the Book of the Cosmos

Imagining the Universe from Heraclitus to Hawking

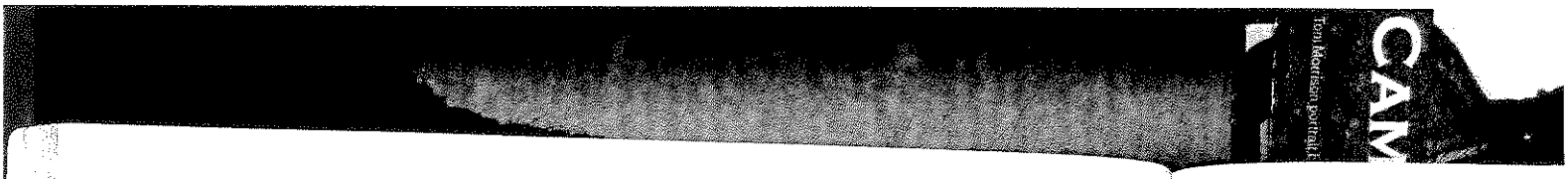
A Helix Anthology

edited by

Dennis Richard Danielson

Cambridge : Perseus, 2000

PERSEUS
PUBLISHING



2

Twice into the Same River?

Heraclitus and Parmenides

Most of us have heard A. N. Whitehead's remark that the history of (western) philosophy is "a series of footnotes to Plato." We may adapt this generalization to western cosmology: In its first two millennia, at least—leaving aside continued biblical influence—it is a series of footnotes to Plato's immediate Greek precursors, known collectively as the Presocratics. They were the first thinkers to engage cosmology as theory, as physics. The Babylonians and ancient Hebrews had a literature embodying stories or expressing awe about the heavens and the earth and about the religious significance of those stories and that awe. But the Presocratics made the first attempts to assemble the conceptual tools with which one might begin to answer the question how. *How did the world, the order, the arrangement of things which we see and of which we are a part come into being?*

One of the most fundamental problems they tackled—a problem still encountered by Big Bang cosmology when it tries to describe the very beginning—concerns the relationship between things that do not change and things that do. The first category usually includes truths of mathematics and laws of physics. The second category includes all observable phenomena including human beings, their bodies, and their institutions. This is the problem of being and becoming, of permanence and mutability, and, some would say, of eternity and time. Moreover, it raises the further question, Which comes first? Which is fundamental? Which, if any, is the governing reality? A further question still is, What is the nature of their relationship?

All of these questions were raised in one form or another by the Presocratics, two of whom—Heraclitus and Parmenides—provide opposite answers.

Heraclitus (fl. c. 5th c. B.
size strife and change.

Everything flows and not
fixed.

You cannot step twice int
ever flowing on.

It is in changing that thin

Homer was wrong in say
gods and men." For if tha

There is exchange of all t
wares for gold and of gol

If there were no sun, the o

Nature loves to hide.

Diogenes Laertius presents
his day, now delivering pr
ately exemplifying the para

Heraclitus held that fire
change for fire, produced
nothing clearly. All things
in flux like a river.

The all is finite and the
again by fire alternately t
according to fate. Of the
world is called War and S
Concord and Peace.

He called change the u
world comes into being in

He does not make it cle
world. He held, however,

me River?

menides

ırk that the history of (west-
ɔ." We may adapt this gener-
› millennia, at least—leaving
of footnotes to Plato's imme-
e Presocratics. They were the
ıs physics. The Babylonians
ng stories or expressing awe
eligious significance of those
the first attempts to assemble
ɛgin to answer the question
ment of things which we see

ey tackled—a problem still
ɛs to describe the very begin-
gs that do not change and
ɛs truths of mathematics and
ll observable phenomena in-
ıstitutions. This is the prob-
mutability, and, some would
he further question, Which
y, is the governing reality? A
ɛir relationship?
or another by the Presocrat-
-provide opposite answers.

Heraclitus

Heraclitus (fl. c. 5th c. B.C.) is best known for his aphorisms, which emphasize strife and change.

Everything flows 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.

It is in changing that things find repose.

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.

There is exchange of all things for fire and of fire for all things, as there is of wares for gold and of gold for wares.

If there were no sun, the other stars would not suffice to prevent its being night.

Nature loves to hide.

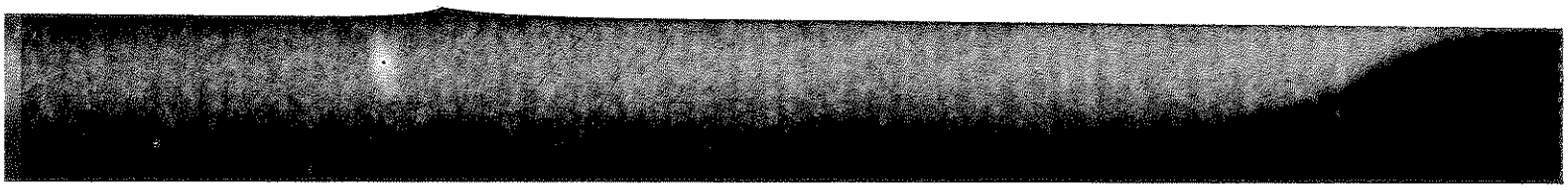
Diogenes Laertius presents Heraclitus as a sort of deconstructionist observer of his day, now delivering profound insight, now confusing the reader by deliberately exemplifying the paradox and contradiction he sees as constituting reality.

