

Lecture I

PHILOSOPHY OF SCIENCE

Introduction

In the following lectures, I wish to discuss in a mainly non-mathematical way, the concepts of modern physics. The word “concepts” refers to the *ideas* that underlie modern physics.

It is true that for the training of professional physicists, to make progress in the exploration of the truths of nature one must learn the mathematical language to facilitate an expression of the laws of nature. Plato advised that: for the students to become educated, they must first master the field of mathematics. Once this is done, he continued, they are ready to study the field of physics. After this, they are finally ready to study philosophy.

It is interesting that about 15 centuries after Plato, in the Middle Ages, the Jewish philosopher/theologian, Rambam (known in the western world as Maimonides) added to Plato’s advice. He wrote a book aimed at the ‘true’ student, called The Guide for the Perplexed (University of Chicago, 1963, transl. S. Pines). In this treatise he advised the student that after following Plato’s advice, in mastering mathematics, physics and philosophy, he was ready to study the spiritual side of the real world — to attempt to understand the Biblical Scriptures in terms of first principles.

I do not generally agree that an education necessitates Plato’s first requirement — a broad knowledge of how to facilitate and to

understand the intricacies of mathematics. Galileo correctly commented that *the book of nature is written in the language of mathematics*. However, according to Plato's own teaching, a language, *per se*, is not the set of concepts that it is meant to express. In this course, we will stress the concepts of physics rather than its mathematical language.

The adjective, "modern," in the title of this course, refers to 20th century physics, from the concepts that underlie elementary particle physics — the physics of the smallest domain — to those of cosmology — the physics of the universe as a whole.

It is significant that the 20th century has witnessed the confluence of two scientific revolutions, rather than one at a time. These are the theory of relativity, led primarily by Albert Einstein, and the quantum theory, led primarily by Niels Bohr. What was fascinating about two rather than one revolution in science was that, on the one hand, each of these theories is incompatible with the other, both mathematically and conceptually, on foundational terms. But on the other hand, each of these theories requires the other for its completion. This is the major problem of modern physics that will be emphasized throughout this course of lectures.¹

Because of their conceptual and mathematical incompatibility, it follows that if one of these two dichotomous theories of matter is true, the other must be false, as foundational truths of nature, even though each has been empirically successful in its own domain of nature. A way out of this dilemma would be to fully reject the underlying concepts of one of these theories while generalizing the other theory so as to recover the empirically successful features of the rejected theory, *as a mathematical approximation*. [This relies on the well-known *principle of correspondence* to tell us how to approach the formal expression of an earlier rejected theory — where it works! — from a later accepted theory in science.] I will argue, toward the end of the course, that, in my judgment, it is the theory of general relativity that will survive to *explain* the basic nature of matter in all domains — from elementary particle physics to cosmology. But the main thrust of the course will be to *explain* the basic concepts of both the quantum and relativity theories. The

readers may then make up their own minds as to which of these theories is more true to nature than the other, in all domains.

At this juncture, I wish to qualify my earlier use of the term “scientific revolution.” I do not believe that the history of science is indeed characterized by ‘revolutions’ — a total rejection of earlier concepts and replacing them with entirely new concepts to explain natural phenomena.² I do believe, based on my study of the history of science, that science progresses in an ‘evolutionary’ manner. Here, there are ‘threads of truth’ that persist from one period of ‘normal science’ to another. Indeed, it is the persistence of these threads of truth that gives us confidence that some of the past ideas play an important role in the shaping of present day ideas as well as the future of science.

It is for this reason that I will begin this course (in Lecture II) with ideas from the past that serve as important precursors for present day ideas and the physics of the future. But before we start it is important to discuss some of the ideas of the philosophy of science.

Philosophy of Science

The first question we must answer is: What is the meaning of “physics”? The word was introduced by Aristotle in ancient Greece. It signifies the ‘science of inanimate matter.’³ Of course, there are other sciences — *psychology* is the science of human consciousness, *anthropology* is the science of human cultural systems, *biology* is the science of life systems, etc. But it is thought that physics is the queen of the sciences because it is framed in foundational terms, starting with first principles, while the other sciences, at this stage of our understanding, are more phenomenological — more descriptive than explanatory. Hopefully, some of these latter sciences will proceed to foundational levels at a later stage.

