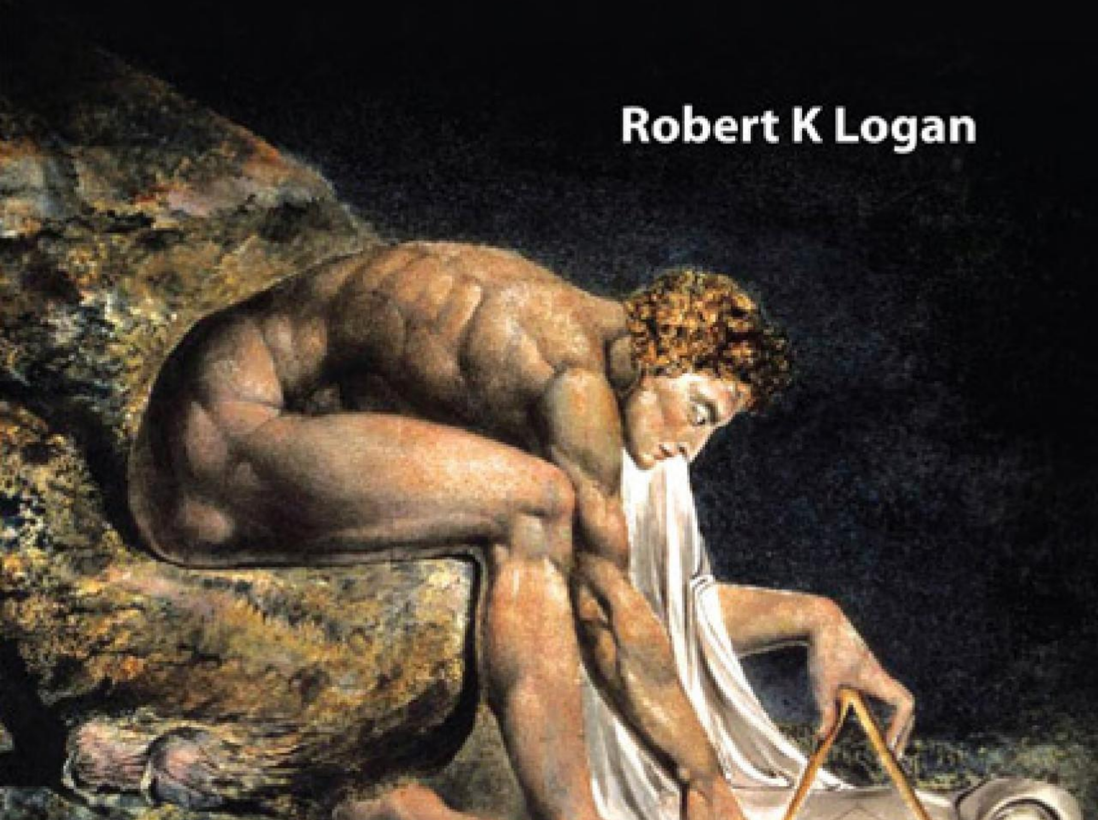
The Poetry of Physics and The Physics of Poetry

Robert K Logan



World Scientific

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and
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Chapter 1

To My Readers

Poets say science takes away from the beauty of the stars — mere globs of gas atoms. I, too, can see the stars on a desert night, and feel them. But do I see less or more? – Richard Feynman

There is poetry in physics and physics in poetry. This book is the product of a course I taught at the University of Toronto starting in 1971 and which I am still teaching at the date of this publication. The course was entitled the Poetry of Physics and the Physics of Poetry. The course was first taught at University College of the University of Toronto and then switched to New College where I also organized a series of seminars on future studies known as the Club of Gnu. After a short recess the course then became a Department of Physics course and was offered as a seminar course for first year students. The purpose of the course that I have now taught for the past 38 years was to introduce the ideas of physics to humanities and arts student who would not otherwise be exposed to these ideas and to try to address the alienation to science that so many of the lay public feel, which is a characteristic of our times. By studying physics without math you, the reader, will encounter the poetry of physics. We will also examine some of the impacts of physics on the humanities and the arts. This is the physics of poetry.

The alienation represented by the gap between the sciences and the humanities is frequently referred to as the two cultures. There are two factors contributing to this alienation; one is the basic lack of understanding of the actual subject matter of science and the other a misunderstanding of the role science plays in our society. Although the fear of science is quite pervasive I believe there are many people interested in leaning about physics. The word "physics'' is derived from the Greek word phusis, which means nature. Those that are curious about the "nature" of the world in which they live should, therefore, want to study physics.

This unfortunately, is not always the case, due in part to the fact that historically physics has been taught in a manner, which alienates most students. This has been accomplished by teaching physics mathematically, which has resulted in more confusion than elucidation for many. Also because the easiest way to examine students and assign grades is to ask quantitative questions, there has been a tendency to teach the formulae of physics rather than the concepts.

This book attempts to remedy this classical situation by communicating the ideas of physics to the reader without relying on mathematics. Mathematical formulae are used, but only after the concepts have been carefully explained. The math will be purely supplementary and none of the material developed later in the book will depend on these formulae. The role of a mathematical equation in physics is also described. To repeat the mathematics is purely supplementary. This book is written explicitly for the people who have difficulty with the mathematics but wish to understand their physical universe. Although all fields of physics are covered the reader will find a bit more emphasis on the modern physics that emerged in the beginning of the 20th century with quantum mechanics and Einstein's theory of relativity. The reason for this is that this physics is less intuitive than classical physics and hence requires more of an explanation.

A second aim of the book is to understand the nature of science and the role it plays in shaping both our thinking and the structure of our society. We live in times when many of the decisions in our society are made by professionals claiming scientific expertise. Science is the password today with those who study social and political problems. They label themselves social scientists and political scientists. It is, therefore, vital to the survival of our society that there exists a general understanding of what science is, what it can do and perhaps most importantly what it cannot do. I have therefore, made an attempt to shed as much light on the scientific process as possible. We will demonstrate that science unlike mathematics cannot prove the truth of its propositions but that it must constantly test its hypotheses.

To restore the perspective of what science is really about we will examine science as a language, a way of describing the world we live in. To this end we will briefly examine the origin and the evolution of language to reveal how the language of science emerged. We will show that the spirit of trying to describe the physical world we live in is universal and can be traced back to preliterate societies and their oral creation myths. It was with writing that the first signs of scientific thinking began to emerge. We will also explain how alphabetic writing influenced the development of abstract science in the West despite the fact that most of technology emerged in China. We will also document the contributions to science by other non-European cultures once again demonstrating the universality of scientific thinking. Hindu mathematicians invented zero and Arab mathematicians transmitted it to Europe providing the mathematical tools for modern science. Arab scientists and scholars contributed to the scientific revolution in Renaissance Europe through their accomplishments in algebra, chemistry and medicine.

Finally, I hope that through this book I will be able to share with the reader the mystical feelings that once characterized our response to our physical environment. Unfortunately, there has arisen in many people's minds a division between the mystical and the scientific. For those in tune with their universe there is no division. In fact quite the opposite is true as these words of Albert Einstein reveal:

> The most beautiful and most profound emotion we can experience is the sensation of the mystical. It is the power of all true science. He to whom this emotion is a stranger, who can no longer stand, rapt in awe, is as good as dead. That deeply emotional conviction of the presence of a superior reasoning power, which is revealed in the incomprehensible universe, forms my idea of God.

Hopefully, the beauty of the concepts of physics will be conveyed so that the reader will come to appreciate the poetry of physics.

In addition to the poetry of physics we will also examine in this book the physics of poetry by which we mean the ways in which physics has influenced the development of poetry and all of the humanities including painting, music, literature and all of the fine arts. Interspersed within our description of the evolution of science we will examine how the arts were influenced by science and vice-versa how the arts and humanities influenced science. There will be more of a focus on poetry because like science it is pithy and it will be easy to demonstrate how science impacted on this art form by quoting from poets ranging from the poetry of creation myths to the poetry of modern times.