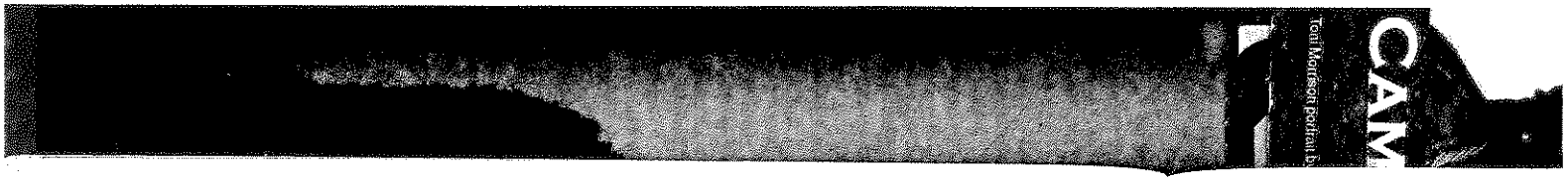
Heraclitus held that fire was the element, and that all things were an exchange for fire, produced by condensation and rarefaction. But he explains nothing clearly. All things were produced in opposition, and all things were in flux like a river.

The all is finite and the world is one. It arises from fire, and is consumed again by fire alternately through all eternity in certain cycles. This happens according to fate. Of the opposites, that which leads to the becoming of the world is called War and Strife; that which leads to the final conflagration is Concord and Peace.

He called change the upward and the downward path, and held that the world comes into being in virtue of this. . . .

He does not make it clear what is the nature of that which surrounds the world. He held, however, that there were bowls in it with the concave sides





turned towards us, in which the bright exhalations were collected and produced flames. These were the heavenly bodies.

The flame of the sun was the brightest and warmest; for the other heavenly bodies were more distant from the earth, and for that reason gave less light and heat. The moon, on the other hand, was nearer the earth; but it moved through an impure region. The sun moved in a bright and unmixed region, and at the same time was at just the right distance from us. That is why it gives more heat and light. The eclipses of the sun and moon were due to the turning of the bowls upwards, while the monthly phases of the moon were produced by a gradual turning of the bowl.

Day and night, months and seasons and years, rains and winds, and things like these, were due to the different exhalations. The bright exhalations, when ignited in the circle of the sun, produced day, and the preponderance of the opposite exhalations produced night. The increase of warmth proceeding from the bright exhalations produced summer, and the preponderance of moisture from the dark exhalation produced winter. He assigns the causes of other things in conformity with this.

As to the earth, he makes no clear statement about its nature, any more than he does about that of the bowls.

Parmenides

Whereas Heraclitus emphasized strife and contingency, his contemporary Parmenides declared the primacy of Being and of Necessity.

One path only is left for us to speak of, namely that *It is*. In this path are very many tokens that what is is uncreated and indestructible; for it is complete, immovable, and without end. Nor was it ever, nor will it be; for now *it is*, all at once, a continuous one. . . .

Moreover, it is immovable in the bonds of mighty chains, without beginning and without end; since coming into being and passing away have been driven afar, and true belief has cast them away. It is the same, and it rests in the selfsame place, abiding in itself. And thus it remains constant in its place; for hard necessity keeps it in the bonds of the limit that holds it fast on every side. Wherefore it is not permitted to what is, to be infinite; for it is in need of nothing; while, if it were infinite, it would stand in need of everything. . . .

Since, then, it has a furthest limit, it is complete on every side, like the mass of a rounded sphere, equally poised from the center in every direction; for it cannot be greater or smaller in one place than another. . . .

Here shall I close my trustworthy speech and thought about the truth. Henceforward learn the beliefs of mortals, giving ear to the deceptive ordering of my words. . . .

Thou shalt know the
the resplendent works
arose. And thou shalt l
faced moon, and of he
surround us, whence th
them to keep the limits
moon, and the sky that
most Olympus, and the

The narrower bands
night, and in the midst
these is the divinity that

The brilliant and c
(1905–1983) sees Aristo
menides. Aristotle's cos
of Copernicus and Gali
resents "a compromise l

On the one side there wa
Ionians, and was contin
regarded the universe as
minated in Leucippus a
dency, which originatec
Parmenides, who taught
illusions of the senses, be
does not, or is different f
visible, unchangeable, a
Reality is a continuous p
stresses, of creative tensi
ity is a solid, uncreated,

The preceding paragr
my purpose is merely to
verse solved the basic di
Materialists, and letting
whereas the rest of the
the Parmenidean "nothi

Once again, it was n
world-views, or "world
the minds of men. This
mere juxtaposition yiel
original Aristotelian twc
seded by an elaborately

ns were collected and pro-

nest; for the other heavenly
: that reason gave less light
rer the earth; but it moved
right and unmixed region,
ce from us. That is why it
and moon were due to the
/ phases of the moon were

ains and winds, and things
s. The bright exhalations,
, and the preponderance of
ease of warmth proceeding
and the preponderance of
er. He assigns the causes of

bout its nature, any more

ngency, his contemporary
Necessity.

t *It is*. In this path are very
uctible; for it is complete,
will it be; for now *it is*, all

ty chains, without begin-
d passing away have been
is the same, and it rests in
nains constant in its place;
that holds it fast on every
e infinite; for it is in need
in need of everything. . . .
n every side, like the mass
r in every direction; for it
her. . . .
thought about the truth.
ar to the deceptive order-

Thou shalt know the substance of the sky, and all the signs in the sky, and the resplendent works of the glowing sun's pure torch, and whence they arose. And thou shalt learn likewise of the wandering deeds of the round-faced moon, and of her substance. Thou shalt know, too, the heavens that surround us, whence they arose, and how Necessity took them and bound them to keep the limits of the stars . . . how the earth, and the sun, and the moon, and the sky that is common to all, and the Milky Way, and the outermost Olympus, and the burning might of the stars arose.

