1958

1. Greek and Medieval Science

Robert L. Bloom
Gettysburg College

Basil L. Crapster
Gettysburg College

Harold A. Dunkelberger
Gettysburg College

See next page for additional authors

Bloom, Robert L. et al. "1. Greek and Medieval Science. Pt. VIII: The Development of Modern Science." Ideas and Institutions of Western Man (Gettysburg College, 1958), 1-11.

1. Greek and Medieval Science

Abstract
What kind of questions did the Greeks ask themselves about the physical universe? We can paraphrase Plato: the stars move about the earth in circles, the perfect paths, and they move with uniform motion as befits divine and eternal beings. But five of these stars are planets (Greek for wanderers) which appear to have irregular motion, first moving forward, then actually stopping, and then moving backward for awhile. Since the heavens are incorruptible, the planets too must really be moving in uniform motion in circular paths. How then can we account for the apparently irregular motions? What uniform motions must be hypothesized to account for the observable wanderings? [*excerpt*]

Keywords
Contemporary Civilization, Science, Medieval Science, Greek, Science, Plato, Universe

Disciplines
Astrophysics and Astronomy | History | History of Science, Technology, and Medicine

Comments
This is a part of Section VIII: The Development of Modern Science. The Contemporary Civilization page lists all additional sections of *Ideas and Institutions of Western Man,* as well as the Table of Contents for both volumes.

More About Contemporary Civilization:

From 1947 through 1969, all first-year Gettysburg College students took a two-semester course called Contemporary Civilization. The course was developed at President Henry W.A. Hanson's request with the goal of "introducing the student to the backgrounds of contemporary social problems through the major concepts, ideals, hopes and motivations of western culture since the Middle Ages."

Gettysburg College professors from the history, philosophy, and religion departments developed a textbook for the course. The first edition, published in 1955, was called *An Introduction to Contemporary Civilization and Its Problems*. A second edition, retitled *Ideas and Institutions of Western Man*, was published in 1958 and 1960. It is this second edition that we include here. The copy we digitized is from the Gary T. Hawbaker '66 Collection and the marginalia are his.

Authors
Robert L. Bloom, Basil L. Crapster, Harold A. Dunkelberger, Charles H. Glatfelter, Richard T. Mara, Norman E. Richardson, and W. Richard Schubart

VIII. THE DEVELOPMENT OF MODERN SCIENCE

Man seems not to make constant progress in all the fields in which he toils. Some eras are marked by great surges of increased mastery in a particular field and are followed by times of continued effort with but little additional skill. Men working in other fields begin to absorb the new knowledge and to readjust their veiws to accommodate it. The period of accommodation may be explosive, as we shall see.

The reasons for the seemingly erratic advances are surely complex. Men live in societies, and men's interests are colored by the needs and interests of society. The kind of society in which a man lives influences the kind of questions he asks himself. As an example, the sixteenth and seventeenth centuries were times in which a new approach to science came to fruition and finally became an important part of Western culture. The study of nature was not dead from the time of the Greeks until the Renaissance, but it was disorganized and burdened with principles which we would no longer call scientific. In the Middle Ages, the principal advances were made in the crafts, as exemplified by the great cathedrals that were built. Man learned both to mine and use the metals with new expertness. He improved his ability to identify and cure disease. In spite of all this, we say that the interval from the Alexandrian Greeks to the late Renaissance was a period of feeble scientific progress. Why do we believe this? By what criteria do we conclude that science had a rebirth in the sixteenth century?

Before we can understand what happened in the scientific world of the sixteenth century, we must know what of the old was cast aside, what was rediscovered, and what was newly discovered. We cannot hope to review all the aspects of the scientific revolution. We shall take only a single thread, choosing to trace man's idea of the structure of the universe and particularly the place of the earth in that universe. This story begins with the Greeks, as do most of the stories of Western man.