This book was written for first year students at the University of Toronto and as such it can be used as a textbook for an introductory non-mathematical two-term physics or science course. It is also written in such a way as to appeal to the general reader. For instructors wishing to use this book as a textbook I have provided some suggestions in Chapter 29 on topics for essay assignments or for classroom discussions.

I would welcome comments or questions from my readers via email at logan@physics.utoronto.ca.

Chapter 2

The Origin of Physics

What is physics? One way to answer this question is to describe physics as the study of motion, energy, heat, waves, sound, light, electricity, magnetism, matter, atoms, molecules, and nuclei. This description, aside from sounding like the table of contents of a high school physics textbook, does not really specify the nature of physics. Physics is not just the study of the natural phenomena listed above but it is also a process; a process, which has two distinguishable aspects.

The first of these is simply the acquisition of knowledge of our physical environment. The second, and perhaps more interesting, is the creation of a worldview, which provides a framework for understanding the significance of this information. These two activities are by no means independent of each other. One requires a worldview to acquire new knowledge and vice versa one needs knowledge with which to create a worldview. But how does this process begin? Which comes first, the knowledge or the worldview?

In my opinion, these two processes arise together, each creating the conditions for the other. This is analogous to a present day theory concerning the existence of elementary particles. According to the bootstrap theory, the so-called elementary particles such as protons, neutrons, and mesons are actually not elementary at all but rather they are composites of each other and they bootstrap each other into existence. But, we are getting ahead of our story. We shall wait till later to discuss the bootstrap theory of elementary particles. For now, it is useful to recognize the two aspects of the process of physics described above. Another way to describe the relationship between "the gathering of facts" and "the building of a framework for the facts" is in term of autocatalysis. Autocatalysis occurs when a group of chemicals catalyze each other's production. Stuart Kauffman has argued that life began as the autocatalysis of a large set of organic chemicals that were able to reproduce themselves.

The study of physics is generally recognized to be quite old but there are differences of opinion as to how old. Some would argue that physics began in Western Europe during the Renaissance with the work of Copernicus, Galileo, Kepler, and Newton. Others would trace the beginnings back to the early Greeks and credit the Ionian, Thales, with being the world's first physicist. Still others would cite the even older cultures of Mesopotamia, Egypt and China. For me, physics or the study of nature is much older having begun with the first humans.

Humans became scientists for the sake of their own survival. The very first toolmakers were scientists. They discovered that certain objects in their physical environment were useful for performing certain tasks. Having learned this they went on to improve on these found objects first by selecting objects more suitable for the task involved and later actually altering the materials they found to produce manufactured tools. This activity is usually referred to as the creation of technology. But the type of reasoning involved in this process is typical of the scientific method, which begins with observations of nature and moves on to generalizations or hypotheses that are tested. For early humans, the generalizations that were made were not in the form of theoretical laws but rather as useful tools. This is exemplified by the achievement of tools for hunting and gathering, pastoralism and agriculture and the use of herbs for rudimentary medicine. All of these activities required a sophisticated level of scientific reasoning. One might dispute this conclusion by claiming that these achievements were technological and not scientific. We usually refer to the acquisition of basic information as science and its application to practical problems as technology. While this distinction is useful when considering our highly specialized world — its usefulness when applied to early human culture is perhaps not as great. A technological achievement presupposes the scientific achievement upon which it is based. The merging of the technological and scientific achievements of early humans has obscured our appreciation of their scientific capacity.

Primitive science, rooted totally in practical application also differs from modern science and even ancient Greek science in that it is less abstract. Astronomy was perhaps our first abstract scientific accomplishment, even though it was motivated by the needs of farmers who had to determine the best time to plant and harvest their crops.

An example of the sophistication of early astronomy is the megalithic structure of Stonehenge built in approximately 2000 B.C. in England, constructed with great effort using heavy rocks weighing up to 50 tons. G.S. Hawkins (1988) in his fascinating book Stonehenge Decoded concludes that Stonehenge was not merely a temple as originally thought but actually an astronomical observatory capable of predicting accurately lunar eclipses as well as the seasonal equinoxes. One cannot help but be impressed when one realizes that the builders of Stonehenge had determined a 56-year cycle of lunar eclipses.

In his book The Savage Mind, Levi-Strauss (1960) reveals another aspect of the scientific sophistication of so-called primitive human cultures whose knowledge of plants rivals that of modern botanists. In fact, Levi-Strauss points out that contemporary botanists discovered a number of errors in their classification scheme based on the work of Linneaus by studying the classification scheme or certain South American Indians.

The examples of early scientific activity so far discussed have centered about the fact gathering aspect of physics. Evidence of interest in the other aspect of physics, namely the creation of a worldview, is documented by the mythology of primitive people. All of the peoples of the world have a section of their mythology devoted to the creation of the universe. This is a manifestation of the universal drive of all cultures to understand the nature of the world they inhabit. A collection of creation myths assembled by Charles Long (2003) in his book Alpha illustrates the diversity of explanations provided by primitive cultures to understand the existence of the universe. Amidst this diversity a pattern emerges, however, which enables one to categorize the various creation myths into different classes of explanations. One of the interesting aspects of Long's collection is that within a single class of explanations one finds specific examples from diverse geographical locations around the globe attesting to the universality of human thought. One also finds that within a single cultural milieu more than one type of explanation is employed in their mythology.

Perhaps the oldest group of emergence myths is the one in which the Earth arises from a Mother Earth Goddess as represented by mythology of North American Indians, Islanders of the South Pacific, and the people living on the north eastern frontier of India. In another set of myths the world arises from the sexual union of a father sky god and a mother Earth goddess. Examples of this form are found in the mythology of ancient Egypt, Greece, India, Babylonia, Polynesia and North America. Other classes of myths include creation by an earth diver, creation from a cosmic egg, creation from chaos, and creation from nothing. In the earth diver myths an animal or god dives into a body of water to retrieve a tiny particle of earth, which then expands to become the world. The cosmic egg myths tell of an egg, usually golden, which appears at the first moment of the universe. The egg breaks open and the events of the universe unfold. In one version the upper part of the eggshell becomes the heavens and the lower part, the Earth. At the beginning of the creation from chaos myths there is disorder or chaos sometimes depicted as water from which a creator creates the universe. Finally, in the creation from nothing myths, which are closely related to the chaos myths, the original starting point of the universe is a void. The best-known example of this group to Western readers, of course, is Genesis, where we read, "In the beginning, God created the heavens and the Earth. The Earth was without form and void and darkness was upon the face of the deep". Other examples of the creation from nothing myth are found among the ancient Greeks, the Australian aborigines, the Zuni Indians of the southwest United States, the Maori of New Zealand, the Mayans of ancient Mexico, and the Hindu thinkers of ancient India.

Having briefly surveyed the various types of creation myths, let us turn to an example of the earliest type and retell the story of Kujum-Chantu, an emergence myth told by the people who live along the northeast frontier of India:

> At first Kujum-Chantu, the Earth, was like a human being; she had a head, and arms and legs, and an enormous fat belly. The original human beings lived on the surface of her belly. One day it occurred to Kujum-Chantu that if she ever got up and walked about, everyone would fall off and be killed, so she herself died of her own accord. Her head became the snow-covered mountains; the bones of her back turned into smaller hills. Her chest was the valley where the Apa-Tanis live. From her neck came the north country of the Tagins. Her buttocks turned into the Assam plain. For just as the buttocks are full of fat, Assam has fat rich soil. Kujum-Chantu's eyes became the Sun and Moon. From her mouth was born Kujum-Popi, who sent the Sun and Moon to shine in the sky.

