

Harry Varvoglis

**History
and
Evolution
of
Concepts
in
Physics**

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*To Maria, Natasha and Christina, who
listened to me patiently for so many years
talking about physics and astronomy*

Preface to the Greek Edition

As the title *History and Evolution of Concepts in Physics* indicates, this book essentially encompasses two different approaches of the same topic, which is the course of evolution of physics throughout history, from historical times to the present. The first approach, *History of Physics*, deals with people (great scientists, important inventors, etc.) and their activities, along with their personalities, their family and scientific environment, and the social framework of their era. Inevitably, the life and work of every great scientist occupies a separate chapter; if the scientist has contributed to several areas of physics, all contributions are discussed in the same chapter.

In doing so, however, one tends to lose the coherence of the *Evolution of Concepts in Physics*, which is the second approach. The reason is that, in every branch of physics, the concepts evolved at different paces over the years, depending on the available, at the time, experimental data (which, in turn, depend on the existing laboratory instruments and their precision) and mathematical tools (which, in turn, depend on the stage of development of the mathematical arsenal). For instance, the topics of mechanics and gravitation were feasible targets for Newton to attempt the development of the corresponding theories, while optics was not, since the latter required more advanced experimental concepts (e.g., diffraction and polarization), more advanced mathematics (e.g., complex functions), and longer time span for those concepts to attain a certain level of maturity. As a result, concepts in every branch of physics evolved at different paces following different routes, a fact suggesting that it may be better to present each topic separately. This approach alone, however, could compromise the unity of the presentation, since the work of every great scientist would have appeared fragmented in the various chapters of the book.

It is obvious that these two different approaches for presenting an account of the evolution of physics over the centuries have, each, advantages as well as weaknesses. In this book, I tried to reconcile the two different approaches; I give emphasis on the evolution of concepts, including, at the same time, several historical notes for every scientist, in an attempt to present his work and personality within the framework of his era. Hopefully, the final result will help the reader to understand the way physics evolved to the present day.

I would like to thank all those who helped in improving the book, pointing out mistakes, oversights, and ambiguities in the draft. These are, in alphabetical order, Profs. B. Charmandaris, K. Melidis, S. Persidis, N. Spyrou, and A. Varvoglis. I would also like to thank my colleagues Profs. E. Meleziadou-Dompoula and J. Touloumakos, for their help in the paragraph regarding the Museum of Alexandria, as well as the text editor of the Greek edition and my former student, S. Oikonomidis, for his useful remarks that helped improve the book.

Thessaloniki, April 2011

Preface to the English Edition

The translation of the Greek original in English was performed while I was a visiting professor in the *Theoretical Astrophysics Section* of the Institute for Astronomy and Astrophysics of the Eberhard Karls University of Tübingen during spring 2012. I would like to thank for the hospitality Prof. K. Kokkotas. The English version of the book benefited from the suggestions by Prof. J. Teichmann and an anonymous referee. I would like to thank Ch. Varvogli for her help in drawing Figs. 2.2 , 2.3, 4.2, and 4.10, S. Kartsaklis of Klidarithmos Publishing for his help in drawing Figs. 4.8, 4.11, and 5.1, and Prof. V. Tsamakda for providing Fig. 7.1 Above all, I would like to thank M. Mikedis of Klidarithmos Publishing for editing the final version of the book and Dr. Angela Lahee for her help since the first submission of the manuscript to Springer.

I would be glad to provide, free of charge, to anyone interested a full set of electronic slides covering the content of the book—suitable for approximately thirty 45m lectures.