1. Greek and Medieval Science

What kind of questions did the Greeks ask themselves about the physical universe? We can paraphrase Plato: the stars move about the earth in circles, the perfect paths, and they move

Types of approaches. The kind of society a man lives in will determine the kind of questions he asks. and the kind of answers they got depended on the questions they asked.

with uniform motion as befits divine and eternal beings. But five of these stars are planets (Greek for wanderers) which appear to have irregular motion, first moving forward, then actually stopping, and then moving backward for awhile. Since the heavens are incorruptible, the planets too must really be moving with uniform motion in circular paths. How then can we account for the apparently irregular motions? What uniform motions must be hypothesized to account for the observable wanderings?

retrograde

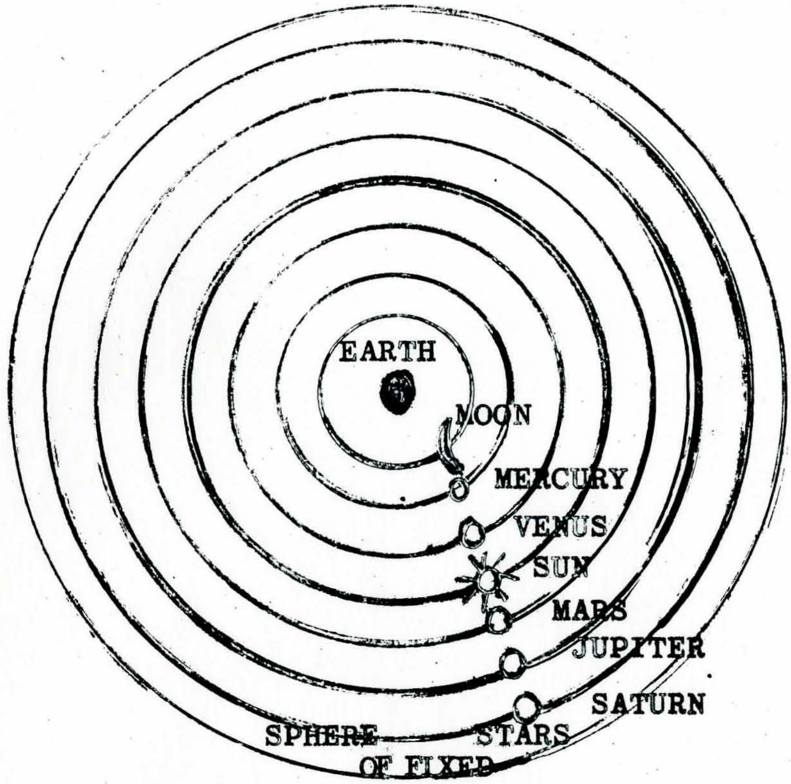
incorruptible must be moving in circles

We note here a typically Platonic approach to a problem about the physical universe. Plato set certain metaphysical conditions on the answer to a physical question. Earlier the Ionians had attempted to explain the motions of the heavenly bodies without invoking any divine being. They made little headway in convincing their contemporaries of the correctness of their approach. In fact they seem to have scandalized the citizenry by their omission of the theological view that the stars were divine. The Pythagoreans wove theology and a mystical reverence for numbers into the study of astronomy, and only then did the main stream of Greek thinkers take any serious interest in the subject. Plato followed the Pythagoreans in stating that uniform circular motion was divinely ordered and thus was surely the motion of the divine heavenly bodies. This view is implicit in the question that was posed.