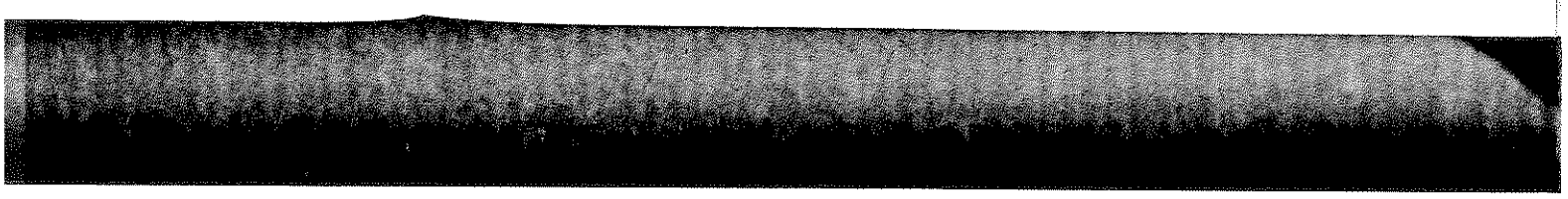
The narrower bands were filled with unmixed fire, those next them with night, and in the midst of these rushes their portion of fire. In the midst of these is the divinity that directs the course of all things.

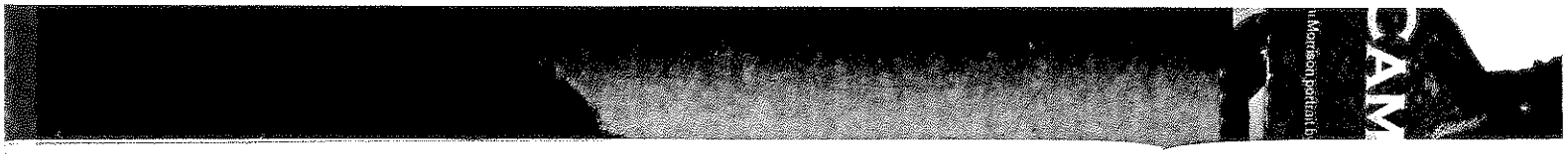
The brilliant and controversial novelist-historian Arthur Koestler (1905–1983) sees Aristotle as brokering a deal between Heraclitus and Parmenides. Aristotle's cosmology—which was superseded only with the advent of Copernicus and Galileo—says Koestler in The Sleepwalkers *(1959), represents "a compromise between two opposite trends in philosophy."*

On the one side there was the "materialistic" trend, which had started with the Ionians, and was continued by men like Anaxagoras . . . ; by Heraclitus, who regarded the universe as a product of dynamic forces in eternal flux; and culminated in Leucippus and Democritus, the first atomists. The opposite tendency, which originated with the Eleatics, found its extreme expression in Parmenides, who taught that all apparent change, evolution and decline, were illusions of the senses, because whatever exists cannot arise from anything that does not, or is different from it; and that the Reality behind the illusion is indivisible, unchangeable, and in a state of static perfection. Thus for Heraclitus Reality is a continuous process of Change and Becoming, a world of dynamic stresses, of creative tensions between opposites; whereas for Parmenides Reality is a solid, uncreated, eternal, motionless, changeless, uniform sphere.

The preceding paragraph is, of course, a woeful oversimplification . . . but my purpose is merely to show how neatly the Aristotelian model of the universe solved the basic dilemma by handing over the sub-lunary region to the Materialists, and letting it be governed by Heraclitus's motto "all is change"; whereas the rest of the universe, eternal and immutable, stood in the sign of the Parmenidean "nothing ever changes."

Once again, it was not a reconciliation, merely a juxtaposition, of two world-views, or "world-feelings," both of which have a profound appeal to the minds of men. This appeal was increased in power when, at a later stage, mere juxtaposition yielded to *gradation* between the opposites; when the original Aristotelian two-storey universe—all basement and loft—was superseded by an elaborately graded, multi-storeyed structure; a cosmic hierarchy





where every object and creature had its exact "place" assigned to it, because its position in the many-layered space between lowly earth and high heaven defined its rank on the Scale of Values, in the Chain of Being. . . . This concept of a closed-in cosmos graded like the Civil Service (except that there was no advancement, only demotion) survived for nearly a millennium and a half.

