing discoveries. For example, he discovered four satellites of Jupiter early in 1610. Later in 1610 Galileo returned to Florence as mathematician and philosopher to the grand duke and chief mathematician of the University of Pisa, without obligation to teach. Nothing was so disturbing to old ideas as what Galileo saw when he turned his telescope on the Moon. His observations of the Moon's surface inspired the revolutionary conclusion that the Moon was not a smooth sphere, as Aristotelians had maintained. He wrote: ""The surface of the Moon is not smooth, uniform, and precisely spherical as a great number of philosophers believe it to be, but is uneven, rough, and full of cavities and prominences, being not unlike the face of the Earth, relieved by chains of mountains and deep valleys." Aristotle's assumption that only matter below the sphere of the Moon was earthy and imperfect was proved to be wrong.

Another similarity, this one between Jupiter and the Earth, was furnished by Galileo's discovery of four satellites of Jupiter, similar to the Earth's single moon. How would they possibly fit into the system of spheres used by everyone since Plato? Galileo considered the "four planets never seen from the creation of the world up to our own time" to be his most important discovery.

In 1613, in a long unpublished letter, Galileo began arguing that Bible and Copernicanism were compatible. Aristotelians tried to bring the power of the Church against Galileo, pointing to Bible passages that clearly described the Earth as unmoving. Galileo argued that while the reconciliation of scientific facts with the Bible was a matter for theologians, they should not interfere with scientists studying nature. In 1616 the Church ordered Galileo not to hold or defend Copernicanism. In 1624, Pope Urban VIII, a friend of Galileo, gave him permission to discuss the Copernican system in a book if he gave the Ptolemaic system equal time. The Dialogue Concerning the Two Chief World Systems was published in Florence in 1632, after some changes required by the Pope. This is usually considered Galileo's masterpiece. Despite his claims to the contrary, the Dialogue represents Galileo's strongest endorsement of the Copernican system over its Ptolemaic counterpart, giving devastating refutations of many central tenets of Aristotelian physics.

There were complaints, and the Inquisition ordered Galileo to appear before it in Rome. He was forced, probably under threat of torture, to acknowledge that he had gone too far in his arguments for Copernicus, and to abjure the Copernican "heresy." His book was put on the Index of forbidden books, where it remained until 1835. In 1633, Galileo himself was sentenced to life in prison. The sentence was immediately commuted to permanent house arrest. He spent his remaining years in his villa in the hills above Florence, writing another masterpiece — not on cosmology but on physics and mechanics (CHP 2011). Till the end, he kept close contact with his friends in the Church.

Aristotelian cosmology envisioned spheres carrying the planets around the Earth—solid crystalline spheres, according to some, which provided the physical structure of the universe. Late in the 16th century, Tycho Brahe observed comets moving through the solar system. This fact shattered the crystalline spheres. Tycho was still conservative, however. He was reluctant to set the Earth in motion. As an alternative to the Copernican universe with all planets circling the sun in the center, Tycho had his own system of the world. In it other planets circled the Sun while the Sun circled a stationary Earth at the center.
From his observations of the 1572 nova and 1577 comet, Tycho was convinced of the falsity of the Ptolemaic system. In Tycho's system the Earth is absolutely fixed, so that the daily motion of the fixed stars is ascribed to a daily rotation of the outermost sphere, as in the Ptolemaic system. (A similar planetary system was proposed in antiquity by Heraklides of Pontus (ca. 388-310 BCE) who, however, ascribed to the Earth a daily axial rotation.)
From the standpoint of apparent planetary motions as seen from Earth, this system is observationally indistinguishable from the Copernican model, yet maintains the fixity of the Earth. The latter belief was held by Tycho to the end of his life. A main reason was that he had been unable to detect the annual parallax of the fixed stars predicted by the Copernican model, despite the unprecedented accuracy of the observations carried out with his giant instruments at Uraniborg. Tycho could measure parallax down to 2 minutes of arc (1/30 of a degree). The

failure to see parallax for fixed stars implied that they would have to be located hundreds of times farther away than Saturn, the outermost planet known at the time. (CHP 2011)

Johannes Kepler (1571-1630)

Born into an undistinguished and poverty-stricken family, Kepler attended the University of Tübingen (now in Germany) on scholarship, studying mathematics and astronomy. He went on to the theological school, intending to become a Lutheran minister. Soon he was asked to leave and teach mathematics at a school in Graz (now in Austria). It was here that he imagined his quixotic world model based on Platonic solids. The theory was wrong, but it made him famous. After Tycho Brahe moved from Denmark to Prague, Kepler visited him there. Kepler recognized the value of Tycho's voluminous observations, more accurate than any previous. He inherited both Tycho's data and the favor of the Emperor following Tycho's death in 1601. Studying the data, Kepler found what later became famous as his three laws, along with many other supposed regularities, some correct and others now forgotten (Levy 2000).

