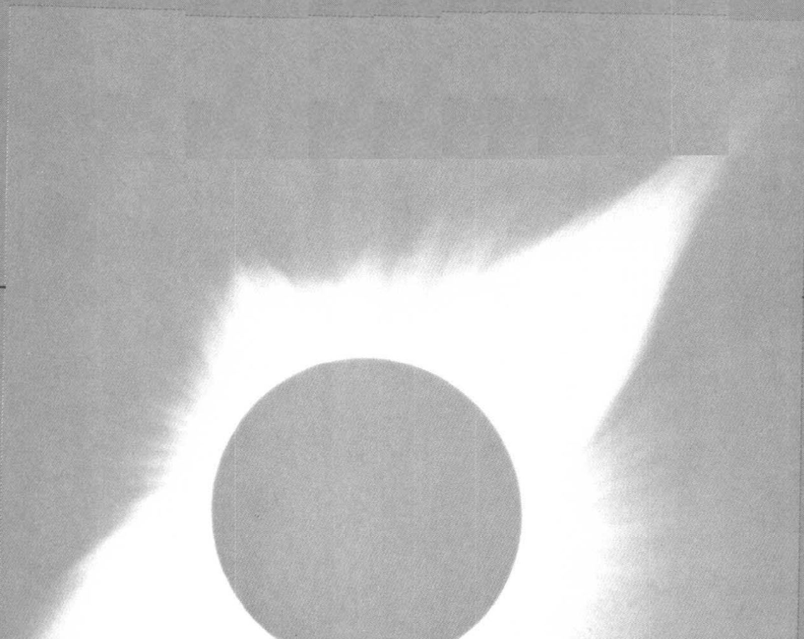
SECOND EDITION

PHYSICAL SCIENCE

A DYNAMIC APPROACH

Robert T. Dixon



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A DYNAMIC APPROACH

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PREFACE

This book has grown out of a series of lectures that have been presented, with great success, to students who typically have little or no background in science or mathematics. It presents, in a rather broad spectrum, the spirit of scientific investigation and attempts to develop in the student an appreciation for the physical universe.

The history of science is used as a tool whereby the student is made aware of the flow of ideas that have issued from the human mind. Of even greater significance, however, the book shows the interaction and interdependence of one person's work upon that of another.

Each chapter is developed from the most obvious relationships (based on experiences that are common to almost everyone or at least those that can be easily visualized by everyone) to the more obscure relationships. Technical terms are used only after adequate definition; in fact the order of introduction of technical terms is the key to this readable, understandable text.

This book will explain many of the phenomena that students have wondered about and will tend to expand the "universe" of each individual reader. It will convey some of the thought processes that brought humans to their present understanding of the universe and will create an interest for deeper study in one or more of the physical sciences.

The book is designed for a one-semester or two-quarter course for liberal arts students. Basically it utilizes a descriptive approach, but the quantitative flavor of science is also introduced and developed in a number of sections. Where this occurs, concepts are always verbalized to provide understanding in cases where mathematical background is lacking.

I would like to acknowledge the fine cooperation of the numerous professional and technical organizations who supplied illustrations for this text, and the very generous assistance of my students who tested many of the approaches I have taken and of my colleagues who have criticized portions of the work—Professors John Elliot, Harold Nemer, John Georgakakos, Ray Hawley, and Bob Southwick. The suggestions of Dr. Wesley E. Lingren, Seattle Pacific University, are also appreciated in addition to those who reviewed the manuscript in its final form. I

would also like to thank the staff of Prentice-Hall, especially Doug Humphrey, Physics Editor; Karen Clemments, production editor; and Dawn Stanley, designer, for their conscientious transformation of the manuscript into a book.

The constant encouragement and patience evidenced by my wife Marian has been of great value to me and it is to her that this book is dedicated.

Riverside, California

Robert T. Dixon

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1 EARLY CONCEPTS OF NATURE

Humans are forever trying to relate to the universe in which they live. Survival, in early times, depended upon learning to live with nature in a harmonious manner. The very fact that humans are intelligent thinking beings suggests that they have long been aware of the events that take place around them, they have recognized certain relationships (cause and effect), and they have turned those relationships to their own advantage. Thus an informal form of "science" began a long time ago. Still fundamental to being a scientist are the following:

1. Be a good observer—notice things around you and describe them accurately.
2. Look for relationships—search for cause and effect.
3. Formulate a theory—express the relationship you suspect to be true.
4. Test your theory—see if a certain set of circumstances will bring forth the expected result.