In spite of the fact that Koestler's antithesis between the Heraclitean and the Parmenidean is an oversimplification (as is his account of a Civil Service universe with "no advancement"—witness Dante), the polarity of "world-feelings" provides a useful insight into the human motivations that underlie world-views. Hélène Tuzet (fl. mid-20th century), author of a large study of cosmos and the imagination (Le cosmos et l'imagination, *1965), further expounds the psychological dimension of the polarity.*

The Parmenidean places himself outside of time and takes the side of the eternal. Underneath his choice, one can detect perhaps a fear, a recoil from whatever is transformed, crumbles, decays . . . ; in short, he recoils from the biological laws which include decomposition as an integral part. Because he fears death, the Parmenidean does not love life. But there is something more: an aesthetic taste, a choice of an idea, and at times, a religious motivation.

The forms of cosmic pathos to which the follower of Parmenides is susceptible are those which have come to terms with the Eternal, attracted by the purity and rigidity of an incorruptible substance. Everything enters into a clear and stable harmony: the Pythagorean aesthetic of numbers and configurations, the circle and sphere as types of perfection, and as the divine type of motion a steady eternal rotation, equivalent to the immoveable. With a greater degree of complexity, the Music and Dance of the planets appear in a harmony of numbers and combination of configurations in a similarly experienced duration and in strictly determined limits.

For this aesthetic of the Eternal is an aesthetic of the Finite: what is perfect or complete necessarily had limits. It is also the aesthetic of Discontinuity and of Hierarchy: the Scale of Being is fixed with distinct levels in the Parmenidean cosmos. Each thing has its place, and the thinking man enjoys the pleasure of feeling that he is in his right place. It is an aesthetic of immutable Unity, and not of a process of Fusion.

The Parmenidean thinker is more or less susceptible . . . to the pathos of Unity in explanation, of simplicity in basic assumptions, and of implacable rigor in formulated laws. There is also the pathos of ideal exactness in the appropriation and coherence of a well-knit network of logical correspon-

dences and relations wh
out.

As for the Heracliteai
order that it may unfol
any deep motivation, w
which life implies, inclu
boldness in his outlook
a willingness to take ris
pathos to instinctive fo
it is in the Parmenidean

The Heraclitean type
change, and transfers to
life. There are dreams
freshness, the pathos o
surge. There are dream
the flow of the forms o
that of Variety: the taste
regular, the original, the
worlds. In opposition
place," there is the into
universal Being. In orde
Heraclitean requires Ple
the infinity of God and

Whereas the Parmen
tions, the Heraclitean,
freedom; and in certai
transport, and of flight
mind. Lastly, the scienc
Cosmic energies are abs
completely smooth rota
and effort, so that his U

SOURCES: Fragments from
wright, New York: Odys
from Thomas L. Heath,
Koestler, *The Sleepwalke*
London: Hutchinson, 19
History of Ideas, vol. 1, e

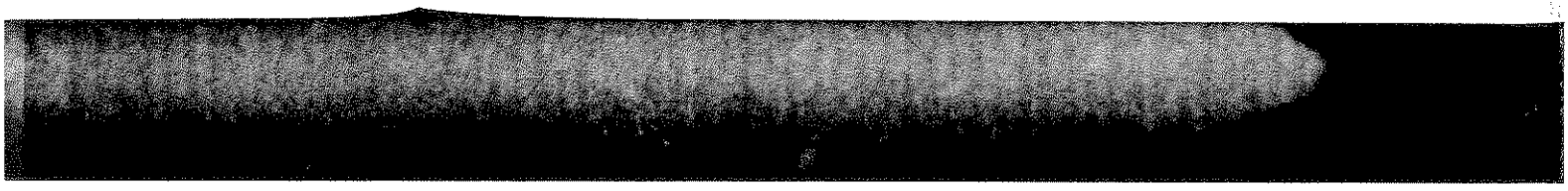
dences and relations which take in the whole of creation and leave nothing out.

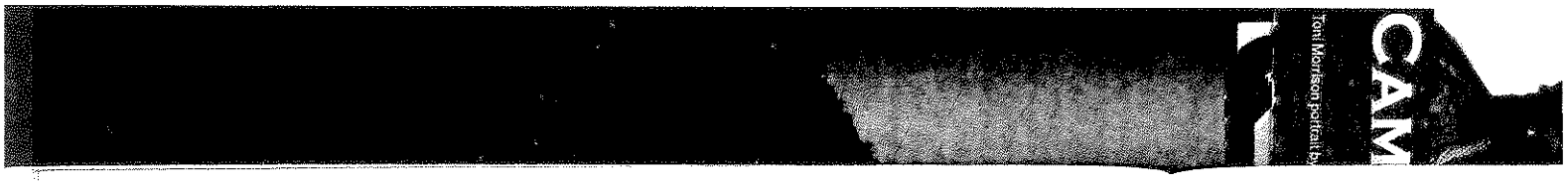
As for the Heraclitean, he is susceptible to the pathos of Becoming, and in order that it may unfold and reveal itself, he needs the Unlimited. If we seek any deep motivation, we discover a taste for life which accepts everything which life implies, including death as a condition for a new birth. There is a boldness in his outlook which rejects protection and authority, and assumes a willingness to take risks of all sorts. The appeal of the Heraclitean kind of pathos to instinctive forces and to the Unconscious is naturally greater than it is in the Parmenidean family of minds.