> The story of Kujum-Chantu attempts a coherent explanation of both the creation of the world and the nature of its physical features and as such it may legitimately be regarded as a scientific hypothesis. Let us compare it with a modern day hypothesis to explain the existence and the nature of the Earth. According to the modern theory, the Earth, the other planets and the Sun were formed together from the same cosmic dust, which explains the various physical features of the Earth such as its molten iron core, its chemical composition and the nature of its physical features. Although the story of Kujum-Chantu may be considered a hypothesis in the loosest sense of the word, it must be conceded that the modern day theory does a better job of explaining the presently known facts about the Earth and as such is considered a more satisfactory scientific theory. It should also be pointed out, however, that there does not exist a set of truly objective criterion for choosing one hypothesis over another.

From our modern scientific point of view we prefer the second theory because it explains more facts. From the point of view of the member of the culture, which worships Kujum-Chantu their story probably gives them a deeper appreciation of the world. Contrary to popular belief there is no scientific manner for arbitrating between two rival scientific theories. Believe it or not, the choice is made on the basis of which theory is most satisfying on human grounds. Copernicus' Sun centered theory of the solar system was preferred at first by its proponents on aesthetic grounds. We shall return to this question when we discuss T.S. Kuhn's (1972) excellent book, *The Structure of Scientific Revolutions* in Chapter 16.

Treating the story of Kujum-Chantu and the modern theory of the creation of the solar system as equivalent theories for the purposes of illustration is perhaps a bit of an exaggeration on my part. The two rival pictures actually differ in a very crucial manner, which actually disqualifies the story of Kujum-Chantu as a bonafide scientific hypothesis. The difference is that the Kujum-Chantu hypothesis does not make any predictions whereas the modern science hypothesis makes a number of predictions, such as the relative chemical composition of the various planets including the Earth and the Sun. A theory, which makes no prediction, is merely an ad hoc (after the facts) explanation of facts, which cannot be tested. A theory, which has the possibility of being proven wrong because of its predictions, but, nevertheless, continues to explain new facts, inspires confidence in its validity. Although there is no objective criterion for choosing theories, the predictive capabilities of a hypothesis have historically provided the mechanism of choice. The best argument that can be made to justify this criterion is that it works. Its adoption has lead to the incredible wealth of knowledge that we now possess.

Science cannot prove that a hypothesis is correct. It can only verify that the hypothesis explains all observed facts and has passed all experimental tests of its validity. Only mathematics can prove that a proposition is true but that proof has to be based on some axioms that are assumed to be obviously or self-evidently true. Karl Popper (1959 and 1979), was annoyed by those Marxists and Freudians, who always wriggled out of any contradiction between their predictions and observations with some ad hoc explanation. He proposed that for a proposition to be considered a hypothesis of science it had to be falsifiable. Using Popper's criteria as an axiom I (Logan 2003) was able to prove that science cannot prove that a proposition is true. If one proved a proposition was true then it could not be falsified and therefore according to Popper's criteria it could not be considered a scientific proposition. Therefore science cannot prove the truth of one of its propositions. This is the difference between science and mathematics. Science studies the real world and mathematics makes up its own world. Scientists, however, make use of mathematics to study and describe the real world.

The two aspects of physics involving the acquisition of information and the creation of a world picture have one feature in common — they both provide us with a degree of comfort and security. The first aspect contributes to our material security. Knowledge of the physical environment and how it responds to our actions is essential to planning one's affairs. It is from this fact acquiring aspect of physics that technology arises. It is from the second or synthesizing aspect of physics, however, that we derive the psychological comforts that accrue from the possession of a worldview. The possession of a worldview is usually associated with philosophy and religion and not physics. This, unfortunately, is our modern predicament. It should be recalled that for preliterate cultures physics, philosophy and religion were integrated. The same was true for Greek culture. Perhaps the enormous mismanagement of our material resources and our environment, which characterizes our times, could be eliminated if we could once again integrate philosophy, religion and physics.

Chapter 3

Ancient Science of Mesopotamia, Egypt and China

The first signs of science began to emerge in ancient Mesopotamia, Egypt and China as these agricultural political economies began to develop technologies to enhance their economies. The knowledge or science that they began to acquire was not systematized and no attempt was made to relate the different discoveries that they were making into a theoretical understanding of their universe. This development had to await the emergence of Greek philosophy, which we will examine in Chapter 4. Nevertheless the three ancient cultures that we will examine in this chapter began to acquire knowledge of mathematics, astronomy, chemistry, botany, zoology, medicine and mechanics and in the case of the Chinese all of these plus magnetism and clockworks.

Mesopotamian Writing and Science

The culture of Mesopotamia refers to the cultures that developed in the valleys of the Tigris and Euphrates river systems. The first culture there was the Sumerian, a non-Semitic speaking people whose origin and language remains a mystery to this day. They were conquered by a Semitic-speaking people, the Akkadians, who are known more commonly as the Babylonian. The Sumerians were the first culture to have invented writing and a mathematical notation. It is believed that the idea of writing spread to China in the East and Egypt in the West and from there to all the cultures of the Old World. Writing was invented independently in the New World by the Mayans. It spread from there to a few other cultures before the arrival of the Europeans. It is possible that the Inca also had a notation systems based on knots tied in ropes, known as quipas but it never flowered into a true writing system as far as we know. The existence of a writing system it seems is essential for a culture to engage in scientific activity. It was only those cultures that possessed a writing system and a system for numerical notation that ever engaged in formal scientific activity.

Not only did writing first emerge in Sumer it was also here that the first formal schools were organized to teach the 3R's, the mysterious skills of reading, writing and arithmetic. It was in these scribal schools that the first primitive forms of science appeared. The major aim of the scribal school quite naturally was professional training to satisfy the economic and administrative needs of temple and palace bureaucracies. "However, in the course of its growth and development, and particularly as a result of the ever widening curriculum, the school came to be the center of culture and learning in Sumer. Within its walls flourished the scholar-scientist, the man who studied whatever theological, botanical, zoological, mineralogical, geographical, mathematical, grammatical, and linguistic knowledge was current in his day, and who in some cases added to the knowledge (Kramer 1959, p. 2)."

Writing and mathematical notation emerged simultaneously in Sumer in 3100 B.C. as was shown by the work of Denise Schmandt-Besserat (1978, 1980, 1981 & 1992). She showed how clay accounting tokens used throughout the Middle East circa 8000 to 3000 B.C. were the forerunners of writing and mathematical notation. Manual labourers in Sumer were divided into two groups, farmers and irrigation workers. The farmers had to pay tributes to the priests in the form of agricultural commodities that were redistributed to the irrigation workers. The farmers were given clay tokens as receipts for their tributes. These tokens two to three centimeters in size and each with a unique shape to represent a different agricultural commodity were sealed inside of opaque clay envelopes. This system developed because of an information overload; it was impossible using spoken language to remember all of the tributes that the priests received. Some brilliant civil servant/priest suggested that before placing the tokens inside the clay envelopes they should impress the token on the surface of the clay envelope while it was still wet so they would not need to break open the envelope each time they wanted to know what was inside. Within fifty years of this development they did away with storing the tokens inside the envelopes and just pressed the tokens on the surface of the envelope without sealing the tokens inside. The impressed envelopes became tablets.

The next development occurred within the city-state of Sumer where they dealt with large quantities and hence a new information overload arose. They developed a system where the token for a ban, a large measure of wheat (a bushel), was used to represent the abstract number ten and a token for the bariga, a small measure of wheat (a peck), was used to represent the abstract number one. If they wanted to record a transaction involving 13 lambs what they did instead of pressing the lamb token into a tablet 13 times was to press the ban token into the wet clay once, the bariga token three times and then they etched the shape that the lamb token into the wet clay with a stylus and this was read as 13 lambs. The reason they etched the shape of lamb token into the clay rather than pressing the lamb token into the clay is that the tablet would be read as one ban of wheat, three barigas of wheat and one lamb instead of 13 lambs. These etched outlines of tokens became the first written words and the impressed ban and bariga tokens the first notated numbers.