Thessaloniki, November 2013

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Abbreviations

FHW	Foundation of the Hellenic World (www.ime.gr)
INFN	Istituto Nazionale di Fisica Nucleare, Italy
Museo Galileo	Museo Galileo—Institute and Museum of the History of Science, Florence, Italy
NASA	National Air & Space Administration, USA
NOESIS	Science Center and Technology Museum NOESIS, Thessaloniki, Greece
Sparkmuseum	John D. Jenkins, www.sparkmuseum.com
STScI	Space Telescope Science Institute (Hubble telescope)

Part I
From Ancient Greece to the Renaissance

Chapter 1

Physical Sciences and Physics

1.1 Philosophy of Physics

The history of any discipline is always based on written texts.¹ In this way, to restrict ourselves to texts of Antiquity, the history of the Jewish people is based on the books of the Old Testament, the history of the Persian Wars on the books by Herodotus and the history of the Peloponnesian War on the books by Thucydides. Even the history of the Trojan War is based on Homer's written work, although this was based, in turn, on earlier oral traditions of the Greeks of Homer's time. This rule, of course, cannot find an exemption in the history of physics. This is the main reason why the history of physics, and hence the evolution of concepts in this science, necessarily starts from the ancient Greeks. It is certain that other people of historical times were also involved in scientific activities, such as the Babylonians, who developed astronomy, and the Egyptians, who developed geometry. But their aim was to solve practical problems of their everyday life and not to understand nature and its laws. The geometry of the ancient Egyptians was developed for the purpose of redistributing land after the annual flooding of Nile, while Babylonian astronomy was limited to the simple recording of astronomical observations, with a few surviving examples of predictions of future events. Instead, the interpretation of nature and its laws, in both these nations, was the responsibility of priests and kings. In other words, the interpretation of nature for them was not a result of rational thinking; it was based on truth by revelation. The "truth" was revealed to rulers, nobles and priests, and accepted, without questioning, by the rest of the people. This truth was closely related to the religion of each nation.

One can find indications of this mode of thinking in Greek mythology, where it is stated that lightning is cast by Jupiter, earthquakes are caused by Hephaestus and storms are raised by Poseidon with his trident. Generalizing this way of thinking, one may conclude that any phenomenon, even the simplest one, such as the motion of bodies, is caused by a god. But in the late 7th century BC there were Greeks who believed that interpretations of this sort were not very reasonable. So, they

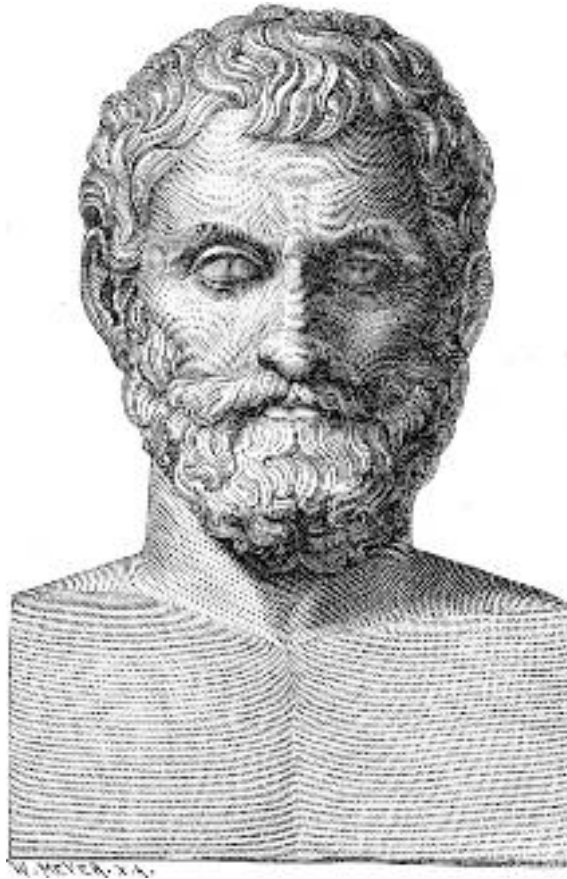
¹ This chapter, as well as the next one, is inspired by the ideas presented in the Introduction of Isaac Asimov's book, *History of Physics*.