The Heraclitean type includes everything arising out of the fascination of change, and transfers to the cosmic plane whatever is integral to the cycle of life. There are dreams of life's genesis: the pathos of Birth and its original freshness, the pathos of continuous Creation and its inexhaustible onward surge. There are dreams of life's evolution: the pathos of continuity and of the flow of the forms of life. Opposing the Parmenidean pathos of Unity is that of Variety: the taste for profusion and even disorder; the taste for the irregular, the original, the unique which will feed the dream of the plurality of worlds. In opposition to the joy of feeling satisfied with being "in one's place," there is the intoxication of being lost in the swarming proliferation of universal Being. In order to accommodate all these wonderful things, the true Heraclitean requires Plenitude, a fullness within the Infinity of space, akin to the infinity of God and to the unlimited capacity of the soul of man.

Whereas the Parmenidean accepts hierarchy and its hemmed-in gradations, the Heraclitean, on the other hand, is alive to the pathos of absolute freedom; and in certain eras, he experiences the pathos of liberation, of transport, and of flight without thought of return. He is a traveler in the mind. Lastly, the science of motion for him is not mechanics but dynamics. Cosmic energies are absorbed in vital forces; he is receptive not to steady and completely smooth rotation but welcomes the conflict of opposites, tension, and effort, so that his Universe tends to be polarized.

SOURCES: Fragments from Heraclitus cited from *The Presocratics*, ed. Philip Wheelwright, New York: Odyssey Press, 1966; Diogenes Laertius and Parmenides cited from Thomas L. Heath, *Greek Astronomy*, London: J. M. Dent, 1932; Arthur Koestler, *The Sleepwalkers: A History of Man's Changing Vision of the Universe*, London: Hutchinson, 1959; Hélène Tuzet, "Cosmic Images," in *Dictionary of the History of Ideas*, vol. 1, ed. Philip P. Wiener, New York: Scribner's, 1973.





3

The Things of the Universe Are Not Sliced Off with a Hatchet

Empedocles and Anaxagoras

What is the relationship between things that do not change and things that do? The question is still with us. The fifth-century B.C. *Presocratic philosophers Empedocles and Anaxagoras, who are sometimes classified as "qualitative pluralists," begin with the changing qualities on the face of things and seek their unchanging roots.*

EMPEDOCLES (C. 484–C. 424 B.C.)

Among Empedocles' sayings are some directly astronomical statements, such as "it is the earth that makes the night by getting in the way of the sun's beams." Empedocles is probably best known, however, for identifying four "elements" or "roots" of physical reality: fire, water, earth, and air. His teaching is not just physics and not just poetry, but poetical physics.

Come now, hearken to my words; learning will enlarge your mind. . . . I shall tell of a twofold process. For at one time there grew to be a single One out of many, while at another time there came to be many by division out of One—fire, water, earth, and the lofty height of air. Apart from these and in balanced relation to them is dreadful Strife; while Love resides in their midst, throughout their length and breadth. Envision her with your mind, instead of sitting with glazed eyes. Mortals can know and recognize her, for she is im-

planted within their boc
amity and do works
Aphrodite. . . .

All of these are equal
tivity and its own chara
round. Nothing is adde
continually perishing, t
nothing else, how coul
crease? And how coulc
these are the only thing
thing in one place and a

Sunbeams and earth,
them, even though thro

Come now, look at tl
case there was anythir
sending warmth and br
ually bathed by his rad
all sides; and there is th
things, come forth. Wh
form and separated; bu
another. Thence have
be. . . . In reality there
another they mix to suc

When painters wise a
tive altars in a temple,
diciously, now a little
likenesses of all things—
water-dwelling fishes,
gods. The way in which
istence, although they a
ferent from this. . . .

These two forces, Str
future; nor will boundl

Now one prevails, n
goes incessantly on its
one another they beco
brought together by Lc
off in different directic
time their enmity is su
Thus in the respect tha
vide from one into mai

planted within their bodies. It is thanks to her that mortals enjoy thoughts of amity and do works of peace. They call her by the names Joy and Aphrodite. . . .

All of these are equal and of the same age, but each has its own kind of activity and its own character, and each gains ascendancy when its time comes round. Nothing is added to them nor taken away from them. For if they were continually perishing, they would at last no longer exist. And since there is nothing else, how could anything be added that would cause them to increase? And how could anything perish, since there is nothing empty? No, these are the only things that are; and by interpenetrating they become one thing in one place and another in another. . . .

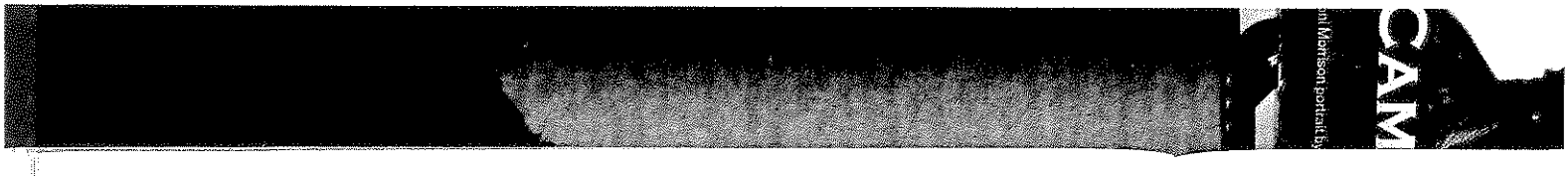
Sunbeams and earth, sky and sea, are at one with the parts that compose them, even though thrown in different guises to mortals' apprehension. . . .