So writing and math started out as a back of the envelope doodle. They were not the invention of writers or mathematicians but humble priests/civil servants who were record keepers. Once reading and writing emerged schools had to be organized to teach these new skills because one cannot learn how to read, write and do arithmetic by watching others do it. It is not the automatic learning that takes place when we learn to talk as young children by listening to our parents and other caregivers speak. The first schools were rectangular rooms that held 30 to 40 students sitting on benches and one teacher at the head of the class (Kramer 1956). The lessons were in reading, writing and arithmetic, a tradition that has lasted 5000 years and will probably continue as long as humans walk upon this Earth.

To prepare their lessons teachers created lists of similar objects like trees, animals, fish, kings, and rivers. These teachers subsequently became scholars. The teacher who prepared the lists of trees headed the botany department and the one who created the list of kings became the political science expert. With scholarship another information overload developed from all the scholars, which was resolved with the emergence of science, a form of organized knowledge beginning around 2000 B.C.

Science emerged as organized knowledge to deal with the information overload created by teacher/scholars. The methods and findings of science are expressed in the languages of writing and mathematics, but science may be regarded as a separate form of language because it has a unique way of systematically processing, storing, retrieving, and organizing information, which is quite different from either writing or mathematics.

The elements of universality, abstraction, and classification that became part and parcel of Babylonian thinking under the influence of phonetic writing subliminally promoted a spirit of scientific investigation, which manifested itself in the scribal schools. The major aim of the scribal school quite naturally was professional training to satisfy the economic and administrative needs of temple and palace bureaucracies.

> However, in the course of its growth and development, and particularly as a result of the ever-widening curriculum, the school came to be the center of culture and learning in Sumer. Within its walls flourished the scholar-scientist, the man who studied whatever theological, botanical, zoological, mineralogical, geographical, mathematical, grammatical, and linguistic knowledge was current in his day, and who in some cases added to the knowledge (Kramer 1959, p. 2).

During the reign of Hammurabi both the writing system and the legal system in the form of the Hammurabic code were regularized and reformed. The writing system that was phonetic and based on a syllabary was reduced to 60 symbols representing the 60 syllables in terms of which all of the words of their spoken language could be represented. Weights and measures were also standardized. These developments were not coincidental. These reforms promoted the paradigms of abstraction, classification, and universality and thus encouraged the development of scientific thinking.

The next two centuries after these reforms represent the first great scientific age of mankind. A new spirit of empiricism and scholarly interest in astronomy, magic, philology, lexicography, and mathematics arose. A primitive place number system was invented as well as algorithms for arithmetic calculations. Mathematical tables were created to simplify calculations. Achievements in algebra included solutions of quadratic equations. Lists of stars and constellations were compiled and the movements of the planets were charted. The scholars of the Hammurabic era "showed such taste and talent for collecting and systematizing all recognized knowledge that Mesopotamian learning nearly stagnated for a thousand years thereafter. ...We find a pervasive idea of order and system in the universe, resulting in large part from the tremendous effort devoted to the systematization of knowledge (Albright 1957, pp. 197–99)."

The Mesopotamians' spirit of order and system is reflected in their cosmology or concept of the universe (Kramer 1959, pp. 77–79). The Babylonian universe, an-ki, is divided into two major components: the heaven (an) and the earth (ki), which emerged from and remain fixed and immovable in a boundless sea, Nammu. Nammu acts as the "first cause" or "prime mover" of the universe. Between heaven and earth there moves Lil, a divine wind (also air, breath, or spirit) from which the luminous bodies (the sun, moon, planets, and stars) arose. The order of creation is as follows: 1) the universe, an-ki (heaven-earth), emerges from the boundless sea Nammu; 2) it separates into heaven and earth; 3) Lil then arises between heaven and earth; 4) from which the heavenly bodies emerge; 5) followed finally by the creation of plants, animals, and human beings. The order of creation found in this cosmogony closely parallels the story of creation found in the Bible in the book of Genesis.

Although Mesopotamian cosmology and cosmogony was polytheistic in nature, there nevertheless evolved some rather abstract notions of the deities that created and controlled the universe. All the elements of the cosmos were attributed to four gods who controlled the heavens, earth, sea, and air. "Each of these anthropomorphic but superhuman beings was deemed to be in charge of a particular component of the universe and to guide its activities in accordance with established rules and regulations (ibid., p. 78)." These four spheres of influence correspond to the four elements of fire, air, water and earth from which the Greeks composed their universe more than a thousand years later.

While Mesopotamian cosmology contains mythic elements, the core of its world picture is based on empirical observations of the natural environment including the heavens. Systematic astronomical observations were not part of the Sumerian tradition but were begun by the Akkadians, worshippers of the sun god Shamash. Their observations were somewhat crude (Neugebauer 1969, p. 97) and it was only with the flowering of the Assyrian empire in approximately 700 B.C. that accurate quantitative measurements were made (ibid., p. 101). Tablets recording these observations have been used to date the chronology of the Hammurabic period (ibid., p. 100). Part of the motivation for these observations was what we could term scientific and part astrological, though the Babylonians made no distinction between science and astrology. Observations made for the purpose of divination served science as well, and paradoxically, vice versa.

Sumerian and Babylonian mathematical tables provide further evidence for the development of scientific thinking in Mesopotamia. These tables were combined with tables of weights and measures indicating that they were used in daily economic life (ibid., p. 31). The clear influence of writing and a notational system upon the development and organization of mathematical skills is easily discernible from these tables. Economics proved to be a motivating factor for both writing and mathematics, which mutually reinforced one another's development.

The results were tables of multiplication, reciprocals, squares, square roots, cubes, cube roots, sums of squares and cubes needed for solutions to algebraic equations and exponential functions (ibid., pp. 33–34). The sexagesimal number system 60 was developed in response to the Babylonians' concern for astronomy. The parallel between the approximately 360-day year and the 360-degree circle are obvious.

Tables of quadratic and cubic functions were prepared for civil-engineering projects of dam building, canal dredging, and the construction of attack ramps to breach the ramparts of besieged walled cities. Certain Babylonian mathematical tablets indicate that astronomy, banking, engineering, and mathematics were practiced in a systematic and scientific manner. Two types of tablets were prepared. In one set, only problems are given, but each tablet contains problems related to the other and carefully arranged beginning with the simplest cases. The second set of tablets contains both problems and their solutions worked out step by step (ibid., p. 43). The achievement of Babylonian mathematics, which has been likened to that of the Renaissance (ibid., pp. 30 & 48), is all the more remarkable when one considers the short period in which it developed and flowered: all within two hundred years or so of the major reforms in the writing system.

The existence of these tablets illustrates two important impacts of writing on science. The first is the impulse to organize information in an orderly and systematic manner. The ordering of individual words that the use of syllabic signs creates in the thought patterns of their users inspires a similar ordering of the contents of their writings. That this was critical for the development of science is beautifully illustrated by the Babylonian mathematical texts created as aids to various scientific and engineering activities.

The second impact of writing is the ability to preserve the accomplishments of one age so that they can form the basis of a later development. Little if no progress was made in Babylonian mathematics from the time of the Hammurabic explosion of knowledge to the Assyrian empire of 700 B.C. Yet the tablets preserved the knowledge that an earlier age had created and they served as the foundation for the Assyrian development.