tried to explain natural phenomena through a system of rational reasoning. This system was called *natural philosophy* and those who were practicing it were called *natural philosophers*.² The first natural philosophers in Ionia, as Asia Minor was named at that time, appeared in the late 7th and the beginning of the 6th century BC. The first important Ionian natural philosopher was Thales of Miletus (ca. 630 BC–ca. 543 BC), who was considered as one of the Seven Sages of ancient Greece (Fig. 1.1). Other important natural philosophers of that era, also from Miletus, were Anaximander (ca. 610 BC–ca. 547 BC) and Anaximenes (ca. 585 BC–ca. 525 BC). Besides the Milesians, other major Ionian natural philosophers were Heraclitus (ca. 544 BC–ca. 484 BC) of Ephesus and Xenophanes (ca. 570 BC–ca. 480 BC) of Colophon. Another core of natural philosophers appeared in Great Greece (Magna Graecia), as were named the Greek colonies in southern Italy and Sicily, mainly represented by Pythagoras of Samos (ca. 575 BC–ca. 495 BC), Empedocles of Agrigento (ca. 495–ca. 435 BC) and Parmenides of Elea (ca. 514 BC–ca. 440 BC) (Fig. 1.2). From the above philosophers, Thales and Pythagoras did not leave behind any written text, while the others wrote books, which unfortunately were lost, except for several extensive excerpts of the books of the latter two (Empedocles and Parmenides). Thus, almost all available information about the ideas of natural philosophers of the 6th century BC is based on brief references to their work, found in books of later authors.

The method followed by the first natural philosophers to explain natural phenomena proved to be extremely successful and was used by all scientists-researchers until the Renaissance. This method seemed more or less similar to the logical method, which was introduced many years later (in the Hellenistic era) and in a more sophisticated form by Euclid of Alexandria (ca. 325 BC–ca. 265 BC) in developing geometry. The Greek natural philosophers started from a *postulate*, which seemed more or less self-evident, and continued with the logical conclusions that could be drawn from it. All conclusions that could be drawn from a set of initial postulates formed a *theory*. The initial postulate, which seems obvious but cannot be proven, in philosophy is called a *hypothesis* (in mathematics, it is called *assumption* or *axiom*). In literature, one can often come across other terms with the same meaning, like *conjecture* and (in German) *Ansatz*.

² It is worth mentioning that today the words *philosopher* and *philosophy* have completely different meaning. In the modern era “Philosophy is the study of general and fundamental problems, such as those connected with existence, knowledge, values, reason, mind, and language” (as defined in Wikipedia). The change is largely due to the philosophical system of Socrates, who focused his thinking on the exploration of the “internal” world of man and not on the understanding of nature. More specifically, Socrates dealt with the consciousness of people, seeking to understand their behavior, ethics, motivation and response to intellectual problems. The most eminent representative of this tendency in ancient Greece was Plato, student of the great Socrates (Fig.1.3).

Fig. 1.1 Thales, from
E. Wallis, *Illustrated History
of the World*, vol. 1 (1875)



The truth of an axiom cannot be proven within the framework of the theory which is based and developed on it. However, the axiom may be verified by showing that the theory, which is developed on it, is consistent with relevant experiments or observations. For example, one of the fundamental axioms of Euclid's geometry is that *two parallel lines do not intersect*. This axiom seems obvious, but as understood by later mathematicians, this holds true only in flat spaces. The surface of the Earth is not flat but curved and that is why two adjacent meridians, which are parallel on the equator (i.e., for a latitude $\varphi = 0$), intersect at the poles. Therefore, Euclidean geometry holds only approximately on the surface of the Earth and only for relatively small distances. When the dimensions of geometric drawings we study on its surface are of the order of hundreds of kilometers or more, then "deviations" from the Euclidean geometry start to appear, such as the fact that the sum of the angles of a triangle is greater than 180° . Therefore, we arrive to the conclusion that an axiom can provide a correct theory

Fig. 1.2 Pythagoras, from *History of Philosophy* (ca. 1660) by Thomas Stanley



PYTHAGORAS

under certain conditions and a wrong one under others. Today, the criterion for accepting a theory, and consequently the axioms on which it is based, is the experimental verification of the predictions arising from it. Using this method, we can prove that a theory is wrong, but we can never prove that it is correct! In simple terms, if experiments are consistent with the theory, then we continue to use it. But if they do not agree, then we reject the theory and the axioms on which it is based, and introduce new axioms. As discussed in the book, this has happened several times in the recent history of physics, but not in ancient times.