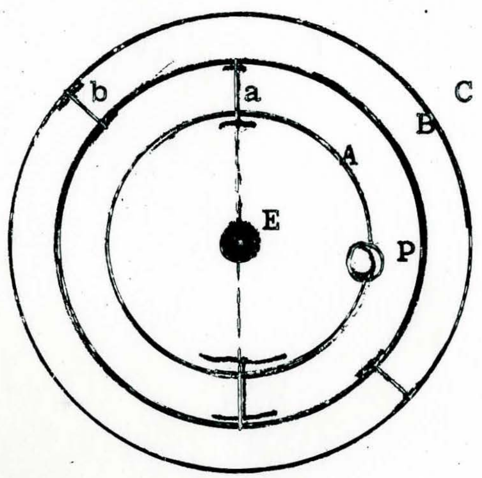
So far as we know, Plato did not attempt to answer his own question, but Aristotle did construct a theory within the restriction imposed by Plato. Aristotle's theory was geocentric (earth-centered) with the earth motionless at the center of the universe and all heavenly bodies circling the earth. The picture is as follows. The earth is placed at the center of the celestial sphere which contains the fixed stars. This sphere rotates about the earth's north-south axis once each day, accounting for the periodic appearance of the stars. The sun, moon, and five planets require separate treatment. To each is assigned a set of interacting spheres whose ordered motions account for the apparent wanderings. These spheres, one inside the other and each centered at the earth, rotate about different axes to account for the fact that these seven bodies do not rise and set at the same point on the earth's horizon. Aristotle's theory is depicted by the diagrams in Figure I.

The moon's sphere, the nearest to the earth, marks the boundary between the changeable, imperfect region of the universe and the unchangeable, perfect region. Within the moon's sphere the imperfect matter consists of mixtures of four elements: earth, water, air, and fire. Every body contains some of each of the elements, and that element which predominates determines the physical properties of the body. For instance, each element has its "natural" position, fire and air above, earth and water below. Thus, the steam rising from a pot of boiling water is due to the introduction of the element fire whose natural position is up. When the steam cools, the fire

qualities & natures of bodies determine their types of actions. (ours is quantitative) heavenly bodies are more perfect than earthly bodies. circular motion is the most perfect. ∴ heavenly bodies must have circular motion. observation wasn't necessary to provide data. practical applications in navigation. "natural" state of properties determines their position.



(a) Aristotle's view of the positions of the earth, moon, sun, five planets, and the fixed stars.



(a) Aristotle's scheme for planetary motion. Planet P is fixed on sphere A centered at the earth E. Sphere A rotates uniformly about the axis (a) through E and fixed rigidly to sphere B. Sphere B rotates uniformly about an axis (b) which is fixed rigidly to sphere C, etc.

FIG. I. ARISTOTLE'S THEORY

planet imbedded in a solid transparent sphere.

leaves. The steam condenses to water and again falls to its natural position. As the quantity of an element present in a body determines the swiftness with which the body returns to its natural position, the heavier solid bodies fall more rapidly. In fact, the nearer to their natural positions bodies get the faster they move, rather like a traveler who moves more and more rapidly as he gets closer to home. emphasis on quality.

A brief aside is called for here. That Aristotle's physics does not coincide with our own today is no cause for belittling Aristotle. Aristotle's physics was built largely on qualitative principles which afforded little place to the ideas of measurement and quantity. Aristotle was a classifier rather than a measurer. As we shall see, our present primary criterion for a scientific theory is that it accurately describe the phenomenon under study and predict quantitatively what will follow from a given set of conditions. Aristotle on the other hand wanted each principle to fit consistently into the entire hierarchy of his philosophical system which encompassed far more than we would include under the heading of science. The validity of a principle in the broad realms in which it was meant to apply was for Aristotle much more important than the detailed predictions which followed from the principle in the narrow region of the physical sciences. theory can be true.

In the fourth century B. C. Alexander the Great conquered Greece and the Near East and proceeded to Hellenize the subject peoples. He built the city of Alexandria in Egypt, and that city became the center of Greek intellectual life under the leadership of Alexander's successors. A museum and a library were built, and these served as the focus for an assemblage of scholars which likely has never been rivaled. While the Alexandrian scientists made remarkable theoretical advances, they were not above considering practical problems. Mechanical devices such as pulleys, tackles, pumps, and gears were in common use. Steam power was used to move floats in religious processions. Even slot machines were in vogue to operate organs, temple doors, and to dispense holy water. Later Greek science best in Alexandria

Alexandrian scientists gave enormous impetus to astronomy and its allied studies. They calculated the radius of the earth and the distance from the earth to the moon. Advances of this nature were possible only because geometry and trigonometry had been developed, the latter largely by Hipparchus (lived about 150 B. C.) who made many of the astronomical measurements himself and who employed latitude and longitude to find points on the earth's surface. The contributions to map making and navigation stemming from this work can hardly be overestimated.