The mathematical and scientific achievements of the Mesopotamian civilization we have just reviewed are certainly worthy of our respect and admiration. We must be careful, however, not to jump to the conclusion that this culture had solidly embarked upon the road of scientific thinking because of the progress in astronomy, mathematics, and engineering that has been described. The reader must bear in mind that the very same practitioners of this rudimentary form of science were also engaged in astrology, the reading of animal entrails, the interpretation of omens, and other forms of superstition. The early forms of science as practiced in Babylon are not a scaled down or less advanced version of science as we know it today but rather a mixture of logic, superstition, myth, tradition, confusion, error, and common sense. No distinction was made between "religious" and "scientific" thinking. "Medicine grew out of magic, and in many cases was indistinguishable from it (Cottrell 1965, pp. 169–71)." What is important about Babylonian science from a historical point of view was its influence on future generations, on the Hebrews, on the Greeks, on the Arabs, and eventually on Renaissance Europe.

The Babylonians made use of a logical mode of thought complete with abstract notions and elements of classification (Albright 1957, p. 198). Their approach was wholly empirical, however, unlike the theoretical and more analytic style of Greek science, which, according to Kramer (1959, pp. 35–36), required "the influence of the first fully phonetic alphabet." For example, the Sumerians compiled grammatical lists and were aware of grammatical classifications, yet they never formulated any explicit rules of grammar. In the field of science, lists were also compiled but no principles or laws were ever enunciated. In the field of law, a legal code was developed but never a theory of jurisprudence.

Egyptian Writing and Science

Like the Mesopotamians the ancient Egyptians also had a writing system and a science tradition. They also engaged in mathematics but unlike the Mesopotamians who were great at algebra the mathematical strength of Egypt was in geometry. Their writing system was not phonetic but pictographic and hence might explain why they did not achieve the same level of abstraction in algebra, which involves the manipulation of a small number of symbols.

The flooding of Nile River was extremely important to the existence of Egyptian agriculture because it supplied the water necessary for farming in a land that was otherwise a desert. The flooding also gave rise to Egyptian geometry in a round about way because of the need to measure the area of land in the possession of a landowner before the inundation of the Nile washed away all the boundary lines between properties. Rather than restore the boundary lines that were destroyed by the flooding, each landowner was provided with a new plot of land more or less in the same location as before and with a total area exactly equal to the amount of land in his possession before the flood. Because of this need to measure the area of land accurately, an empirical science arose called geometry, which literally means earth (geo) measuring (metry). Egyptian geometry is not derived from a set of axioms. There are no theorems or proofs or propositions. There are merely a set of rules that are used strictly for practical applications such as land measuring and construction calculations. They made use of the Pythagorean theorem thousands of years before Pythagoras ever proved the theorem. They did not need a proof. As long as it worked and allowed them to measure land areas accurately and carry out their engineering projects, they were satisfied. It was the Greeks who took the empirical results of Egyptian geometry and turned geometry into a set of axioms and theorems made famous by Euclid's Elements.

In addition to their abilities at geometry the Egyptians were also excellent astronomers, the knowledge of which served their agricultural needs. Agriculture also led to a number of other science based technologies such as irrigation canals and hand powered pumps, the use of yeast to make bread that would rise; pottery; glass making using soda-lime, lead, and various chemical to make tinted glass; weaving, and dyeing in which a number of chemicals were used to achieve a wide spectrum of colours. In addition to agricultural based technologies the Egyptians excelled at the metallurgy of copper, gold, silver, lead, tin, bronze, cobalt (for colouring) and iron. They also made a variety of different coloured pigments for painting. In addition to all of the chemical skills they developed must be added their ability to mummify the dead.

The Egyptians also developed incredible engineering abilities in building the pyramids, the sphinx at Giza, temples with gigantic columns, and obelisks. These engineering feats required a practical knowledge of many of the principles of physics but as with their geometry and chemistry their scientific knowledge grew out of the practical things that they did. There was not much effort made to systematize their knowledge to create a rudimentary form of science as the Greeks eventually did.

Chinese Science

What makes the lack of theoretical science in China so puzzling is the high level of technological progress achieved there, which exceeded that of the Mesopotamians and the Egyptians that we just reviewed and the ancient Greeks who we will study in the next chapter. The list of significant scientific and technological advances made by the Chinese long before their development in the West includes the equine harness, iron and steel metallurgy, gunpowder, paper, the drive belt, the chain drive, the standard method of converting rotary to rectilinear motion, and the segmental arch bridge (Needham 1979). To this must be added irrigation systems, ink, printing, movable type, metal-barrel cannons, rockets, porcelain, silk, magnetism, the magnetic compass, stirrups, the wheelbarrow, Cardan suspension, deep drilling, the Pascal triangle, pound-locks on canals, fore-and-aft sailing, watertight compartments, the sternpost rudder, the paddle-wheel boat, quantitative cartography, immunization techniques (variolation), astronomical observations of novae and supernovae, seismographs, acoustics, and the systematic exploration of the chemical and pharmaceutical properties of a great variety of substances.

Joseph Needham carefully documented through years of historical research the contribution of Chinese science and its influence on the West. Although he championed Chinese technology he nevertheless posed the following question: "Why, then, did modern science, as opposed to ancient and medieval science, develop only in the Western world? (ibid., p. 11)" What Needham meant by "modern science," was abstract theoretical science based on experimentation and empirical observation, which began in Europe during the Renaissance.

Abstract theoretical science is a particular outgrowth of Western culture that is not more than four hundred years old. Nonabstract practical science as it occurs in ancient China, Mesopotamia, Egypt and the remainder of the world is a universal activity that has been pursued by all cultures, literate and non-literate, as part of their strategy for survival. Claude Lévi-Strauss (1960) in *The Savage Mind* gives numerous examples of elaborate classification schemes of preliterate cultures, based on their empirical observations and demonstrating their rudimentary concrete scientific thinking.

China created the most sophisticated form of technology and nonabstract science that the world knew before the science revolution in Europe during the Renaissance. Technological sophistication by itself, however, does not guarantee the development of abstract theoretical science. Other factors (social, economic, and cultural), obviously present in the West and not the East, must have played a crucial role as well. In fact in the next chapter we will show that the critical difference was the difference of the Western writing systems based on the phonetic alphabet of 20 to 30 characters as opposed to the Chinese writing system that contains thousand of characters and makes use of pictorial elements and a limited amount of phonetics.

Before delving into the impact of the Chinese writing system, let us first review the fundamental elements of Chinese science. According to classical Chinese scientific thought the universe consists of five elements: earth, water, fire, metal, and wood. The five elements are ruled by the two fundamental universal and complementary forces of yin and yang, which represent, respectively, the following pairs of opposites: cold and warm; female and male; contraction and expansion; collection and dispersion; negative and positive. The five elements and the two forces of yin and yang form a blend of opposites in which a unity emerges more through harmony than through the fiat of preordained laws (Needham 1956). Chinese scientific thought always had a mystical and mysterious aspect to it. The Confucians and Logicians, who were rational, had little interest in nature. The Taoists, on the other hand, who were interested in nature were mystics who mistrusted reason and logic. Chinese science was colored by the Taoist attitude toward nature, which is summarized by the following passage from the Huoi Nan Tzu book: "The Tao of Heaven operates mysteriously and secretly; it has no fixed slope; it follows no definite rules; it is so great that you can never come to the end of it; it is so deep that you can never fathom it (ibid., p.16)."

It is not difficult to understand how the Taoist mystical attitude toward nature might preclude the development of abstract science. We are still left, however, with the question of why those who were rational, such as the Confucists and the Logicians, were not interested in nature and why those who were interested in nature, such as the Taoists, were mystical. In other words, why wasn't there a group in China that was both rational and interested in science and nature? Eberhard (1957) offers an explanation: Science had only one function, namely, to serve the government and not its own curiosity. All innovations were looked upon as acts of defiance and revolution. The difficulty with the explanation provided by Eberhard is that it applies to the West as well. Western scientists faced the same problems in Europe. The work of Copernicus was openly contested and then suppressed by the Church, yet the Copernican revolution succeeded.