BASIC NEEDS OF MAN

The basic survival needs of early humans included food, clothing, and shelter. How can we know the way in which early humans met those needs when they left no written record? The archaeologist who is continually digging into the past would look at the flint tools shown in Figure 1.1 and would construct a story something like this: Early humans used clubs to kill animals for food, but one day they saw an animal accidentally impaled on the broken branch of a tree, and at that moment got the idea that a spear might be more effective than a club in killing wild animals. Furthermore, if a sharp stone were placed at the head of the spear, it would penetrate the hide of the animal more easily than a sharpened stick and it would be more

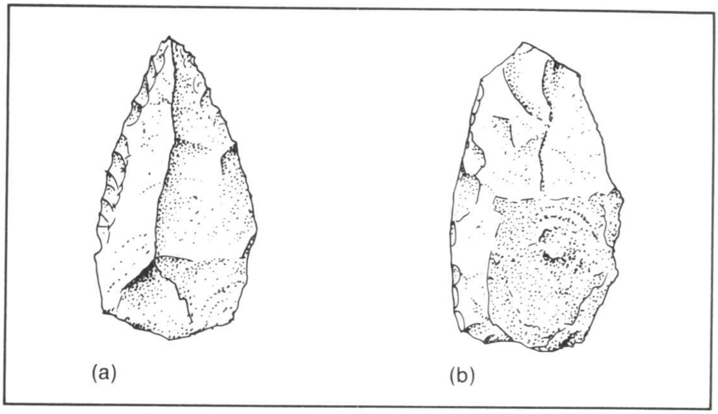

Figure 1.1 Flint tools of the Stone Age: (a) spear head; (b) scraper for working hides.

durable. Certainly the spearhead shown in Figure 1.1(a) gives evidence of a deliberate effort on the part of early humans to shape the stone by a chipping action. The stone shown in Figure 1.1(b) suggests a scraping tool with which to prepare the skins of animals for clothing. So it is that much of the early history of human's efforts to relate to nature comes by piecing together such sketchy evidence as this.

A very significant thing happened when humans discovered fire: At first they did not understand that burning represents a chemical reaction, but the lack of such understanding did not prevent the use of their newfound phenomenon to add new dimensions to living—such as cooked food and the comfort of a warm cave. By 4000 B.C., near the end of the Stone Age, humans had moved into what is called the Neolithic period—the age of working with metals. Perhaps this period began with the discovery of a shiny material—gold—which can be found in nature in almost pure form. Most other metals appear in mixtures called *ores*. In an attempt to shape such material, these later Stone Age people found that they could beat the gold into a flat sharp-edged instrument (or ornament) without it breaking; however, such instruments would not hold an edge but would blunt easily.

Eventually other metals, such as copper and tin, were found; but these were not in pure form and had to be separated from the rock (ore) by heating in a fire. Thus with the discovery of fire, smelting was made possible, and by 3000 B.C., humans had learned to produce metal instruments ranging from hunting spears to cooking utensils. The Bronze Age was ushered in when humans blended (by heating) copper and tin. Consider a bronze sword or spearhead; it is capable of maintaining a sharp edge. Undoubtedly, this fact was discovered only after other mixtures had been attempted, some of which led to useless products. In a similar fashion, the path of modern science is not always a smooth one but often leads into blind alleys from which the researcher must turn back and take another road.

NOMADS TURN TO FARMING

Early humans were basically hunters and therefore nomads—always searching for a new food supply. By about 5000 B.C., however, a significant change took place. Humans learned to domesticate animals and to grow crops, which allowed them to remain in one place. But what would these people look for if they were settling in one place to farm? They would certainly desire fertile soil, an ample and ready supply of water, and the warmth of the sun for a significant part of the year. The earth provides all these elements in certain naturally fertile river valleys, for example, the Tigris and Euphrates rivers of Mesopotamia (today called Iraq) and the Nile River of Egypt. We recognize these and several other river valleys as the seats of early civilization. The fact that men and women could remain in a single location and produce their own food led to other significant steps—such as groups banding together for their mutual benefit, bartering with others, and developing a common language, as well as establishing a division of labor. These are the roots of civilization.