Then what is the meaning of the word “science”? It is the pursuit toward the fundamental *truths* of the natural world. These are expressed in terms of the *laws of nature*. That is to say, the fundamental goals of science are the ‘truths’ of the natural world. These truths, in turn, are at the *explanatory level* of our understanding.

They follow from the *descriptive level* of scientific knowledge. Though some scientists believe that the descriptive level of science is all that there is to know, that is, they believe that scientists should only ask ‘what’ questions, I believe that the explanatory level that follows the descriptive level is the actual goal of science — the answers to the ‘why’ questions. It is the approach that provides the *understanding* of the natural world that we seek. The former philosophical (epistemological) view is that of *positivism* while the latter view is that of *realism*. The latter view was that of Einstein, when he said: “the most incomprehensible thing to me is that we can comprehend anything at all about the real world.”⁴

Truth

Our primary goal in science, then, is to acquire the truth about the natural world. It is important to be cognizant, in this regard, that there are different kinds of truth, defined in different contexts.

As I see it, there are three types of truth that we signify in science. The first is ‘analytic truth.’ This is an irrefutable type of truth — it is a *necessary truth*. All mathematical truths are of this sort. For example, the statement $2 + 3 = 5$, is a necessary truth. Defining the integers 2 and 3 as intervals along a linear scale, and the logical definitions of + and =, the conclusion 5 is a necessary, irrefutable truth. It is not tied to nature — it comes from the thinking of the human mind that leads to the invention of the rules of a logical system.

The second type of truth is *scientific truth*. It is, in principle, a *refutable truth* — it is ‘contingent.’ The conclusion of a scientific truth starts with a *guess* about a law of nature to underlie some physical phenomenon. One arrives at this law from hints received from our perceptions of the phenomenon itself as well as from our intuition. The alleged law of nature then leads, by logical deduction, to particulars that are the predictions of empirical facts of nature. If these predictions agree with the empirical facts, then we may say that the original law that led to these results is *scientifically true*. But this is not a necessary truth. It is only as true as the premises that led to the alleged law of nature. Such a law may be

confirmed in terms of different empirical facts predicted by this law for a very long time, perhaps centuries, but it may then be refuted by new empirical evidence that is not predicted by this law of nature, or a demonstration of logical inconsistency in its expression. An example is Newton's second law of motion, $F = ma$. It was empirically verified from the 17th century until the 20th century. Then, Einstein's relativistic mechanics refuted and replaced it. Einstein had then refuted Newton's alleged law of motion. It is important, then, that a scientific truth, tied to nature, is in principle refutable, while an analytic truth, tied to logic, is in principle not refutable. Thus, they are in different contexts. One may then not answer a scientific question with an analytic argument, or answer an analytic question with a scientific argument — they would be non-sequiturs. For example, Pythagoras, in ancient Greece, claimed to come to scientific conclusions about the structure of the universe from mathematical (analytic) arguments.⁵ This is a false claim, as it is a non-sequitur.

A third type of truth is a *religious truth*. It is a truth that is based on faith. This truth is irrefutable as is an analytic truth, but it is not subject to the rules of an invented logical system, as is mathematics. A belief in God is an example of a religious truth. Another example is the scientists' belief that for every effect in the world, there is an underlying cause. (*This is a law of total causation.*) Indeed, it is the *raison d'être* of the scientist to pursue the cause-effect relation that is a law of nature. The pursuit is based on his or her *faith* in the law of total causation. Because this type of truth is in a different context than the analytic or scientific truths, one cannot prove a scientific statement (or an analytic statement) with a religious argument. It would be a non-sequitur. Because scientific truth is in a different context than religious truth, a scientist may have faith in the existence of God (or not have such faith) without giving up his or her integrity as a scientist!

An example that demonstrates this fallacy is in the subject of cosmology (as we will discuss more fully in Lecture IX). It was discovered in the 1920s by E. Hubble, that the galaxies of the universe are moving away from each other at a particular rate, in accordance

with the ‘Hubble law,’ $v = Hr$, where v is the speed of one galaxy relative to another and r is their mutual separation.⁶ Thus, as r increases, v increases linearly — i.e. the galaxies are accelerating relative to each other’s positions, linearly. That is, if, for example, the distance between galaxies doubles, so would their relative speed of separation double. This is called the “expansion of the universe.” [*What is meant by this expansion is not that the universe as a whole is expanding into empty space — because there is no empty space! The universe, by definition, is all that there is! What is meant by the expansion of the universe is that the density of the matter of the universe, at any location within the universe, relative to any observer, is decreasing with respect to any observer’s time measure.*]

Thus if we extrapolate backwards in time, we come to greater and greater densities of the matter of the universe. In the limit, we come to a maximum density and a maximum instability. At that point in time, there is predicted to be a gigantic explosion — the ‘big bang’ — when all of the matter of the universe starts its expansion phase. From the present day astrophysical measurement of the expansion, the Hubble constant H may be determined and the time when the ‘big bang’ happened may be estimated. It is found to be between 12 and 15 billion years ago.