Yu-Lan Fung (1922) explains the lack of interest in theoretical science in the following terms: "Chinese philosophers loved the certainty of perception, not that of conception, and therefore, they would not and did not translate their concrete vision into the form of science." The aim of Chinese culture was to live in harmony with nature with no need to subdue it or have power over it as is the case in the West. The philosophical disposition of the Chinese was to focus on their internal reflective state rather than take the external active stance that the West adopted to develop scientific thinking. Fung's explanation is similar to that of Latourette (1964), who claimed that Chinese thinkers, unlike their Western counterparts, were more interested in controlling their minds than nature itself, whereas in the West, the opposite was true. We will see in the next chapter that the difference in the Western and Eastern writing systems also played a role.

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Chapter 4

Physics of the Ancient Greek Era

In the last two chapters we attempted to show how the roots of scientific thinking first arose in pre-literate societies and then in Neolithic civilizations. It is with the ancient Greek thinkers, however, that the study of physics first became defined. The word physics itself is derived from the Greek word, φυσισ (phusis) meaning nature. The Greeks gave more than a name to the study of physics for it is with them that the abstract development of physics began. They are the first to apply deductive thinking to physics, to investigate the relation of physics to mathematics, and to search for a universal explanation of nature's mysteries. Although certain Greek thinkers understood the value of the empirical approach the Greeks had difficulties combining this aspect of physics with the abstract deductive theoretical aspect of physics they so highly prized. It is for this reason most likely that Greek physics did not come to full flower. However, it served as the basis for the final flowering of physics that finally occurred in Western Europe during and just after the Renaissance. Like the Renaissance thinkers there is much we can learn from the Greeks by studying both their successes and the reasons for their failures.

Greek science did not begin in isolation in fact quite the opposite is the case. Being a trading people the Greeks were in contact with the intellectual influences of other cultures such as Mesopotamian astronomy and mathematics, Hebrew philosophy and Egyptian astronomy, medicine, chemistry and mathematics. Perhaps the most important influence of all was the Egyptian discovery of geometry from their practice of land measurement. Note the word geometry comes from the Greek words for earth, geo and measure, meter. Because of the overflow of the Nile each year, which destroyed the boundaries of each persons land it became necessary to develop methods of land measurement, which led empirically to many of the results of geometry.

It was the role of the Greeks to formalize these results and derive them deductively. It is the physicist Thales, considered one of the world's Seven Wise Men by the Greeks, who first began this process of deriving the empirically based results of the Egyptians deductively. In the deductive process one makes a set of assumptions or axioms, which one considers to be self-evident truths. For example in geometry, it is assumed that the shortest distance between two points is a straight line. From these self-evident truths or axioms one then derives results using the laws of logic. An example of such a law is if $a = b$ and $b = c$ then $a = c$. The Greeks and Thales were the very first to use this method of obtaining or organizing knowledge. Up until this time knowledge was arrived at inductively i.e. by example or observation. For example, if I notice every time I put a seed into the ground a plant grows I learn by induction that seeds give rise to plants. If I notice that seeds from oranges always give rise to orange trees and seeds from lemons give rise to lemon trees I would conclude by induction that apple seeds give rise to apple trees and peach seeds to peach trees. The process of induction also involves logic. It differs from deduction, however, in that its results are not based on a set of axioms. Although the Greeks used both methods of reasoning they had a definite preference for the deductive method.

The Greek tradition of deductive geometry begun by Thales was continued by the mystic Pythagoras and his followers, who formed a brotherhood to practice the religious teachings of their master. Perhaps the best known result of their work is the Pythagorean theorem, which relates the sides of the right triangle in the accompanying Fig. 4.1 by $a^2 + b^2 = c^2$, where c is the length of the hypotenuse and a and b are the lengths of the other two sides. Perhaps the most significant discovery that Pythagoras made, however, was the relationship between harmony and numbers. He first discovered the relation between the length of a string to the frequency of the sound it emitted. He then discovered that those intervals of the musical scale that produced the fairest harmony were simply related by the ratio of whole numbers. This result led to a mystical belief in the power of numbers, as is expressed by the fragments of the Pythagorean disciple, Philolaus, who wrote:

> In truth everything that can be known has a Number, for it is impossible to grasp anything with the mind or to recognize it without.

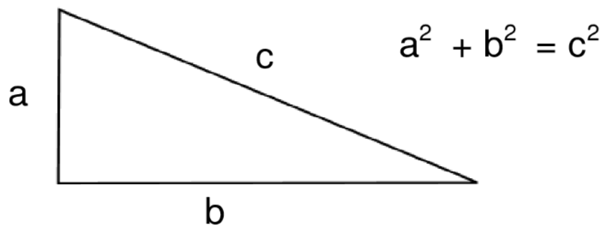

Fig. 4.1. Pythagorean Theorem

They believed that numbers were the basic stuff of the universe and that harmony controlled both the physical universe and the human soul.

Their belief in the power of numbers has been realized to the extent that almost all the phenomena described by physics is expressed in terms of mathematical equations. Their mystical approach to numbers would not have uncovered these laws, however. More than a consideration of numbers was required. Our knowledge of physics was not just arrived at using logic; observation of and experimentation in the physical world were also required. The Pythagorean infatuation with numbers can be easily understood however, when one realizes that with their discoveries regarding harmony, they were the very first to find such a dramatic connection between numbers and nature.

Despite their strong theoretical bias as illustrated by the Pythagoreans belief in numbers the Greeks also had a strong empirical tradition. This tradition was begun by Thales the very man who introduced deductive geometry into Greek thought. Thales and his Ionian followers are considered to be the world's very first physicists and philosophers. Their careful observations of nature led them to a number of conclusions held today. They believed that change and movement are caused by physical forces, that it is possible to have a void, that ice, water and steam are three different phases of water and that the changes from one phase to another are caused by condensation and rarefaction. They believed in the conservation of matter, which proved to be such an important assumption for the development of chemistry and was only recently shown not to be the case for the nuclear reactions of fission and fusion in which mass is destroyed and converted into energy.

Anaxagoras on the basis of his investigation of a meteorite concluded that the heavenly bodies are composed of rocks. This idea was extremely revolutionary because it was the common belief that the heavenly bodies were gods and goddesses. Anaxagoras was banished for his idea and almost lost his life on its account. His idea was also rejected by Aristotle, as were the concept of a void and the concept of human evolution. Anaximander argued the case for human evolution almost 2500 years before Darwin on the basis of his observations of the human embryo and on the grounds that since the newborn human child is completely helpless humans must have descended from a more primitive form of life whose young are self-sufficient. Another biological conclusion reached by the Ionian philosophers was their belief in the inherent healing power of nature.

Of all these important discoveries perhaps the most important contribution the Ionian physicists made to our intellectual heritage was their idea that all matter of the universe was composed of a single substance. Modern physics has shown that this is not the case, as there are a number of elementary particles or quarks out of which the elementary particles are composed. Still the concept of a universal such as a primary substance was the precious gift of Greek thought. We shall return to the question of why the concept of a universal arose among the Greeks. For the moment let us review their various systems. Thales, the originator of the concept, believed all matter was composed of water. His disciple Anaximander believed that all things were composed of a neutral substance he called apieron whose literal Greek meaning is infinite or limitless. He believed that the various opposite such as hot and cold, dry and wet, light and dark were all contained within this neutral substance apieron and became separated to form the various substances observed in nature. For Anaximenes the primary substance is air and the diversity of matter is explained in terms of the varying densities of air. For example, as air becomes thinner it becomes like fire and as it becomes denser it turns from air to mist to dew to water to mud to earth to stone and so on.