Although nomadic people would certainly have noticed the cycles in nature, such as day and night and the monthly phasing of the moon, their success as farmers would depend upon recognizing the cycle of the seasons. If they planted seed in the wrong season, they could not expect a harvest. At first this cycle of sowing and reaping must have gone through a period of experimentation (trial and error). Let's suppose that these early people had decided that the spring was the best time to plant seed. What observation could they (or you) have made that would have indicated the approach of spring? They might have noticed the changing number of daylight hours and recognized a correlation between the altitude of the noon sun and the longer or shorter days.

Imagine an experiment that they may have performed—you could try it today. As the days are getting shorter (toward winter), choose what you think to be the shortest day and place a stick in the ground that points directly to the noon sun. The stick will cast no shadow at this moment. Now bide your time, as the days get longer, until the longest day is reached, and place another stick in the ground that points to the noon sun. The first stick will cast a shadow, even at noon, but the second stick will not cast a shadow at this moment. You have marked the extreme positions of the noon sun—higher in the sky on the longest day (which we would associate with summer) and lower in the sky on the shortest day (which we would associate with winter).

The spring should fall halfway between these two extremes. A stick should then be placed in the ground making an angle halfway between the two sticks already placed. Allowing time to pass from the shortest day until the midway stick casts no shadow at noon, the early observer would have an indication of the season called spring—a time to plant seed. This springtime event corresponds to March 22 on our calendars and we call it the *vernal* (spring) *equinox.* The longest day, when the second stick had no shadow

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corresponds to June 22 we call it the *summer solstice*. As the sun returned to cast no shadow from the midway stick, the date is September 22 and we call it the *autumn equinox*. Finally, as the days continued to shorten and the first stick cast no shadow, the date is December 22 and we call this the *winter solstice*. Similarly, the early farmer could mark the critical seasons of the year with three sticks in the ground. See Figure 1.2.

BABYLON, CRADLE OF ASTROLOGY

At the heart of Mesopotamian civilization is the city of Babylon, and the recorded history of this Middle East area takes us back to about 3000 B.C. In addition to the ideas expressed in the last paragraph, the Babylonians were particularly interested in the lunar cycle (the cycle of the moon's phasing). They observed this cycle over and over again, noting the period of time from one full moon to the next. This is not as easy as it may sound, for the cycles in nature generally do not occur in units of whole days. Therefore one does not merely observe a single cycle if one desires to determine the period precisely.

The Babylonians observed that twelve lunar cycles occurred in 354 days, and upon dividing 354 days by 12, they discovered the average period of one cycle to be $29\frac{1}{2}$ days. Out of this discovery came the division of time called a *month* (one can see the derivation of the word from "moonth"). But how could anyone place $29\frac{1}{2}$ days in a month—the extra half-day would create a real problem? The Babylonians solved that one by placing 29 days in the first month and 30 days in the next, and so they alternated the number of days in the month throughout the year. Six months of 29 days each and six months of 30 days each make 354 days, which averages out to $29\frac{1}{2}$ days per month.

If a year started with a new moon, then the new moon would appear at the beginning of each month, making it easy to predict the phase of the