Kepler believed that God the Creator had created an orderly and harmonious world. Kepler was committed to Copernicus's heliocentric system both for its technical advantages, which made it possible to dispense with some of the complications of Ptolemy's system, and on philosophical grounds, including a symbolic identification of the Sun with God at the center of all things. Kepler's colorful life was marred in the end by, among other things, his mother's trial for witchcraft, and a periodically nomadic and economically uncertain existence under the stress of wars and political upheavals. (CHP 2011)

Belief in uniform circular motion had been a fundamental aspect of Western astronomy for two millennia. This belief was broken early in the 17th century. Kepler, using Tycho's observational data, showed that the Earth and the other planets all travel around the Sun in elliptical orbits. This was the first of Kepler's three laws. It was published in 1609 in Kepler's book on his new astronomy, Astronomia nova. The laws Kepler found for the motions of the planets applied equally to the orbit of the Earth. He had abandoned the ancient distinction between the physics of our earthy sphere below the Moon and the celestial physics of a higher realm (Levy 2000 CHP 2011).

Aristotelian physics no longer worked in the universe of Copernicus and Kepler. A new explanation of how the planets continued to retrace the same paths forever around the Sun remained a central problem of cosmology until Isaac Newton explained how objects move under gravity. He accomplished this by showing how motions in the heavens obey the same laws that determine the movement of bodies on Earth. This led the way to understanding what was increasingly seen as a mechanical universe.

Check Your Progress I

Note: Use the space provided for your answers.

1) What was Galileo's opinion on Bible and science?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………

2) Briefly mention the contribution of Kepler to cosmology?
……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………

4.3 THE MECHANICAL UNIVERSE

The mechanical universe was initiated by Newton and taken up by other scientists.

Isaac Newton (1642-1727)

Since his father died before his birth and his mother remarried within 3 years, Newton was left in the care of a grandmother. Difficult early years may have contributed to his difficult personality as an adult. He graduated from Trinity College, Cambridge, and served there as Lucasian Professor. Later Newton was warden of the mint in London and president of the Royal Society. Newton's remarkable intellectual accomplishments include creation of the calculus, invention of the reflecting telescope, development of the corpuscular theory of light, and development of the principles of gravity and terrestrial and celestial motion. A "Newtonian" worldview came to permeate understanding not only of the physical world, but also of such intellectual fields as politics and economics—in which people sought simple and universal laws of the type demonstrated by Newton in physics and astronomy. (CHP 2011)

The omnipresence of God pervaded the Newtonian cosmos. The divine presence operated as an immaterial "*aether*" that offered no resistance to bodies, but could move them through the force of gravitation. Newtonian gravitational theory practically demanded a continual miracle to prevent the Sun and the fixed stars from being pulled together. Newton envisioned an infinitely large universe, in which God had placed the stars at just the right distances so their attractions cancelled, as precisely as balancing needles on their points. Another possible solution was to place the fixed stars at such vast distances from one another that they could not attract each other perceptibly in the few thousand years since the Creation.

The ancient assumption that the stars were fixed in position was not seriously questioned until 1718, when the English astronomer Edmond Halley reported a remarkable discovery. Three bright stars were no longer in the positions determined by ancient observations. The stars were freed to move like normal physical objects. (CHP 2011) Newton treated the motions of the stars and planets as problems in mechanics, governed by the same laws that govern motions on Earth. He described the force of gravity mathematically.

Descartes, Laplace and other Critics

The French philosopher René Descartes, on the other hand, had proposed a non-mathematical model. He suggested that the universe consists of huge whirlpools ("vortices") of cosmic matter. Our solar system would be only one of many such whirlpools. Descartes banned from scientific investigation "occult" phenomena, or causes hidden from the senses. He had celestial matter circulating about the Earth, pushing all terrestrial matter toward the Earth. Descartes' followers distrusted Newton's alternative, a mysterious gravitational force acting at a distance.