Come now, look at the things that bear witness to what I said formerly, in case there was anything defective in my earlier account. Behold the sun, sending warmth and brightness everywhere, and the countless things perpetually bathed by his radiance; there is also the rain-cloud, dark and cold on all sides; and there is the earth, from which solid bodies, the foundations of things, come forth. When Hostility is at work, all these things are distinct in form and separated; but they come together in Love, and are desired by one another. Thence have sprung all the things that ever were, are, or shall be. . . . In reality there are only the basic elements, but interpenetrating one another they mix to such a degree that they assume different characteristics.

When painters wise and skilled in their craft are preparing sumptuous votive altars in a temple, they use pigments of many colors and blend them judiciously, now a little more of this and now of that; thereby they produce likenesses of all things—of trees, of men and women, of beasts and birds and water-dwelling fishes, and even of such honored beings as the long-lived gods. The way in which all the actual things of the world have come into existence, although they are incalculably more numerous, is essentially no different from this. . . .

These two forces, Strife and Love, existed in the past and will exist in the future; nor will boundless time, I believe, ever be empty of the pair.

Now one prevails, now the other, earth in its appointed turn, as change goes incessantly on its course. These alone truly are, but interpenetrating one another they become men and tribes of beasts. At one time they are brought together by Love to form a single order, at another they are carried off in different directions by the repellant force of Strife; then in course of time their enmity is subdued and they all come into harmony once more. Thus in the respect that by nature they grow out of many into one, then divide from one into many, they are changing things and their life is not last-



ing, but in respect of their perpetual cycle of change they are unalterable and eternal.

As things came together in harmony, Strife withdrew to the outermost region.

In that condition neither can the sun's swift limbs be distinguished, no, nor shaggy mighty earth, nor the sea; because all things are brought so close together in the perfect circularity of the Sphere.

Equal on all sides and utterly unlimited is the Sphere, which rejoices in its circular solitude. There is no discord and no unseemly strife in his limbs. There is no pair of wings branching forth from his back. He has no feet, no nimble knees, no genitals. He is spherical and equal on all sides.

When, in the fullness of time set by the primordial oath, Strife had grown to greatness in the limbs [of the Sphere] and was flaunting his demands for honors and privileges, . . . then all of God's limbs in turn began to quake.

ANAXAGORAS (fl. MID-5TH CENTURY B.C.)

Anaxagoras, like Empedocles, uttered the occasional intriguing astronomical aphorism. He states, for example, that "it is the sun that puts brightness into the moon." But also like Empedocles, he struggled at a philosophical level to give voice to the dynamic tension between change and continuity, and between reality and appearance.

Because of the weakness of our senses, we are not able to judge the truth. Appearances are a glimpse of the unseen. The Greeks do not rightly understand what they call coming-to-be and perishing. A real thing does not come-to-be or perish; occurrences that are so called are simply the mixing and separating of real entities. . . .

The things of the universe are not sliced off from one another with a hatchet, neither the hot from the cold nor the cold from the hot. In everything there is a portion of everything else, except of mind; and in some things there is mind also.

Some of Anaxagoras's reflections are fascinating for the expression they give to incipient ideas of the infinitesimal, a notion important not only for calculus but also ultimately for cosmology.

Since the great and the small share equally with respect to the number of parts they possess, here is a further reason why everything must possess a portion of everything else. Thus nothing exists apart; everything has a share

of everything else. For si
complete isolation to be
thing to come-to-be out
plicity of different ingre
from the lesser as there

In the small there is r
fined by reference to nc
than what is big. The la
thing taken from its ow

Anaxagoras postulates
from this he appears to
creative or creating prin

All things were togethe
smallness too was unli
them could be distingui
were together, before an
discernible. This was b
with dry, hot with cold,
earth in the mixture, as
the utmost variety. . . .
know the number of thi

While other things ha
limited, autonomous, ar
For if it were not by it
would thereby participa
everything that exists t
share in the universal r
prevent it from having
does, whereas the truth
purity, has knowledge o

For Anaxagoras, the ex
dering of things.

Mind took charge of th
rotate from the very beg
extends over a larger sp
things that are mingled
known by Mind.

ıge they are unalterable

rew to the outermost re-

be distinguished, no, nor
are brought so close to-

ıere, which rejoices in its
emly strife in his limbs.
back. He has no feet, no
on all sides.
ıl oath, Strife had grown
aunting his demands for
turn began to quake.

TURY B.C.)

l intriguing astronomical
that puts brightness into
t a philosophical level to
and continuity, and be-

le to judge the truth. Ap-
o not rightly understand
ing does not come-to-be
ıe mixing and separating

ɔm one another with a
from the hot. In every-
nind; and in some things

the expression they give
rtant not only for calcu-

:spect to the number of
erything must possess a
:; everything has a share

of everything else. For since there is no smallest amount, it is impossible for a complete isolation to be brought about, and it is equally impossible for anything to come-to-be out of not-being. In everything there is always a multiplicity of different ingredients; and there are as many ingredients separable from the lesser as there are ingredients separable from the greater.

In the small there is no least, but always a lesser; for being cannot be defined by reference to non-being. Likewise there is always something bigger than what is big. The large and the small are thus equal in amount. And each thing taken from its own standpoint is large and small simultaneously.