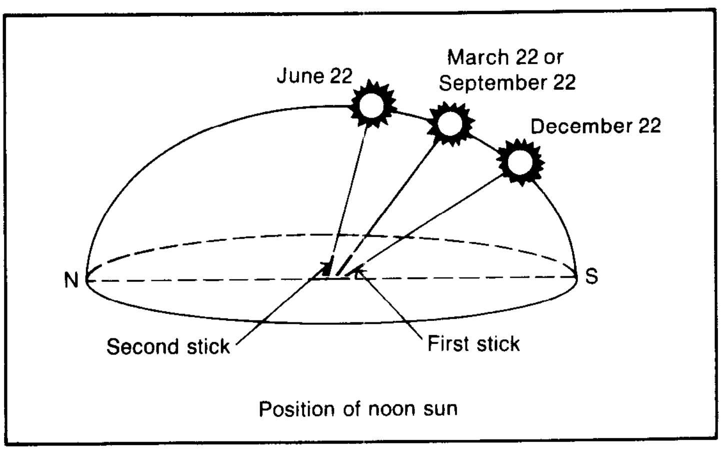


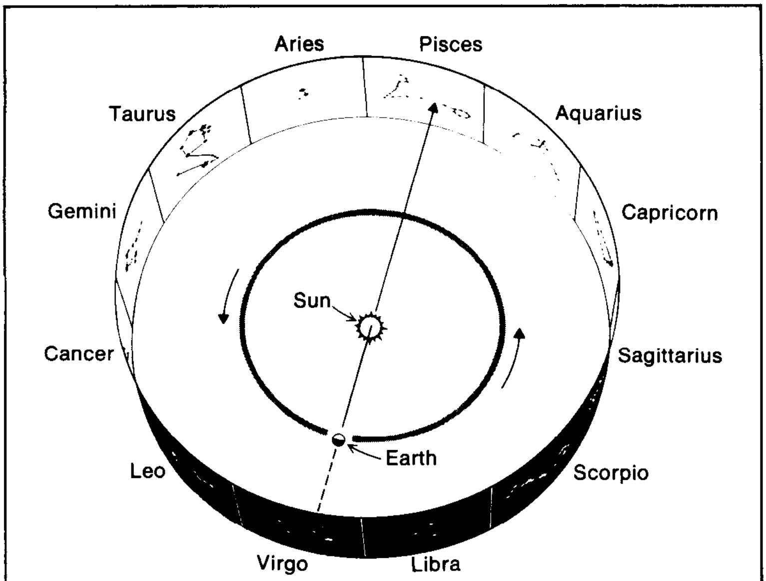
Figure 1.2. Three sticks, which respectively mark the noon sun on the shortest day of the year, on the longest day of the year, and at a mid-point between these two extremes, can be used to keep track of the seasons and thereby to mark the passage of one year.

moon on any date of the year. Such a calendar is called a *lunar* calendar, and many cultures have used lunar calendars; but they always experienced a particular problem—the year of seasons is not 354 days long, but $365\frac{1}{4}$, and eventually one must decide whether a calendar based on the cycles of the moon phases or one based on the cycle of seasons is more advantageous.

The roots of astrology also lie with the Babylonians. It seems that they were open to the idea that the knowledge and plans of the gods might be revealed through the motions of the sun, moon, and planets, and so the future might also be revealed. Therefore the Babylonians systematically recorded the positions of these bodies as they moved with respect to the stars. It was they who assigned arbitrary meanings to their placement at any given time.

With the apparent motion of the sun through the stars being completed in just over 354 days (twelve lunar months), it was quite logical that the Babylonians divided the apparent path of the sun into twelve parts—the twelve signs of the zodiac. They envisioned the groupings of stars along this path as eleven different creatures plus one inanimate object (the balance or scales called *libra*), hence the word *zodiac* from the same root word as we derive *zoo*. Although they did not visualize the apparent motion of the sun among the signs of the zodiac, as deriving from the earth's revolution, we have shown the effect they saw in Figure 1.3. Although there are a total of

Figure 1.3. As the earth revolves about the sun, the sun appears to align itself with each sign of the zodiac in succession. The sun is shown aligned with Pisces, but in one month's time it will align with Aries, and so forth. In one year, the sun will again align with Pisces.



88 constellations in the sky, the twelve corresponding to the signs of the zodiac remain special because they represent the path through which the sun, moon, and planets appear to move. Hopefully you will learn to recognize these twelve constellations so that you will know where to look for the planets in the sky.

Astrology, from the time of its inception, has been a great motivator for persons to chart the sky and record the motions of the planets. Much of the ancient record to which astronomers refer today would not be available had such motivation to know the future been lacking. Most of the observers we will mention, who lived before the seventeenth century, were actually astrologers, and they were supported in their work by kings and rulers. Astronomy parted company with astrology at about this time because scientists recognized that godlike creatures neither pushed the planets nor were synonymous with them in any way, and furthermore that the gravitational effects of the planets (which astrologers had thought to be effective in controlling one's life) were far less effective on a newborn infant than were the gravitational effects of the doctor and nurses who attended the birth. (See the work of Galileo and Newton in Chapters 2 and 4.) Astrologers today still make some of the false assumptions mentioned above, and humans still spend more than a million dollars per year in the name of this nonscience.

SUPERSTITION VERSUS SCIENTIFIC EXPLANATION

It was traditionally the responsibility of the astrologer to predict eclipses, because if an eclipse could be predicted, then the terror and stigma attached to such events were mollified; but woe to the astrologer who failed to predict an eclipse because such failure might cost him his life.

For early humans, the only explanation for an eclipse lay in superstitions that had grown over the years. For example, in certain cultures it was thought that a dragon had swallowed the sun when it was eclipsed. By banging pans the people believed that they could frighten the dragon, who would then regurgitate the sun. Of course this remedy worked every time, which only reinforced the tradition! Only after such an event was explained in terms of the moon passing between the earth and the sun, and only after such events became predictable, could the superstition be dispelled. You will see this pattern repeated many times as human understanding of the universe broadened and deepened.