Descartes' mechanical, mechanistic cosmology was highly acceptable within the general seventeenth-century conception of the world as a machine. His explanations, though, were but qualitative re-descriptions of phenomena in mechanistic terms. During the course of the eighteenth century, vortex theory proved unable to calculate the observed planetary motions. Meanwhile, the rival Newtonian theory advanced from one precise quantitative success to another (Hollar 2011).

The solar system contains many bodies, and the calculation of the orbit of any planet or satellite is not simply a matter of its gravitational attraction to the body around which it orbits. In addition, other bodies have smaller, but not negligible, effects (called "perturbations"). For example, the Sun alters the Moon's motion around the Earth, and Jupiter and Saturn modify the motions of each other about the Sun. A Swiss mathematician, Leonhard Euler, helped develop the mathematical techniques needed to compute perturbation effects. First he applied them to the Moon, and then, in 1748, to Jupiter and Saturn, with partial success (CHP 2011 and Hollar 2011).

Still unexplained were large anomalies in the motions of Jupiter and Saturn, and an acceleration of the Moon's orbital speed around the Earth. The French mathematical astronomer Pierre-Simon Laplace resolved these in 1785 and 1787. In his book Mécanique Céleste, published in five volumes between 1799 and 1805, Laplace summarized his studies of celestial mechanics. Here he proposed that all physical phenomena in the universe could be reduced to a system of particles, exerting attractive and repulsive forces on one another.

Laplace's writings were not just for scientists. His 1796 book Exposition du Système du Monde summarized for lay people the general state of knowledge about astronomy and cosmology at the close of the 18th century. In the book, Laplace advanced an idea that became known as the "nebular hypothesis." He suggested that our solar system, and indeed all stars, were created from the cooling and condensation of a massive hot rotating "nebula" (a gassy cloud of particles). The nebular hypothesis strongly influenced scientists in the 19th century, as they sought to confirm or challenge it. Elements of the idea remain central to our current understanding of how the solar system was formed. (CHP 2011)

Writers of the Romantic period in the early 19th century— for example William Wordsworth in England and Friedrich Schelling in Germany — reacted against Newtonian cosmology. Convinced that the cosmic order was beyond scientific explanation, they sought to breathe divine life back into what seemed an overly mechanized and increasingly godless universe.

The German philosopher Immanuel Kant argued against the Romantics, insisting that metaphysics could not provide an account of the foundations of physical, corporeal nature, and that the issue of the existence of God was completely divorced from direct sense experience. For him, the Newtonian solar system provided a model for the larger stellar system. Kant reasoned that the same cause which gave the planets their centrifugal force, keeping them in orbits around the Sun, could also have given the stars the power of revolving. And whatever made all the planets orbit in roughly the same plane could have done the same to the stars. Nebulous-appearing objects in the heavens became, in Kant's mind, island universes, like colossal solar systems.

Kant's thoughts about the universe had little observational content. The foundations of his cosmological hypotheses were philosophical and theological. Observation first entered cosmology in a major way late in the 18th century, thanks to an English amateur astronomer, William Herschel (Dougherty 1953).

William Herschel and the Construction of the Heavens

The Newtonian solar system offered a model for the larger stellar system. The arrangement of the stars might well be similar to that of the planets. Furthermore, the Newtonian system provided by analogy a physical explanation for a disk structure. The same cause which gave the planets their motion and directed their orbits into a plane could also have given the power of revolving to the stars and brought their orbits into a plane (CHP 2011).

In the late 18th century, observation at last entered stellar cosmology in a major way, in the person of the English amateur astronomer William Herschel. His discoveries were made possible by large telescopes of his own construction. From his observations, William Herschel reported in 1784: "A very remarkable circumstance attending the nebulae and clusters of stars is that they are arranged into strata, which seem to run to a great length; and some of them I have already been able to pursue, so as to guess pretty well at their form and direction. It is probably enough, that they may surround the whole apparent sphere of the heavens, not unlike the milky way, which undoubtedly is nothing but a stratum of fixed stars" (CHP 2011).

Herschel's telescopes, culminating in 1789 with an awkward monster forty feet tall, were one of the wonders of the world. These powerful telescopes not only revealed more moons about planets and resolved some fuzzy-appearing nebulae into clusters of stars, but also enabled Herschel to reach farther into space than anyone had done before, and to begin to outline the structure of our galaxy. Herschel observed stars seemingly lying between two parallel planes and running on to great distances. He concluded that the Milky Way (a luminous band of light circling the heavens) is the appearance of the projection of the stars in the stratum (CHP 2011 and Coles 2001).