The astronomy that was developed by the Alexandrians came to the West through Arab translations of the Almagest of Claudius

first great step into naturalistic science & universe Aristotle probably used observation more than platonists.

Ptolemy (c. 90-168). We do not know exactly how much of this work is Ptolemy's and how much is a compilation of work already done by others. We do know that Hipparchus contributed significantly. The Ptolemaic picture is a modification of Aristotle's, retaining the feature of uniform circular motion. The earth is still thought to be at the center of the universe and stationary. The innovation rests in what is called epicyclic motion. This is illustrated in Figure II (a). Let E be the position of the earth, and let the point A move around its circle (the deferent) with a uniform speed. The point P represents the position of a planet which moves on a second circle which always centers at A. The latter circle is called an epicycle. The sizes of the circles and the rates at which their circumferences are described may be entirely independent of each other.

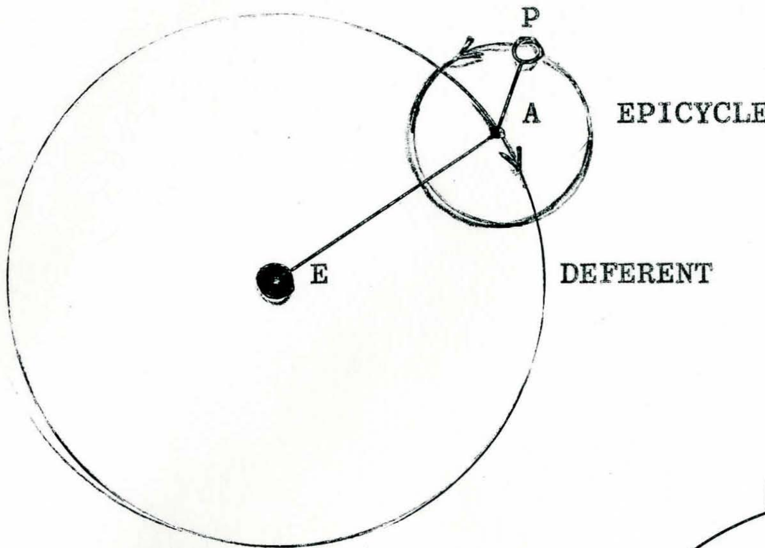
This ingenious scheme allows the explanation of two disturbing phenomena of the heavens. First, the planets seem to go through the retrograde motion we have already discussed. Second, at some times the heavenly bodies appear closer to the earth than at other times. The retrograde motion can be described neatly by means of epicycles as shown in Figure II (b), and the eccentricity of a path by the same means is shown in Figure II (c). Actually Ptolemy needed a more complex scheme than this to give an accurate description of the observed motions, so he put epicycles on epicycles. As later modified, the Ptolemaic scheme needed about eighty circles to account for the motions of the sun, moon, and five known planets. In addition Ptolemy violated one of the original conditions as stated by Plato, namely that the earth was the center of the universe. In order to get better agreement with the observed motions, he constructed some of his deferents so that they were not concentric with the earth.

Ptolemy's system accounted for the motions as well as they could be measured with the instruments of the time. His work became the basis for navigation. And to a large extent it still is, since for navigational purposes we are primarily interested in the apparent motions of the planets and stars.