EGYPTIAN CIVILIZATION

The very existence of life in Egypt was based on the flooding of the Nile River, for this phenomenon brought natural irrigation and fertile silt to the broad farmlands on the river's banks. Characteristic of any civilization is the division of labor and specialization, and it soon became the prerogative of the priestly order to predict the overflow of the Nile. This was possible because the cycle of its overflow was seasonal, matching the yearly cycle of the sun that we traced earlier. The Nile begins to rise and approaches its flood stage on the longest day of the year, so it was merely a matter of predicting the longest day of the year (the summer solstice). This was done in a very spectacular way at the Great Temple of Amen-Ra at Karnak (Figure 1.4). The temple was so oriented that on the longest day of the year, the rays of the setting sun would stream through a long series of doorways and literally "flash" upon the "holy of holies," and whomever was seated upon the throne was revealed at that moment in a mystical fashion. As was true of many early cultures, the sun became a godlike figure to be worshiped.

Records indicate that the Egyptians had a calendar of 360 days per year (twelve months of 30 days each), and yet the priests knew that the period of time between "flashes" upon the throne was not 360 days and that such a calendar would get out of synchronization with the season by several days per year if not corrected. But how would they, or anyone, determine more precisely the number of days in a year of seasons? Let's suppose that the priest kept a record of the number of days between successive "flashings" upon the throne as follows:

First year	365 days
Second year	365 days
Third year	366 days
Fourth year	365 days
Fifth year	365 days
Sixth year	365 days
Seventh year	366 days
Eighth year	365 days
Total	2922

Averaging these numbers yields $2922 \div 8 = 365\frac{1}{4}$ days per year.

This illustrates again a very important principle that has always been valid in scientific investigation: Making repeated independent observations of a phenomenon and then averaging those observations can be assumed to produce a result that is more accurate than any single observation chosen at random.

In order to compensate for the quarter day in the calculation above, we add a day to every fourth year. It was Julius Caesar who inaugurated the leap year.

THE EGYPTIAN "UNIVERSE"

Although the Egyptians were rather sophisticated in their understanding of the yearly cycle of seasons, their model of the universe seems very primitive. They had no indication that the earth was round, and like so many early cultures, the sun was an object to be worshiped as a god. They named the