The *scientific question* then arises: How did all of the matter of the universe get into the state of maximum density and instability in the first place? Some (including a number of astrophysicists and physicists) have answered: The ‘big bang’ occurred when God created the universe! But this *religious answer* to a scientific question is a non-sequitur! Indeed, a bona fide scientific question requires a bona fide scientific answer!

The only answer that I see is that before the matter of the universe reached the critical state of maximum density and instability, it was contracting (imploding) from a less dense state toward this more dense state. And before the contraction, the matter of the universe was expanding, and so on *ad infinitum*. This is the *oscillating universe cosmology*. We will discuss it in more detail toward the end of this course of lectures. Suffice it to say at this point that the theory of general relativity allows for this resolution because the parts

of this theory that relate to the force of matter on matter (the affine connection terms) are not ‘positive-definite.’ This implies that gravitational forces entail both attractive and repulsive forces. Under the conditions of sufficiently high density of matter and relative speeds, the repulsive force dominates. This leads to the expanding universe — that matter repels other matter. But when the matter becomes sufficiently rarefied, the attractive force dominates the repulsive force and the expansion changes to a contraction.

This view then predicts, from General Relativity, that the universe is a closed system, undergoing a continual cyclic process of expansion and contraction. The ‘big bang’ we talk about, then, about 12 to 15 billion years ago, is only the beginning of this particular cycle. One might then ask: when was the *actual* ‘beginning’ of the universe — the ‘beginning’ of all of the cycles? (This is the ‘beraisheet’ — the opening word of the Bible.) This is not a scientific question! It is a religious question. It is not definable in terms of our concept of ‘time.’ The idea of ‘timelessness’ is reflected in one of the Kabbalistic names for God — ‘*haya-hoveh-yeeheeyeh* (*was-is-will be*).

We see here how important it is to clearly distinguish between scientific truth and religious truth. It is only the former that we focus on in this course of lectures. [*It is the recognition of this difference between scientific truth and religious truth that led the courts in the US to the ruling that the religious assertion, called “intelligent design,” may not be taught in the schools as though it were a scientific explanation for the creation of the universe — that it would be a violation of the Constitution’s separation between church and state.*]

Significant Questions in Science

Finally, on the subject of the philosophy of science, it is noteworthy that the theoretical scientists spend most of their time on either answering questions or asking questions. The former is tied mostly to questions of phenomenology (*description* — the ‘what’ questions) and the latter is tied mostly to questions of foundation (*explanation* — the ‘why’ questions).

The difficult thing about asking a question in science is to know in advance if this would be a significant question — that is, a question whose answer could add to our comprehension of the natural world. For it is possible that a scientist may spend most of his or her professional life, as well as the lives of admiring colleagues and students, in trying to answer an insignificant question! Thus it would be useful if there would be some criteria that could help the scientist to decide beforehand if a question in science is indeed significant. One criterion that I have proposed is that if a question leads to *more questions*, it is more likely significant than if it leads to no more questions. The reason is my belief, based on the history of science is that the total understanding of any phenomenon in nature is unbounded — it is infinite in extent. Thus if there would be no more questions about it, the phenomenon would appear to be totally understood — the investigator would claim to have infinite knowledge about it! Since human beings are finite, this would be impossible (i.e. human beings cannot be omniscient)!

I believe that it is for this reason that in the 16th century Galileo said: “there is not a single effect in nature, even the least that exists, such that the most ingenious theorists can arrive at a complete understanding of it.”⁷ This idea stands against the current claims that physicists have discovered a ‘theory of everything!’⁸

In the next lecture, we will present some of the ideas of classical physics from the 16th century onward that were important precursors for the ideas of physics of the 20th century — the quantum and relativity theories.