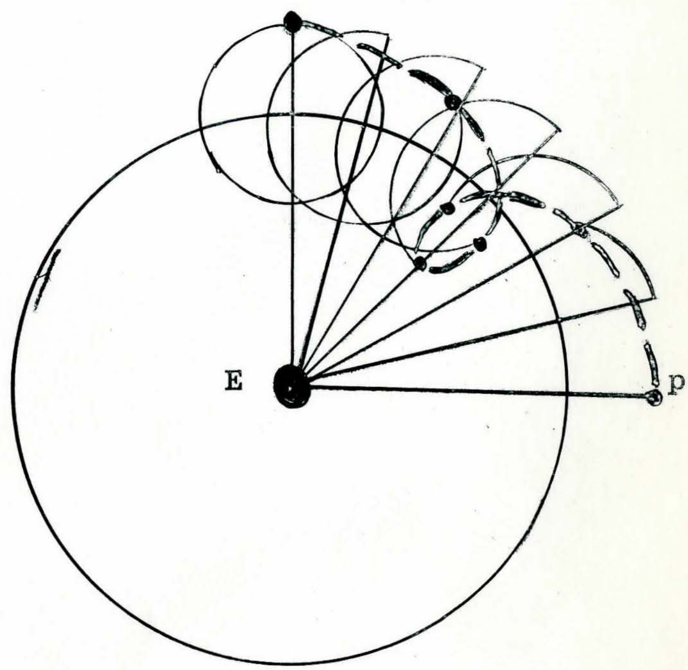
We can see that the system of epicycles rapidly becomes complex, as more epicycles are added, and it is difficult to picture clearly what kind of motion might result from the simultaneous application of several epicyclic motions. But mathematical complexity did not bother the Greeks. In fact they reveled in it and admired the man who could grasp the mathematical subtleties of such a theory.

Here then was the ultimate answer to Plato's question. The Ptolemaic theory represents the highest point of Greek astronomy. It could have been constructed only by a people who coupled a mastery of the mathematical disciplines with a creative imagination. (Ptolemy's theory also represents the conviction that the physical universe is rational rather than capricious, and that being rational it is understandable to man.) This view, possibly

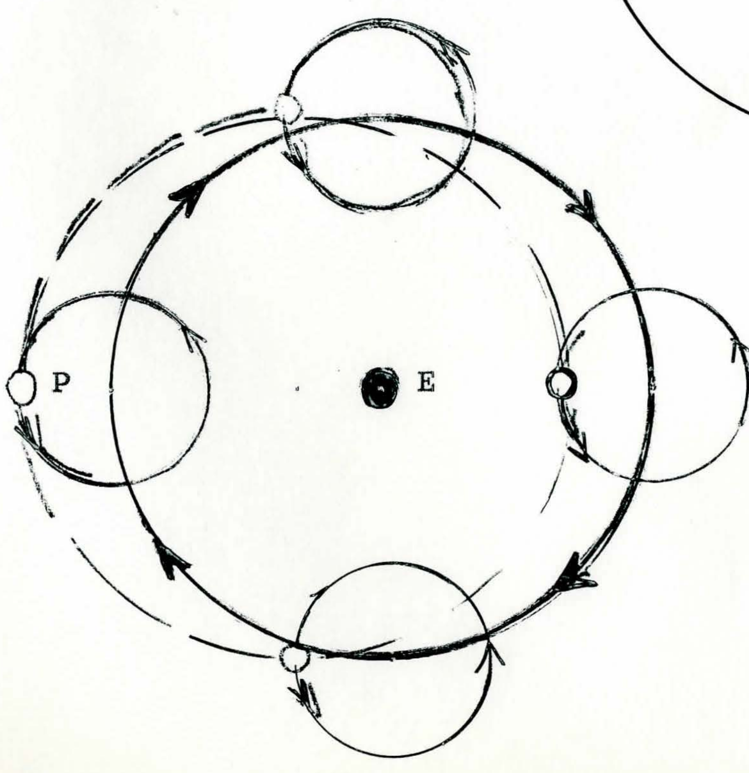
made an effort to contain observable data. Came closer to providing a place for observational data. Rid of transparent sphere. Planets stay out there in view of their nature.



(a) EPICYCLIC MOTION



(b) RETROGRADE MOTION IN EPICYCLIC MOTION



(c) ECCENTRICITY OF PATH IN EPICYCLIC MOTION

FIG. II. PTOLEMY'S THEORY

more than anything else, is the Western heritage from Greek scientific thought.