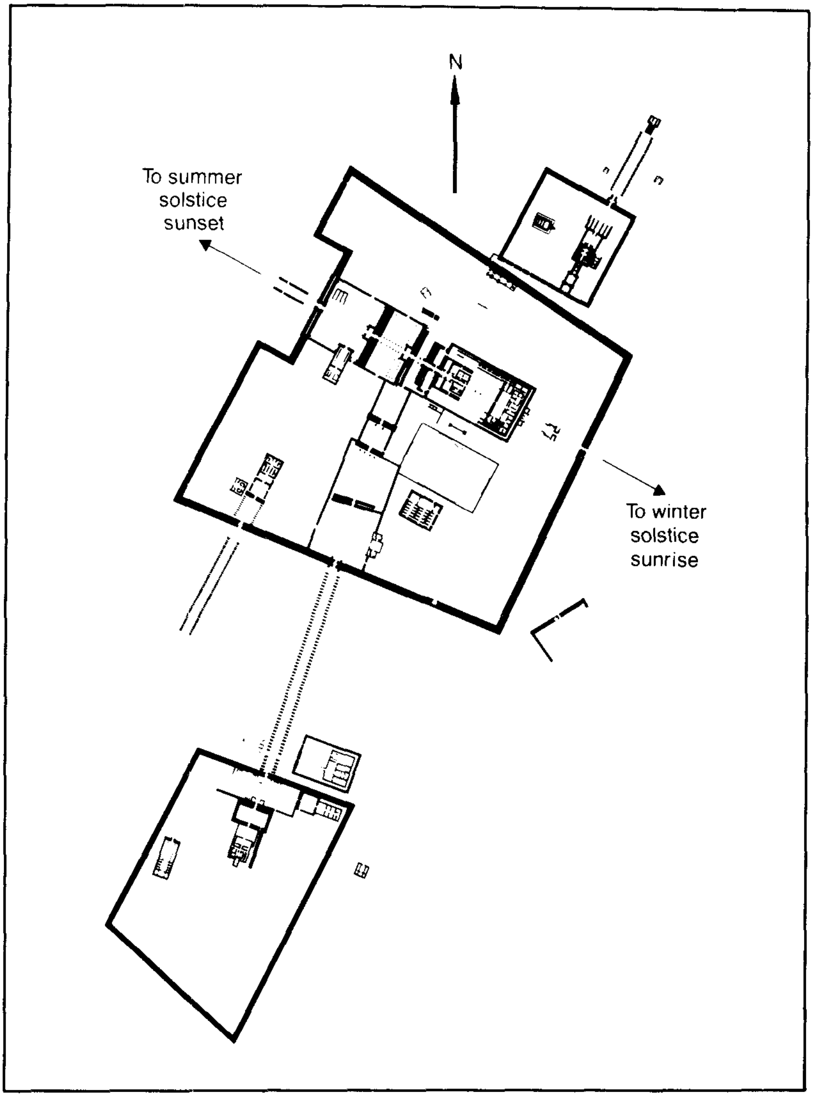


Figure 1.4. The Great Temple of Amen-Ra at Karnak, Egypt, shows an alignment of many corridors and doorways with the setting sun at the time of the summer solstice. On the longest day of the year, the sun's last rays would seem to flash upon the holy of holies, creating a rather mystical phenomenon. (Griffith Observatory, Joseph Bieniasz)

sun god, Ra, and pictured him moving in his barge up over the back of the sky goddess, Nut, in the daytime. At night he would fall into the hands of the god of the underworld, who would conduct him under the flat earth to reappear the next day (see Figure 1.5). For the early Egyptian, this model constituted the entire universe.

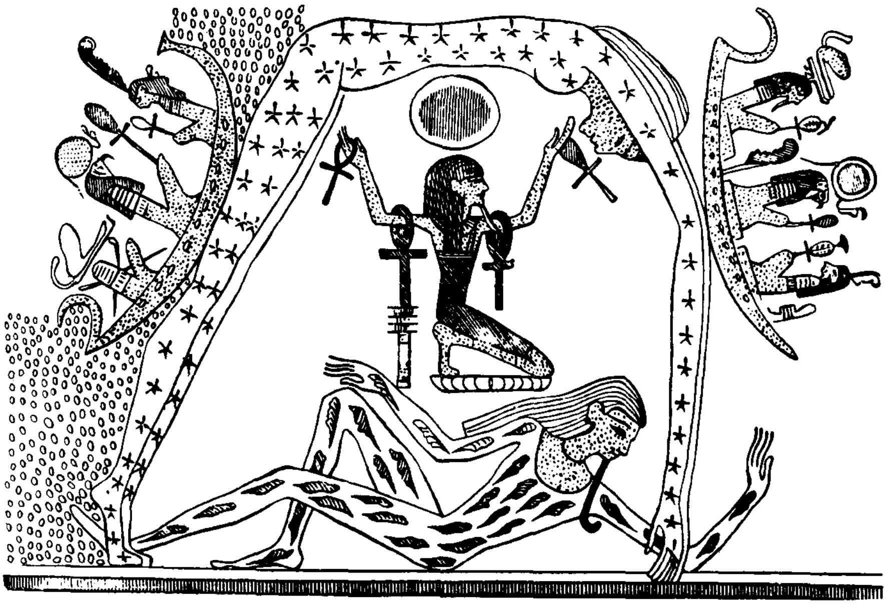


Figure 1.5. An Egyptian concept of the universe and the motion of the sun across the sky. The sun god Ra travels in his barge up over the sky goddess Nut. (Yerkes Observatory)

We also find evidence of early civilizations in India and China; however, the evidence is not as clearly defined as in Babylon and Egypt. What is a bit surprising is that we have evidence of an early civilization in the British Isles.

STONEHENGE

There are numerous arrangements of stones dotting the plains of England and Brittany (France), but the most spectacular is found in the Salisbury Plain of England, a monument called Stonehenge (see Figure 1.6). Scientists have dated a set of deer antlers used as digging tools at this site and found it to have been constructed between 3000 B.C. and 2000 B.C. It is as old as some of the civilizations we have been discussing, yet it shows a degree of sophistication that seems improbable for the time. First, the stones are arranged so precisely that the midwinter sunrise aligns perfectly with two principal stones, as does the midwinter sunset and the midsummer sunrise and sunset—in this way measuring the period of a year as precisely as did the Egyptians. But Stonehenge does more; it also records the rising and setting points of the moon throughout the month and throughout the year. As a result, it is possible to predict the alignment of the moon, sun, and earth, and hence the occurrence of eclipses. We have seen how important the

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