So far, the relation between axioms and theories has not changed significantly. All theories, from the theories of motion of Galileo and Newton to the general theory of relativity of Einstein, are based necessarily on hypotheses-axioms. On the other hand, from what has been said in the previous paragraph, it is evident that hypotheses are the weak point of any theory. Therefore, it seems reasonable to try to limit, as much as possible, the number of unproven assumptions—the axioms upon which a theory is based. This concept was first introduced explicitly by

Fig. 1.3 Plato, by L. Drossis and Attilio Picarelli; in front of the entrance of Academy of Athens (photo by author)



William of Ockham (1285–1349), an English philosopher of the Middle Ages. For this reason, the attempt to limit the number of hypotheses on which a theory is based is commonly referred to as *Ockham's razor*. According to Ockham's razor:

- If two different assumptions lead to conclusions that agree with an observation or experiment, we “prefer” the one that explains more phenomena.
- Between two theories that explain the same phenomena, we “prefer” the one that starts with fewer assumptions.

1.2 From Natural Philosophy to Physics

The term *natural philosophy*, describing the study of natural phenomena, remained in use from the 6th century BC until many years after the Renaissance. The modern word introduced in its place, *science* (from the Latin word *scientia*, which means science, knowledge) was introduced only recently—in the 19th century. Even today, the higher university degree awarded in Western Europe and the United States for studies in science bears the name *Doctorate in Philosophy* (Philosophiae Doctor, PhD). Furthermore, the word *physics* is quite recent and its original meaning encompassed all branches of science. But as the scope of science became deeper and broader, and knowledge kept accumulating, natural philosophers had to specialize, by selecting a particular field of science. These fields received distinct names and started separating from the previously unique space of natural philosophy. The study of abstract relations of shapes and numbers was named mathematics. The study of the position and motion of celestial bodies was named astronomy (from the Greek words *αστηρ*, which means star, and *νέμω*, which means distribute, allot). The study of the physical characteristics of the Earth, the planet on which we live, was called geology. The study of the structure, function and interactions of living organisms was named biology. The study of the composition and interactions of substances was called chemistry, and so forth. Today, the term physics ended up describing the study of all natural phenomena that do not come under any of the other independent fields mentioned above—that is, those that were separated from the main branch of natural philosophy. For this reason, today, physics ended up comprising a rather heterogeneous set of knowledge that is difficult to fit in a general and unique definition. It certainly includes phenomena such as motion, heat, light, sound, electricity and magnetism. All these are forms of energy, so the study of (classical) physics can be understood as mainly the study of interactions of matter and energy. This definition can be interpreted either in a narrow or in a broad sense. If interpreted in a narrow sense, then we come to the study program, the syllabus, of a “typical” Physics Department. But if interpreted in a broad sense, physics includes a large portion of the remaining fields of science. For example, the chemical bonds between atoms are due either to electrostatic forces between ions (ionic bond) or to forces of quantum mechanical origin (covalent bond). Therefore, a large part of chemistry should be considered as a subset of physics. Following similar reasoning, biology can, as well, be considered to comprise a large amount of physics, mainly regarding the synthesis of molecules supporting life and the energy balance of living organisms. We might even claim that the branch of medicine called physiology, which deals with the function of human organs, lies within the realm of physics. This is because our ears and eyes transform sound and light energy into nerve signals through processes that are applications of acoustics and optics, respectively. Besides, as we shall see later in the book, many physicists of the 18th and 19th century were holding degrees in medicine.