What we know of the philosophical systems of Thales, Anaximander, and Anaximenes does not come directly from their writings but rather from the comments about their work by later authors such as Plato and Aristotle. The first Ionian physicist-philosopher to have left a substantial fragment of his writing behind is Heraclitus whose fascinating aphorisms are still of philosophical, scientific, and literary interest.

His faith in the empirical method as well as his understanding of it are attested to in the following aphorisms:

> The things of which there can be sight, hearing and learning — these are what I especially prized. Eyes are more accurate

> witnesses than ears. Eyes and ears are bad witnesses to men having barbarian souls. Men who love wisdom should acquaint themselves with a great many particulars. Seekers after gold dig up much earth and find little.

For Heraclitus the primary material of the universe is fire but his emphasis was more on fire as a process rather than as a substance. In reading his fragments if one thinks of fire as representative of energy then the overlap of Heraclitus' thinking and our own ideas regarding conservation of energy is amazing. He writes:

> This universe, which is the same for all, has not been made by any god or man, but it always has been, is, and will be — an ever kindling fire, kindling itself by regular measures and going out by regular measures. There is exchange of all things for fire and of fire for all things, as there is of wares for gold and gold for wares.

The ideas contained in these two aphorisms almost completely parallel my personal belief that from conservation of energy and the equivalence of mass and energy generally expressed as $E = mc^2$, one is forced to conclude that the universe always was and always will be since the creation or destruction of the universe would involve the most colossal violation of energy conservation imaginable. I have underlined my belief because there are many physicists who believe in the big bang theory that the universe began some 15 billions years ago, but once again we are getting ahead of our story. More of this later.

The idea that the universe is represented by fire in the sense of process rather than substance is substantiated by the following fragments:

> The phases of fire are craving and satiety. It throws apart, then brings together again; it advances and retires. Everything follows and nothing abides; everything gives way and nothing stays fixed. You cannot step twice into the same river, for other waters and yet others go ever flowing on. Cool things become warm, the warm grows cool, the moist dries and the parched becomes moist. It is in changing that things find repose. It should be understood that war is the common condition, that strife is justice, and that all things come to pass

> through the compulsion of strife. Homer was wrong in saying "would that strife might perish from amongst gods and men". For if that were to occur then all things would cease to exist.

The Heraclitean picture of the universe in which all things are in a state of flux is rather stark and not very comforting, even though these processes are according to him ruled by logos or reason, viz., "All things come to pass in accordance with this logos".

It is not surprising that a reaction to the Heraclitean point of view developed since as stated earlier one of the aims of a worldview is to relieve one's anxieties about the uncertainties of the world not reinforce it. Using for, perhaps, the first time in our intellectual history an internally self-consistent logical argument Parmenides developed a counterview to Heraclitean flux in which the universe was an unchanging static unit. Parmenides argued that the concept of Non-being is logically self-contradictory. "Non-being cannot be and therefore no change is allowed for if a change from the state A to state B occurs then state A will not-be. But not-being is impossible and therefore nothing changes." If this is true then concludes Parmenides what appears to our senses as change must be deception and should not be trusted. With this very simple argument Parmenides caused every subsequent Greek thinker to question the value of the empirical approach. Parmenides views were challenged by contemporaries who argued that his system did not allow motion. His disciple Zeno countered their challenge with the following proof of the non-existence of motion.

> If anything is moving, it must be moving either in the place in which it is or in a place in which it is not. However, it cannot move in the place in which it is (for the place in which it is at any moment is of the same size as itself and hence allows it no room to move in) and it cannot move in the place in which it is not. Therefore movement is impossible.

Either because of their faith in empiricism was weak or because they were so impressed by their new discovery of deductive logic, the influence of these arguments of Parmenides and Zeno on Greek thought was enormous. Instead of concluding that there are limitations to deductive reasoning as is now recognized, the Greeks, by in large, concluded that sense data could not be trusted. Anaxagoras writes "because of the weakness of our senses we are not able to judge the truth". Even the subsequent empiricists such as Empedocles and the atomists, Democritus and Leucippus pay their respects to Parmenides argument by incorporating into their world system certain immutable elements of which the universe is composed.

For Empedocles the four immutable substances of which the universe is composed are Earth, Water, Air and Fire. Since most entities are mixtures of these elements the cause of the observed change of the world is due to the fact that the four basic elements are attempting to coalesce into pure states.

The atomists Leucippus and Democritus believed in the existence of tiny particles that they called atoms, invisible to the human, which possess only the properties of size, shape and motion. Each object is composed of a different combination of atoms. Although individual atoms cannot change their properties the objects of which they are composed can change as different combinations of these atoms form. The prediction of atoms some 2500 years before their actual discovery is a tribute to the richness of the thought of the early Greek physicists. The fact that our modern days atoms are mutable is not a shortcoming of our ancient predecessors but rather a failure on our part in labeling. We should have reserved the name atom for elementary particles such as proton, neutrons and electrons and called the objects that we now label as atoms by some other name. Or perhaps we should have reserved the word atom for quarks because as we will discover neutrons decay into protons, electrons and neutrinos, but more of that later.

The effect of Parmenides paradox on other thinkers was more devastating and contributed in my opinion to the demise of Greek physics. Although the Greek empirical tradition continued its value was seriously called into question. For example, Plato's mistrust of the senses was so great that he schizophrenically created two worlds, one the world of sense perception, which he wants us not to trust and the other, the world of ideas or forms, the only world where truth and knowledge is possible.

The physics of Aristotle represents a synthesis of Ionian materialism and the Platonic concern for form for he held that form and matter are inseparable. It is important to review his physics not because he represents the highest achievement of Greek science (in certain ways his work is retrograde) but because of his enormous historical influence particularly with the thinkers of the Middle Ages with whom modern science began. His influence, in part, was due to the methodical way in which he argued away any other point of view but his own, such as the atomists' concept of a void. The other reason is, like Plato, he founded a university, the Lyceum, which propagated his point of view.

The Parmenidean influence on Aristotle expresses itself, as with Plato, in a dichotomy. He divides the universe into two concentric spherical regions. At the center is the imperfect Earth constantly in change surrounded by the sphere of perfection, the immutable heavens. In the sub-lunar region of imperfection, matter is composed of the four Empedoclean elements, which are trying to arrange themselves into four concentric spheres in which the element earth is at the very center followed by water, air, and fire somewhat like the way these substances are arranged into the solid earth, the oceans and the atmosphere with fire having the property that it rises to the top. This model explains gravity as the tendency of earthy things to gather together. Change in general is explained in terms of the propensity of the Empedoclean elements to coalesce.

Aristotle postulated a fifth element, the eternal and unchanging aether, which completely fills the heavens so there is no empty space. "Nature abhors a vacuum." The heavenly bodies move naturally without the assistance of any force in perfectly circular orbits, the circle being the most perfect shape imaginable. Aristotle astronomy was adopted from the work of Eudoxus. It was later developed by Ptolomey who changed details of the system but left the basic structure unchanged.

Motion on Earth unlike the heavenly motion tends to be rectilinear and constantly requires the action of a force. Since a concept of inertia is missing not even constant rectilinear motion can be explained without the action of some force. For example, Aristotle explains that the reason an arrow continues to move once it has lost contact with the bow is that as the arrow moves it creates a void, which nature abhors and hence the arrow is pushed along by the air rushing in to fill up the vacuum. If a force produces a constant speed then we are left with the puzzle of why falling objects accelerate. Aristotle claims that since the falling object is traveling back to its proper place in the universe the joy of its returning home makes it speed up.