In his 1785 paper "On the Construction of the Heavens," Herschel wrote that our Milky Way is a very extensive, branching, compound Congeries of many millions of stars. Herschel's drawing shows a cross section through the Milky Way, our galaxy, as determined from his observations. In the course of time, remarkable new observational techniques, photography and spectroscopy, did address cosmological questions, but indecisively. In 1835, the prominent French philosopher Auguste Comte, remarked that humans would never be able to understand the chemical composition of stars. He was soon proved wrong, because spectroscopy and photography helped bring about a revolution in people's understanding of the cosmos. For the first time, scientists could investigate what the universe was made of. This was a major turning point in the development of cosmology, as astronomers were able to record and document not only where the stars were but what they were as well. Amateur astronomers — the professionals by definition were already engaged in well-defined research projects such as mapping stars — made photographs that showed some nebulae were made up of many stars. But other nebulae remained obdurately nebulous. And nobody was able to decisively show changes in nebulae over time. (CHP 2011)

Spectroscopy held out a promise of differentiating between nebulae made of many stars and those made of glowing gases, and also of determining if nebulae were rotating . But here also the conclusions were questionable. As, indeed, was cosmology itself as a scientific endeavor. Advances in cosmology during the nineteenth century were considerable, but only in the twentieth century would cosmology be transformed from speculation, based on a minimum of observational evidence and a maximum of philosophical predilection, into a respectable observational science.

Approaching the beginning of the 20th century, the worldview pioneered by Herschel was vastly different from that of Aristotle or even Copernicus. No longer were human beings necessarily at or very near the center of the universe (Coles 2001). The Milky Way was now understood to be an optical effect, with our solar system immersed in a much larger stratum of stars, a roughly disk-shaped stellar system. Possibly other island universes were scattered throughout a possibly infinite space.

Changing cosmological understanding is manifested in changing social views. Now that we Earthlings were but one of possibly many intelligent inhabitants of a possibly infinite universe, there was less reason to believe that we had been created in the best of all possible worlds, and perhaps more sympathy for discontent with the established social hierarchy.

Check Your Progress II

Note: Use the space provided for your answers.

1) How did Kant's contribution differ from other scientists?

……
……
……

2) Briefly mention the contribution of William Herschel?

……
……
……

4.4 FROM OUR GALAXY TO ISLAND UNIVERSES AND MORE

At the beginning of the 20th century, astronomers were unsure of the size of our galaxy. Generally, they believed it was not much greater than a few tens of thousands of light years across, and perhaps considerably less. (A light year, nearly six trillion miles, is the distance traveled in a year moving at the speed of light in a vacuum.) Also, observations early in the 20th century made it seem that our solar system was near the center of the galaxy. (CHP 2011). Therefore the English astronomer Arthur Eddington said in 1914: "It is believed that the great mass of the stars … are arranged in the form of a lens- or bun-shaped system … considerably flattened towards one plane … the Sun occupies a fairly central position."

Shapley's New Model of the Universe

This vision of the universe was soon replaced with a revolutionary new conception, based largely on the observations of the American astronomer Harlow Shapley at the Mount Wilson Observatory. The astronomer and scientific entrepreneur George Ellery Hale had founded the observatory on a mountain peak overlooking Los Angeles in 1904, and four years later master instrument-builder George Ritchey completed a 60-inch reflecting telescope designed specifically for astronomical photography.

The first hint of a drastically revised understanding of our galaxy came in 1916. Studying a "globular cluster,"—a group of hundreds of thousands of stars—Shapley noticed faint blue stars. If they were similar to bright blue stars near the Sun, they must be about 50,000 light years away to explain why they looked so faint. He pushed ahead to establish distances more conclusively using a new and ingenious method of measuring the universe (CHP 2011 and Coles 2001)

Shapley built a new understanding of the universe by measuring distances to stars based on properties of a type of variable stars called "Cepheids" (named after the constellation Cepheus, in which a typical such star was first noticed). They are giant stars, and thus visible to great distances. Each Cepheid varies in brightness over time. In 1908 the American astronomer Henrietta Leavitt had pointed to a remarkable rule that Cepheids obey. During routine comparisons of photographs she discovered variable stars, brighter on some photographs and fainter on other photographs taken at different times. Leavitt noticed that the brighter the variable star, the longer its period.