According to what we have said so far, the differentiation of science into disciplines is ultimately an artificial classification, established mainly in the 19th century. The evolution of science, however, is an ongoing process and so the above “technical” classification soon started to lose its strict meaning. As knowledge continued to accumulate, the boundaries of disciplines became fuzzy and ultimately many of them started to overlap; as a result, the techniques and methods of one discipline could be used in other disciplines. For example, in the second half of the 19th century, techniques used in physics enabled the determination of chemical composition and physical structure of stars. In this way, the science of astrophysics was born. The study of oscillations excited in the Earth’s crust by earthquakes created geophysics. The study of chemical substances by using methods of physics created physical chemistry. The application of the laws of physics in the motion and functions of living organisms was called biophysics. The applications of physics in medicine, e.g., modern imaging methods (CT and MRI) or the use of radiation for the treatment of cancerous tumors were named medical physics. As far as mathematics is concerned, it was from the beginning the basic tool of physics. However, research on the basic principles of physics today is so highly specialized and requires such an extensive mathematical background, that this tool has evolved to a degree that is very difficult to differentiate between an applied mathematician and a theoretical physicist. At this point, it should be noted that mathematicians that contributed to the development of physics fall into two categories:

- In the first category belong all those mathematicians who described or solved, using mathematics, known problems in physics (in the narrow or broad sense). These were, for example, Joseph Louis Comte de Lagrange (1736–1813), who worked on gravity and classical mechanics, Johann Carl Friedrich Gauss (1777–1855), who worked on gravity and electromagnetism, Jules Henri Poincaré (1854–1912), who worked on mechanics and relativity, etc.
- In the second category belong those who developed theories using completely abstract mathematical structures or models that did not seem, at the time, to bear any relation with observable nature and its properties, but whose results found application in physics *a posteriori*. These include, for example, the non-commutative algebra of Sir William Rowan Hamilton (1805–1865) and Lie groups of Sophus Lie (1842–1899), which find applications in theoretical mechanics, the Riemann tensor of Georg Friedrich Bernhard Riemann (1826–1866) and the Ricc tensor of Gregorio Ricci-Curbastro (1853–1925), which find applications in general relativity, etc.

As a result, many great scientists of the 18th and 19th century can be considered as belonging to different disciplines, depending on how one views and approaches their work. For example, Joseph-Louis Gay-Lussac (1778–1850) and Michael Faraday (1791–1867) can be regarded as chemists, while in this book are considered as physicists. On the other hand, Christiaan Huygens (1629–1695), Sir

Isaac Newton (1642–1727), Charles Augustin de Coulomb (1736–1806), Galileo Galilei (1564–1642) and Gustav Robert Kirchhoff (1824–1887) may be considered as mathematicians, but again in this book are classified as physicists.

Chapter 2

The Ideas of Greeks About Nature

2.1 The Basic Assumptions of Aristotle on Motion and Gravity

Motion was one of the earlier phenomena that were studied by ancient Greek natural philosophers. One might initially assume that motion is a characteristic of life: people and animals move freely, while dead men and stones do not. It is possible of course to make a rock to move, but this usually happens through the impulse given to it by a living being. This initial impression, however, does not seem to withstand a critical approach, since it cannot explain the immobility of plants that are definitely living organisms, while there are also many examples of motion that have nothing to do with life. For example, celestial bodies move in the sky without any apparent cause. The same happens with dust or sea waves, that are raised by the wind. Of course, one could assume that heavenly bodies are pushed by angels, that the wind is the breath of Aeolus, god of wind, and that storms are raised by the trident of Poseidon, god of the sea. Such hypotheses were indeed common in most early civilizations and prevailed until the Renaissance. The Greek natural philosophers, however, tried to propose interpretations arising from the implementation of rational thinking and based on phenomena that are perceptible with our senses. This consideration of nature, therefore, excluded from possible explanations of natural phenomena the angels and the gods of wind and sea.