With the exception of the atomists and the astronomers, Heracleides (not to be confused with Heraclitus) and Aristachus, to be discussed below the worldview of Aristotle held swayed until the Copernican revolution of the 16th century. Some thinkers have considered this a tribute to Aristotle who they say was 2000 years ahead of his time. From my point of view, however, it is only a reflection of his ability to suppress ideas other than his own by logically arguing them away. He thereby created an atmosphere that was not inductive to new ideas as is illustrated by the reception of the ideas of the two post-Aristotelian astronomers Heracleides and Aristachus. Heracleides proposed that the daily rotation of the heavens could be more easily explained in terms of the rotation of the Earth rather than the entire heavens. He also proposed that the planets Mercury and Venus orbit the sun instead of the Earth. Aristachus incorporating these ideas, also proposed that the Earth orbited the sun and not vice-versa. His contemporaries found it difficult to accept the movement of the Earth. Also the enormous distance to stars that his system implied was difficult for them to comprehend. Some 2000 years later, however, the ideas of Aristachus formed the foundation of the Copernican system.

While no major new worldviews developed after Aristotle, the Greeks achieved a number of solid results in which mathematical concepts played an important role. These included a formulation of the mathematical laws of simple machines such as the lever, the wedge, the screw and the pulley, begun by Archimedes and completed by Hero, as well as Archimedes' advances regarding hydrostatics including his explanation of buoyancy.

The Roman interest in physics was almost exclusively in terms of practical applications. Their engineering achievements such as their aqueduct system supplying Rome with millions of gallons of fresh water, their sewage system, their road system and their harbors are all worthy of mention. Little can be said about the scientific achievements during the early Christian era, which immediately followed the Roman period. Interest in science declined to an even greater extent, as theology became the dominant concern of the day. The Greek scientific tradition continued in the East, however, by Arabic scholars whose major contribution was the development of algebra and chemistry. To them we owe thanks for the transmission of the concept of zero, a non-trivial concept invented by Hindu mathematicians. They also preserved much Greek learning that might have been lost otherwise.

When the resurrection of interest in science took place in Europe during the Renaissance the three sources of ancient Greek learning were from those original Greek works that survived and from the comments and translations of both Latin and Arabic scholars. Before turning to the rise of modern science in Europe let us first examine the question of why abstract scientific thinking first began in Ancient Greece.

In the last chapter we pointed out that the scientific achievements of the ancient cultures we studied were intimately connected with their technological activities. One is tempted like a number of authors to conclude that the Greek achievement of an abstract science is connected with their knowledge of the technical achievements of the people they were in contact with such as the Egyptians and the Mesopotamians. If this is true one wonders why the Chinese did not develop abstract physics since their technological superiority to the Greeks is attested to by their invention of clocks, iron casting, paper, block printing, movable print, silk, animal harnesses, irrigation canals, suspension bridges, gun powder, guns and porcelain to mention a few. Joseph Needham in his book The Grand Titration claims the Chinese played an important role in the developments of science in the West as information of their discoveries reached Europe. I am sure to some extent this is true but one cannot help but ask the question if technology plays such an important role why didn't the Chinese develop science themselves.

When I first formulated this question when I wrote the first draft of this book way back in 1973 my answer to this question was in terms of two influences, which were felt much more strongly by the Greeks than the Chinese, namely codified law and monotheism. The first of these influences, the codification of law in the West, began in Babylonian under Hammurabi. In China behavior was guided more by tradition, moral persuasion and social pressure than by a legal code. The Chinese had laws but they were not codified. The law was an important part of Greek life with a philosopher often playing the role of the lawgiver in his society. It is not much of a stretch that the concept of human law would lead one to develop the notion of the laws of nature. The analogy between these two concepts of law was expressed by a number of the early Greek physicists. Anaximander wrote: "The Unlimited (Apieron) is the first principle of things that are. It is that from which the coming-to-be takes place, and it is that into which they return when they perish, by moral necessity, giving satisfaction to one another and making reparation for their injustice, according to the order of time."

The other influence that I identified was also felt much more strongly in the West than the East and that was the Hebrew concept of monotheism. Before the Jewish concept of God people believed that a god was localized in a place such as on the top of a mountain or under the sea. The influence of the god and hence the laws pertaining to his worship were only local in nature. They held sway over the small territory in which they were worshipped. With the concept of an omnipresent God whose law applied everywhere the idea of a universal law developed. All of the early Ionian physicist and later empiricists were monotheistic and believed in a universal law as is illustrated by the following quotes from Heraclitus, "All things come to pass in accordance with this Logos" and from Anaxagoras, "And Mind set in order all that was to be, all that ever was but no longer is, and all that is now or ever will be."

These fragments illustrate the intimate connection for the Greek physicists between the belief in universal law and monotheism, which parallels the Jewish relationship of Jehovah and the Law. The Greek deity is usually an abstraction of reason as is illustrated by the way Heraclitus and Anaxagoras refer to him as Logos and Mind respectively.

This was my explanation for why abstract science began in the West as of 1974 when I first met my colleague Marshall McLuhan, an English professor at the University of Toronto and the communications theorists who was famous for his one-liners: "the medium is the message", "the global village" and "the user is the content." McLuhan (1962 & 1964) together with Harold Innis (1971 & 1972), whose works McLuhan built upon, were the founders of a tradition known as the Toronto School of Communications. The Toronto School established at the University of Toronto in the fifties explored the ways in which media of communication, including the alphabet, have shaped and influenced human culture and its various social institutions. In particular, McLuhan showed that the use of the phonetic alphabet and the coding it encouraged led the Greeks to deductive logic and abstract theoretical science. The tradition that began as the Toronto School of Communication now has a much broader geographic base and has given rise to the term media ecology (see www.media-ecology.org).

In 1974 McLuhan, having heard of my Poetry of Physics course, invited me to lunch at St. Michael's College at the University of Toronto. He asked me what I had learned from my Poetry of Physics project. I told him of my attempt to explain why abstract science began in the West instead of China because of the traditions of codified law and monotheism as I described above. McLuhan agreed with me but pointed out that I had failed to take into account the phonetic alphabet, another feature of Western culture not found in China, which had also contributed to the development of Western science. Realizing that our independent explanations complemented and reinforced each other, we combined them in a paper entitled “Alphabet, Mother of Invention” (McLuhan and Logan 1977) to develop the following hypothesis:

> Western thought patterns are highly abstract, compared with Eastern. There developed in the West, and only in the West, a group of innovations that constitute the basis of Western thought. These include (in addition to the alphabet) codified law, monotheism, abstract theoretical science, formal logic, and individualism. All of these innovations, including the alphabet, arose within the very narrow geographic zone between the Tigris-Euphrates river system and the Aegean Sea, and within the very narrow time frame between 2000 B.C. and 500 B.C. We do not consider this to be an accident. While not suggesting a direct causal connection between the alphabet and the other innovations, we would claim, however, that the phonetic alphabet (or phonetic syllabaries) played a particularly dynamic role within this constellation of events and provided the ground or framework for the mutual development of these innovations.

The effects of the alphabet and the abstract, logical, systematic thought that it encouraged explain why abstract science began in the West and not the East, despite the much greater technological sophistication of the Chinese, the inventors of metallurgy, irrigation systems, animal harnesses, paper, ink, printing, movable type, gunpowder, rockets, porcelain, and silk.

There is a reason why the alphabet has had such a huge effect on Western thinking. Of all the writing systems, the phonetic alphabet permits the most economical transcription of speech into a written code. The phonetic alphabet introduced a double level of abstraction in writing. Words are divided into the meaningless phonemic (sound) elements of which they are composed and then these meaningless phonemic elements are represented visually with equally meaningless signs, namely, the letters of the alphabet. This encourages abstraction, analysis (since each word is broken down into its basic phonemes), coding (since the sounds of spoken words are coded by visual signs), and decoding (since those visual signs are transformed back to spoken sounds through reading).