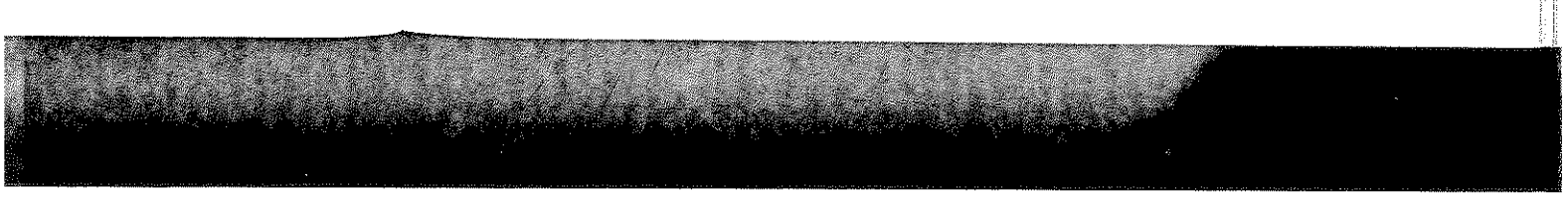
Anaxagoras postulates a single physical source of all things. Yet, separate from this he appears to assume the existence of something transcendent, the creative or creating principle, which he calls Mind (nous).

All things were together, unlimited both in number and in smallness, for smallness too was unlimited. And when all things were together, none of them could be distinguished because of their smallness. . . . When all things were together, before any separating had taken place, not even any color was discernible. This was because of the utter mixture of all things—of moist with dry, hot with cold, bright with dark. And there was a great quantity of earth in the mixture, as well as seeds which were unlimited in number and of the utmost variety. . . . Neither in speculation nor in actuality can we ever know the number of things that are separated out. . . .

While other things have a share in the being of everything else, Mind is unlimited, autonomous, and unmixed with anything, standing entirely by itself. For if it were not by itself but were mixed with anything else whatever, it would thereby participate in all that exists; because, as I have said before, in everything that exists there is a share of everything else. If Mind were to share in the universal mixture, the things with which it was mixed would prevent it from having command over everything in the way that it now does, whereas the truth is that Mind, because of its exceptional fineness and purity, has knowledge of all that is, and therein it has the greatest power.

For Anaxagoras, the exercise of Mind is preeminently in the creation and ordering of things.

Mind took charge of the cosmic situation, so that the universe proceeded to rotate from the very beginning. At first the rotation was small, but by now it extends over a larger space, and it will extend over a yet larger one. Both the things that are mingled and those that are separated and individuated are all known by Mind.



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. This includes the revolving movements of the stars, of the sun and moon, and of the air and aether as they are being separated off. It was the rotary movement that caused the separation—a separation of the dense from the rare, the hot form the cold, the bright from the dark, and the dry from the moist.

When Mind first set things in motion, there began a process of separation in the moving mass; and as things were thus moving and separating, the process of separation was greatly increased by the rotary movement.

The rotation and separation are characterized by force and swiftness. The swiftness makes the force. Such swiftness is not like the swiftness of anything known to us, but is incalculably greater.

SOURCE: *The Presocratics*, ed. Philip Wheelwright, New York: The Odyssey Press, 1966.

Atoms

Leu
E

From the point of view o
cient thinkers are those k
phers Leucippus and D
which in turn was dissem
the Nature of Things (De

Much of what we kn
come down to us in mer
lowing account from Liv
3rd century A.D.) we ca
B.C.?), the founder of at
in terms of the physical i

Leucippus was born at E
He was a pupil of Zeno.
ited, and they all change
as the full. The worlds a
tangled with one anothe
arises the substance of th
moon. The earth rides s
like that of a drum. Leu
ples. . . .

Although mathematical
back into the vocabulary

it ever was but no longer is,
the revolving movements of
nd aether as they are being
used the separation—a sep-
he cold, the bright from the

gan a process of separation
noving and separating, the
e rotary movement.
by force and swiftness. The
ke the swiftness of anything

lew York: The Odyssey Press,

4

Atoms and Empty Space

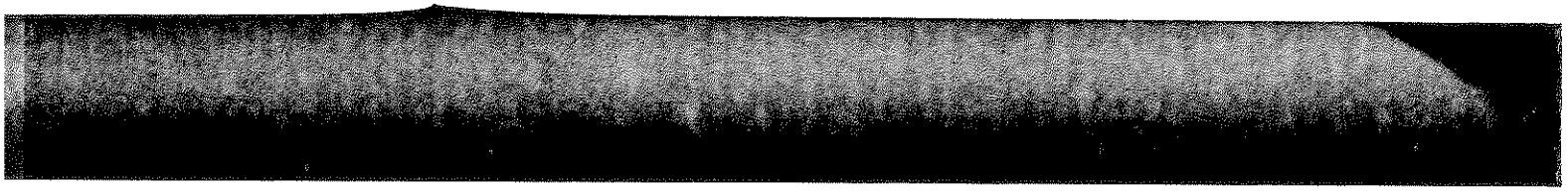
Leucippus, Democritus, Epicurus, Lucretius

From the point of view of modern cosmology, some of the most interesting ancient thinkers are those known as the atomists. The Greek Presocratic philosophers Leucippus and Democritus provided the basis of Epicurus's physics, which in turn was disseminated through the Roman Lucretius's great poem On the Nature of Things (De Rerum Natura).