Another fact that opposes this theocratic interpretation was the existence of cases of motion that could not be interpreted easily as a result of divine influence. For example, the smoke of a fire is not rising vertically, but follows a complex turbulent motion. A stone, that is released from some height above the Earth's surface, moves directly downward, although no one pushes it in that direction. Surely, even the most "fanatical" mystic finds it difficult to accept that every breath of air and every piece of matter contains a small god (or demon!), who pushes them here and there.

The Greek natural philosophers created many philosophical systems, that is, many theories about nature and its phenomena, each based on different hypotheses. These theories were brought together and codified into a single theory by the

Fig. 2.1 Aristoteles by G. Tsaras; in the campus of the Aristotelian University of Thessaloniki (photo by J. Tsouflides)



Greek philosopher Aristotle (384 BC–322 BC), who was born in Stagira of Chalkidiki (Northern Greece), but studied and taught in Athens (Fig. 2.1). Aristotle's theory was based on the following assumptions:

First hypothesis Earth is the center of the universe.

Second hypothesis All material objects are made of the four elements originally proposed by Empedocles and later adopted by Plato, namely earth, water, air, and fire.

In order to explain the motion of bodies not being pushed by living things, Aristotle put forward an extra third hypothesis:

Third hypothesis Each of these elements has its natural place, or physical location, in the universe.

The natural place of element earth, the main constituent of all solid bodies around us, is the center of the universe. So, all solid matter is accumulated in the center of the universe and creates the world in which we live. The ancient Greeks knew that from all solid geometric shapes with the same volume, sphere is the one that has the smallest surface area. So, if it is correct that every piece of solid matter is accumulated as close to the center of the universe as possible, then Earth must be spherical in shape. In addition, its center shall coincide with the center of the universe.

The physical location of the element water is just above the surface of the earth's sphere, forming a water shell with spherical surface.

The physical location of the element air is just above water.

Finally, the physical location of the element fire is above air.

2.2 Success of the Basic Assumptions of Aristotle

Aristotle's theory was very successful at the beginning, because observations seemed to agree with predictions. As far as we can, at least, understand with our senses, Earth is spherical and is located in the center of the universe, since we are surrounded by a hemispherical dome (the sky), where the celestial bodies (stars and planets) are moving. Oceans cover large areas of Earth's surface (we now know that they cover about 2/3 of it), so water is indeed over earth. Air surrounds earth and sea. Finally, during storms, high in the atmosphere, occasionally appear indications of fireballs in the form of lightning. The same theory can even explain the behavior of objects that do not consist of "pure" elements. For example, wood floats in the water because it is a mixture of earth and fire. When wood is burned, the fire is released and moves upwards, while the remaining "earth", the ash, cannot float on the water anymore and heads towards its natural place, below water.

Furthermore, the hypothesis of "natural place" could explain the phenomenon of motion. Assuming that there is a natural place for everything, it was very reasonable to deduce that whenever an object is removed from its normal position, it tends to return to it at the earliest opportunity. For example, a stone, held by someone in the air, manifests its "tendency" to return to its natural place by "pushing" the hand downwards. We could conclude that this is why the stone has weight. This explains why, if we release it, the stone will fall immediately to the ground, that is, towards its natural place, without having to assume the intervention of any "higher power". By similar reasoning, we can explain why tongues of fire move upwards, why pebbles sink when they are thrown into the water and why air bubbles rise in a glass of beer.

A similar reasoning can also explain the phenomenon of rain. When the sun's heat evaporates water (converts it to air according to Aristotle), water vapors rise spontaneously, seeking their natural place, which is over earth and water. But once vapor is condensed, the resulting water falls in the form of drops towards its natural place, which is the region below air but over earth.

Using the hypothesis of "natural place", one may arrive to more advanced conclusions. Suppose we know that an object is heavier than another. The heavier object shows greater tendency to return to its natural place. Indeed, observations seem to confirm this conclusion, since light objects such as feathers, leaves and snowflakes fall slowly, while stones and bricks fall faster. By symbolizing the weight of a falling body with B and its velocity with v , we can express Aristotle's

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