Alexandrian Greek culture and its creative science declined. The fire begun by Julius Caesar to destroy the Egyptian fleet spread to the city and burned part of the great library. There followed a series of similar catastrophies in which most of the collection was lost. It had been gathered over a period of centuries and is estimated to have contained from 500,000 to 700,000 manuscripts. An attempt was made to replace the destroyed works, but the loss was irreparable. Later Alexandria became a center of Christian thought; and when the Roman Emperor Theodosius the Great permitted the destruction of heathen temples, a mob of Christian fanatics destroyed much of what was left of the library in 391. There is some question whether the Moslems finished razing the library when they conquered the city in 641, but there is no question that by that time the great work of the Greek scientists at Alexandria had lost its influence on Western thought.

While the Romans had every opportunity to carry on where the Greeks left off in science, they did not. In writing a history of the great ideas in mathematics, physics, and astronomy no mention need be made of the Romans. They considered themselves practical men, and in fact they were expert engineers. They were interested in particular, concrete problems but not in abstractions or in theoretical science with its general principles. As a consequence they missed the Greek spirit of science entirely, and failed to realize that theoretical mathematics and science form the fountainhead of ideas which permit the solution of even the most practical problems. In spite of this, Greek science was preserved to a great degree by the Arabs who translated Greek documents into their own languages. The Arabs also made contributions of their own, principally in mathematics and medicine, which were eventually to become part of Western thought.

As the Roman Empire crumbled and finally fell, the Christians took over most of the intellectual leadership of the West. In the rush to Christianize the barbarians, they saw no need to stress the ideas of Greek thought. Some even tried to wipe out every remnant of misleading and confusing pagan Greek science. This effort was crowned with great success. In place of using the rational Greek astronomy and cosmology, they interpreted the Scriptures literally for scientific purposes. The Scriptures were even used to refute the contentions of Greek astronomy, even the idea that the world was a sphere. Insisting that the earth has a "face" and "four corners," some concluded that it was flat. They also pictured the earth to be at the bottom of the "world" as a consequence of its great weight. They saw the skies as a tent or as a cylindrically shaped vault. They convinced themselves that the tabernacle which Moses built in the wilderness was designed after the pattern of the universe. All this was put down in a complete cosmology by one Kosmos near the middle of the sixth century.

It is likely that Kosmos was originally from Alexandria, the very ground on which walked the giants of Greek science. Kosmos became a monk, and though he never rose to high office in the Church, his arguments were tacitly accepted. His work won popular acclaim and an audience for centuries. He too believed that the tabernacle was a true model of the universe. From the fact that the table in the tabernacle was a rectangle twice as long as wide and was oriented in an east-west direction, he concluded that the earth too was a rectangle with its long side twice the length of the short and with its long sides pointed in the east-west direction. Outside the earth there was water and then another earth, the site of Paradise. Then rose the four walls of the universe topped by a cylindrical dome. One modern author likens the whole thing to "a traveling trunk with a curved lid." The entire universe was divided in two. The stars, sun, and moon were carried in their courses by the angels below the dividing line. Above, comparable to beyond the veil of the tabernacle, was heaven, the final home for the saved. Kosmos ridiculed the idea that men could be hanging by their feet from the bottom side of the earth.

The Eastern Church was more prone to these dogmatic notions of the structure of the universe than was the Western, although the leaders of the Western Church never felt themselves called upon to correct any of these views, if in fact they thought them to be in error. The collapse of the science of astronomy during these years can be understood only in the light of the intellectual climate of early medieval Europe. The good Christian of that era had little interest in the natural sciences or even in the study of the simplest events of nature that surrounded him. His deeper thoughts were fixed on heaven, where he hoped to spend all of eternity. He believed that God was principally concerned with man, and he viewed the fruits of this world as serving man's, and hence God's, purposes. The purpose of the sun was to warm man. Rain existed to slake man's thirst and to insure good crops.