Shapley used the period-luminosity relation to estimate distances. First, he collected all the available data on Cepheid stars, from his own observations and from other astronomers including Leavitt. The distance to some of the nearer Cepheids had been measured, and thus Shapley could figure out their absolute magnitudes. The only physics he needed was the simple rule that brightness decreases with the square of the distance. Then Shapley graphed period versus absolute magnitude (CHP 2011 and Coles 2001).

Shapley made the reasonable assumption that Cepheids in distant globular clusters obey the same physics as nearby Cepheids. He observed the periods of distant Cepheids, read off their presumed absolute magnitudes from his graph of period versus luminosity, and compared that absolute magnitude with the observed apparent magnitude. This produced distances to many far-away Cepheids—and to the globular clusters in which they resided. (Some globular clusters did not have Cepheids he could measure, and he used other, cruder methods to estimate their distances.)

Shapley found that the globular clusters are arranged symmetrically around the galaxy, about as many above the plane of the galaxy as below. The clusters seemed to avoid the plane itself, the Milky Way. Shapley wrote that "this great mid-galactic region, which is peculiarly rich in all types of stars, planetary nebulae, and open clusters, is unquestionably a region unoccupied by globular clusters." Shapley acknowledged that there was an alternative explanation. Maybe globular clusters were not, as he believed, actually missing from the region, but instead were hidden by clouds of absorbing matter along the spine of the Milky Way (CHP 2011).

The dwindling significance of humans and their particular planet had dwindled further still. Shapley noted a historical progression from belief in a small universe, with humankind at its center, to a larger universe with the Earth further from the center. The geometry had been transformed from geocentric to heliocentric to a-centric. The psychological change was no less, he insisted, from homocentric to a-centric. Some astronomers had long doubted that the solar system was near the center of the galaxy and that people enjoyed a privileged place in the universe. They felt that the odds, given a random distribution, were small. Now Shapley gave this philosophical position scientific basis.

Hubble's Important Discoveries

Shapley's galaxy was far larger than any previous estimate (aside from earlier guesses of an infinite stratum of stars). It might indeed be the entire universe. For Shapley had showed that globular clusters were clearly part of the galaxy, not independent island universes. Other nebulae (concentrations of stars and dust), especially spiral-shaped ones, might still lie outside our galaxy. But if they were similar in size to our now enormous galaxy, they seemed implausibly large. Separate island universes were not impossible, but they seemed less likely now that Shapley had multiplied the size of our galaxy many fold. (CHP 2011)

Shapley defended his conclusions in the so-called "Great Debate" before the National Academy of Sciences on 26 April 1920. His major concern was the size of the galaxy. His model of a drastically larger galaxy, with the solar system far from its center, was largely correct. But he was on less solid ground when he argued that the spiral nebulae, which seemed to be much smaller, were part of our galaxy. His opponent, Heber Curtis, argued that the galaxy could be as large as Shapley said, yet still be only one of many island universes, if it happened by chance to be several times larger than the average. Ultimately observations would prove Curtis correct, but in 1920 Shapley had the stronger position (CHP 2011 and Coles 2001).

The centuries-old debate was resolved only by new scientific evidence, produced using larger telescopes and new observational techniques, including photography and spectroscopy. The key proponent of island universes was Edwin Hubble (1889-1953), who like Shapley did his revolutionary work at the Mount Wilson Observatory. Writing in his doctoral thesis in 1917, Hubble noted that catalogs already included some 17,000 small, faint nebulous objects that could ultimately be resolved into groupings of stars. Perhaps 150,000 were within the reach of existing telescopes. Yet, he wrote, "Extremely little is known of the nature of nebulae, and no significant classification has yet been suggested; not even a precise definition has been formulated." The way Hubble discovered to classify nebulae is described here.

After serving in World War I, Hubble joined the Mount Wilson Observatory staff. There he took photographs of nebulae with the new 100-inch reflector, the most powerful telescope in the world. Hubble discovered variable stars in an irregular nebula. By now Shapley had left Mount Wilson for the Harvard College Observatory. Hubble wrote to Shapley in 1923 to tell him of the discovery. Hubble also said he was going to hunt for more variable stars and to investigate their periods. Shapley wrote back, "What a powerful instrument the 100-inch is in bringing out those desperately faint nebulae." (CHP 2011)

Early in 1924 Hubble wrote to Shapley again. This time Hubble reported, "You will be interested to hear that I have found a Cepheid variable [star] in the Andromeda Nebula [M31]. I have followed the nebula this season as closely as the weather permitted and in the last five months have netted nine novae and two variables." When he found a Cepheid variable, Hubble realized he held the key to distance. As Shapley had used the period-luminosity relation for Cepheids to find distances to globular clusters in our galaxy, so Hubble could find the distance to the spiral nebula M31. Hubble found that "the distance [to M31] comes out something over 300,000 parsecs." This was roughly a million light years, and several times more distant than Shapley's estimate of the outer limits of our own galaxy. Hubble continued: "I have a feeling that more [Cepheid] variables will be found by careful examination of long exposures" (CHP 2011).