By about the ninth century most of the learned men in the West had returned to the astronomy of the Greeks, and accepted the spherical shape of the earth. The Greek works themselves were not yet known, but many of the Roman writings in circulation carried fragments of Greek science. In the twelfth century the Arab translations of Aristotle became available through the Moors, and these too were incorporated into the astronomy of the times. At the same time the Arabic number system with its symbols for zero and the first nine integers was introduced, but it was not to have common scientific use until the end of the fourteenth century.

As we have seen, the Church finally adopted Aristotle. His science and philosophy began to be woven into the cloth of Christian dogma. Thomas Aquinas (c. 1225-1274) completed the synthesis by asserting that there were two kinds of truths, the supernatural and the natural. These he held were distinct, supernatural truth being attained by revelation and natural

truth by reason. By accepting both means, although holding supernatural truth supreme, he was able to join the pagan Aristotelian ideas with the Christian theology. Aristotle's physics, through Thomas' interpretation, became the Christian authority on questions dealing with nature.

Dissent to this trend existed at scattered points but was drowned in the flood of esteem afforded Aristotle. Roger Bacon (c. 1214-1294) made little scientific contribution, but he recognized the potential that mathematics along with experimentation had for the study of nature. He also recognized that parts of the Old Testament contradicted the best scientific evidence then available, and he suggested a thorough scientific investigation into these matters. As we have seen, his was a voice in the night. He had little if any influence on the general trend of scientific thought during his lifetime. We can only guess the contributions he might have made had he lived in a different atmosphere.

Probably the cosmology of Dante (1265-1321) as it is described in his great work, Divine Comedy, is representative of the learned man's view of the universe in the High Middle Ages. While we recognize the dangers inherent in making literal interpretations of the work of poets, there is good reason to believe that Dante's description represents his literal notions about the heavens and the place of the earth. A representation of Dante's conception of the universe is shown in Figure III.

We have reviewed the history of Western man's pictures and theories of the universe up to the Renaissance. During the Renaissance rumblings were heard against the authoritarian hold that the Church had on the intellectual life of the West. But the Church successfully maintained its position by restraining free thinkers in one way or another. Leonardo da Vinci (1452-1519) had scientific views that were well beyond his time, but he was wise enough (from his personal point of view) to refrain from making his beliefs commonly known. But there is no question that da Vinci and others like him succeeded in clearing some path for those who were to carry the banner of unfettered scientific inquiry, sometimes reluctantly, into open combat with those who would suppress it in the name of authority.

While the rediscovery of classical thought brought scientific information that was new to Western man, more important it helped make possible a new spirit of approach to scientific problems. Although the humanists contributed to a better understanding of Greek science by preparing more accurate editions of classical works, they too set up new authorities to be slavishly followed. The scholastics dominated the scene, and they were interested in constructing systems of knowledge that would be all inclusive. They were not observers of nature for the most part, but they were speculative thinkers who used the tool of deduction with a high degree of agility. They based their conjectures on Aristotle, as interpreted for Christians, and appealed to such authority to prove their contentions. Experimental

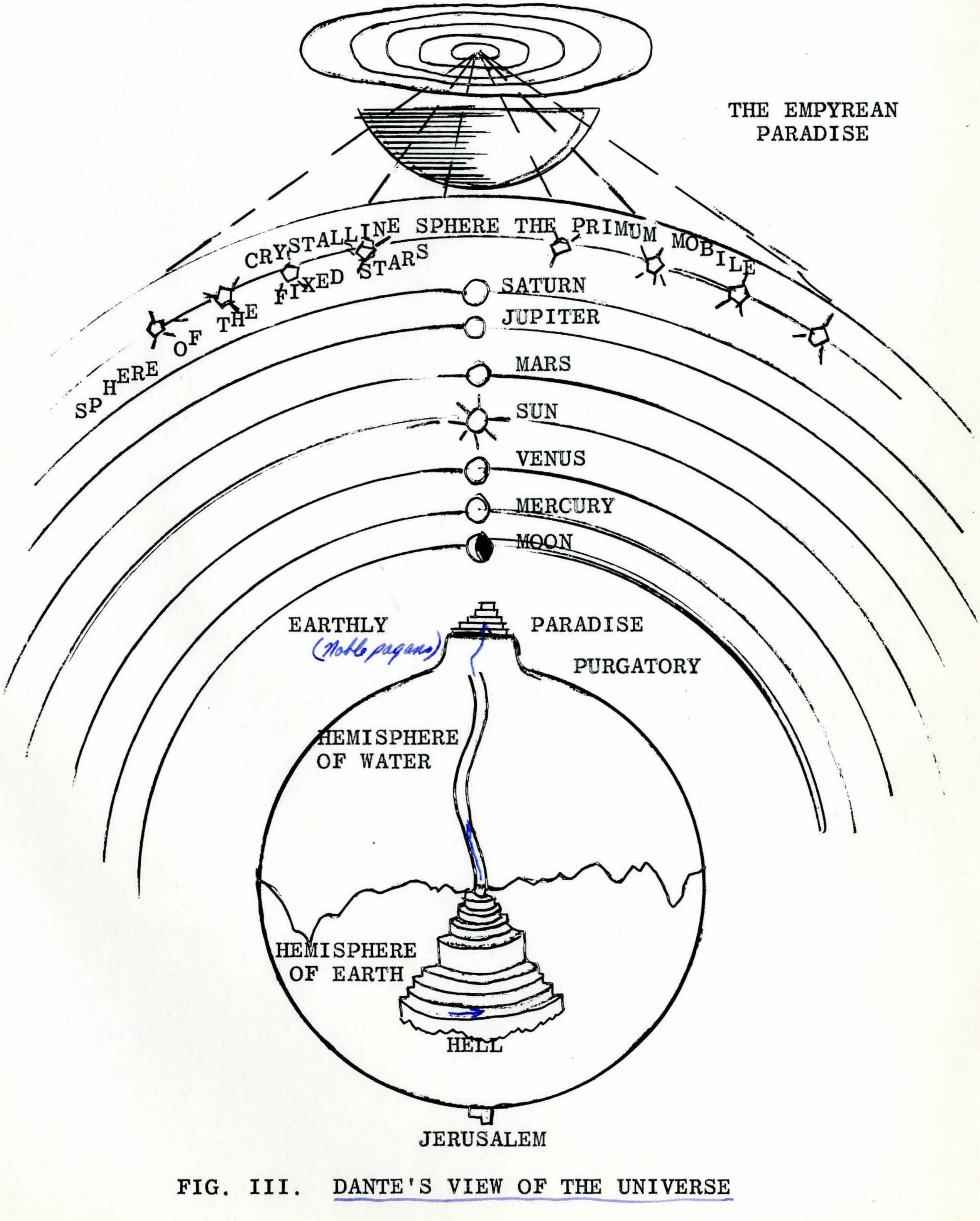


FIG. III. DANTE'S VIEW OF THE UNIVERSE

science had few practitioners. Science became static, and a static science is no science at all.

An example of the new freedom of the mind that grew out of the Renaissance can be found in the bold attacks that were made on the Aristotelian and Ptolemaic theories of the universe. We shall illustrate the transition into modern science largely through the works of four men: Copernicus, Galileo, Kepler, and Newton. No claim is made for completeness, for these four were dependent on untold numbers of other scientists and philosophers. But by reviewing some of the labors of these men we shall be able to see the change in the very questions man asked himself about nature and the resistance met by the new questions and their answers.

A love of the world - Renaissance - set up new authorities reassert the authority of the ancient Greeks. Critical spirit (Valla). Pushing of Church to one side removed the influence of the Church - Feeling of "this world." Protestant Ref. emphasis on God instead of man. Science developed in both religions. Several groups & several answers.

2. Copernicus