On reading Hubble's letter, Shapley remarked to a colleague who happened to be in his office, "Here is the letter that has destroyed my universe" (CHP 2011). Shapley admitted that the large number of photographic plates that Hubble had obtained were enough to prove that the stars were genuine variables. By August, Hubble had still more variables to report. Shapley was glad to see this definite solution to the nebula problem, even if it refuted earlier evidence against spiral nebulae as island universes. Hubble's discovery of Cepheid variable stars in spiral nebulae, and the distance determination confirming that spiral nebulae are independent galaxies, were officially announced on New Year's Day, 1925, at a meeting of the American Astronomical Society. He followed this preliminary paper by further work over the next four years, with convincingly voluminous detail. A good part of Hubble's genius, and much of the acceptance that his revolutionary conclusions commanded, were due to lots of hard work.

Before the 1920s ended, astronomers understood that the spiral nebulae lie outside our own galaxy. In the previous decade Shapley had multiplied the size of the universe by about ten times. Hubble multiplied it by another ten - if not more. Hubble's universe was no longer the one all-comprehending galaxy envisioned by Shapley. Henceforth the universe was understood to be composed of innumerable galaxies spread out in space, farther than the largest telescope could see. Hubble next would show that the universe is not static, as nearly everyone then believed, but is expanding. What he had made infinite in space, he would make finite in time (CHP 2011). That was the cosmology till the beginning of 20th century. The story of the contemporary cosmology will be taken up in the following units.

Check Your Progress III

Note: Use the space provided for your answers.

1) What is an island universe?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

2) What are were some of the important discoveries of Shapley?

……………………………………………………………………………………………………
……………………………………………………………………………………………………
……………………………………………………………………………………………………

4.5 LET US SUM UP

In this unit we traced the origin and development of scientific cosmology till the beginning of 20th century. This is to give a bird's eye-view of the cosmological journey and is a preparation for the coming units.

4.6 KEY WORDS

Aether: According to ancient and medieval science aether also spelled æther or ether, is the material that fills the region of the universe above the terrestrial sphere. Modern science has given up this notion.

Cepheid variable: Any of a class of pulsating, yellow, supergiant stars whose brightness varies in regular periods: from the period-luminosity relation, the distance of such a star can be determined

Island universe: Obsolete term used for the galaxies when it was first realised that they exist separately from our own galaxy and at great distances from each other. Now we do not hold on to this theory any more.

4.7 FURTHER READINGS AND REFERENCES

CHP (Center for History of Physics) 2011 "The Start of Scientific Cosmology" http://www.aip.org/history/cosmology/ideas/start-of-scientific-cosmology.htm

Coles, P. *Cosmology : A Very Short Introduction*. Oxford: Oxford University Press, 2001.

Domínguez-Tenreiro, R, Quirós M. *An Introduction to Cosmology and Particle Physics*. Singapore: World Scientific, 1988.

Dougherty, KF. *Cosmology, an Introduction to the Thomistic Philosophy of Nature*. Peekskill, N.Y Graymoor Press, 1953.

Heller, M, Woodin WH. *Infinity: New Research Frontiers*. Cambridge: Cambridge University Press, 2011.

Hollar, S. *Astronomy: Understanding the Universe*. New York: Britannica Educational Pub. in association with Rosen Educational Services, 2011.

Levy, DH. *The Scientific American Book of the Cosmos*. New York: St. Martin's Press, 2000.

Martinez, VJ, Trimble V, Pons-Bordería M-J. *Historical Development of Modern Cosmology : Proceedings of an International Summer School Held at Universidad Internacional Menéndez Pelayo, València, Spain, 18-22 September 2000*. San Francisco: Astronomical Society of the Pacific, 2001.

Nozawa, H. *Cosmology, Epistemology, and the History of Geography*. Institute of Geography, Faculty of Letters, Kyushu University, 1986.

Yourgrau, W, Breck Ad, Alfvén H, University of Denver. *Cosmology, History, and Theology*. New York: Plenum Press, 1977.