Much of what we know about Leucippus, Democritus, and Epicurus has come down to us in mere fragments and in the writings of others. In the following account from Lives of Eminent Philosophers *by Diogenes Laertius (fl. 3rd century A.D.) we catch a glimpse of the thought of Leucippus (fl. 440 B.C.?), the founder of atomism, and of his effort to account for the universe in terms of the physical interaction of material things moving in space.*

Leucippus was born at Elea, but some say at Abdera and others at Miletus. He was a pupil of Zeno. His views were these. The sum of things is unlimited, and they all change into one another. The All includes the empty as well as the full. The worlds are formed when atoms fall into the void and are entangled with one another; and from their motion as they increase in bulk arises the substance of the stars. The sun revolves in a larger circle round the moon. The earth rides steadily, being whirled about the center; its shape is like that of a drum. Leucippus was the first to set up atoms as first principles. . . .

Although mathematical conceptions such as infinity cannot precisely be read back into the vocabulary of ancient Greek thought, Leucippus is clearly in-



volved in forging ideas essential for a grasp of the physical universe—such as those of empty space, of the unlimited (or the boundless), and of the physically irreducible or indivisible (which is the root meaning of atom*).*

He declares the All to be unlimited, as already stated. But of the All, part is full and part empty, and these he calls elements. Out of them arise the worlds unlimited in number and into them they are dissolved. This is how the worlds are formed. In a given section many atoms of all manner of shapes are carried from the unlimited into the vast empty space. These collect together and form a single vortex, in which they jostle against each other and, circling round in every possible way, separate off, by like atoms joining like. And, the atoms being so numerous that they can no longer revolve in equilibrium, the light ones pass into the empty space outside, as if they were being winnowed. The remainder keep together and, becoming entangled, go on their circuit together, and form a primary spherical system. This parts off like a shell, enclosing within it atoms of all kinds. And, as these are whirled round by virtue of the resistance of the center, the enclosing shell becomes thinner, the adjacent atoms continually combining when they touch the vortex.

In this way the earth is formed by portions brought to the center coalescing. And again, even the outer shell grows larger by the influx of atoms from outside, and, as it is carried round in the vortex, adds to itself whatever atoms it touches. And of these some portions are locked together and form a mass, at first damp and miry, but, when they have dried and revolve with the universal vortex, they afterwards take fire and form the substance of the stars.

Democritus (c. 460– c. 370 B.C.) and Zeno (fl. mid-5th century B.C.)

Democritus, Leucippus's student, became much better known than his teacher, even though it is unclear to which of the two his teachings actually belong. In any case, Democritus became a conduit for atomism's basic ideas. As we have already seen in Leucippus, part of the challenge was to forge conceptual tools that would account for continuity, and hence physical movement, in space.

The paradoxes of Zeno are the most famous expressions of the mind's difficulty in conceptualizing becoming*, of which simple physical motion is one species. Zeno argued: "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 wh
the history of mathema
ial, as the struggle to de
Zeno's paradox indic
sense of "room to mov
worth noting that in D
ings, the concept of ato

The first principles of t
else is merely thought to
come into being and per
not nor pass away into
size and number, and th
and thereby generate al
these are conglomeratio
that these atoms are im
been composed of such
also the soul, which is ic

To glimpse Democritus'
teachings, physical as w
by proponents both of I
ist: It reduces things of t
tion. The All, accordin
physical. This is worth
fragments, that "Man i
idea of the macrocosm
pean thought within a
analogy between large a

Ep

It was under the name
accompanying "this-wo
quent history. Diogenes
himself that summarizes

Epicurus to Herodotus,
For those who are un
go into the longer treati

physical universe—such as
undless), and of the physi-
neaning of atom*).*

ated. But of the All, part is
ut of them arise the worlds
ved. This is how the worlds
anner of shapes are carried
se collect together and form
other and, circling round in
ing like. And, the atoms be-
equilibrium, the light ones
e being winnowed. The re-
go on their circuit together,
s off like a shell, enclosing
irled round by virtue of the
omes thinner, the adjacent
vortex.
ought to the center coalesc-
by the influx of atoms from
ex, adds to itself whatever
locked together and form a
dried and revolve with the
form the substance of the

O B.C.) AND
RY B.C.)

ch better known than his
two his teachings actually
it for atomism's basic ideas.
challenge was to forge con-
and hence physical move-

expressions of the mind's dif-
nple physical motion is one
nust be moving either in the
t. However, it cannot move
it is at any moment is of the
to move in], and it cannot

move in the place in which it is not. Therefore movement is impossible." In the history of mathematics and physics, such conundrums are not at all trivial, as the struggle to develop the calculus attests.

Zeno's paradox indicates perhaps why a concept of space or void in the sense of "room to move" was so important to the atomists and others. It is worth noting that in Diogenes Laertius's summary of Democritus's teachings, the concept of atoms and the concept of space or void go together:

The first principles of the universe are atoms and empty space. Everything else is merely thought to exist. The worlds are unlimited [or boundless]. They come into being and perish. Nothing can come into being from that which is not nor pass away into that which is not. Further, the atoms are unlimited in size and number, and they are borne along in the whole universe in a vortex, and thereby generate all composite things—fire, water, air, earth. For even these are conglomerations of given atoms. And it is because of their solidity that these atoms are impassive and unalterable. The sun and the moon have been composed of such smooth and spherical masses [i.e., atoms], and so also the soul, which is identical with reason.

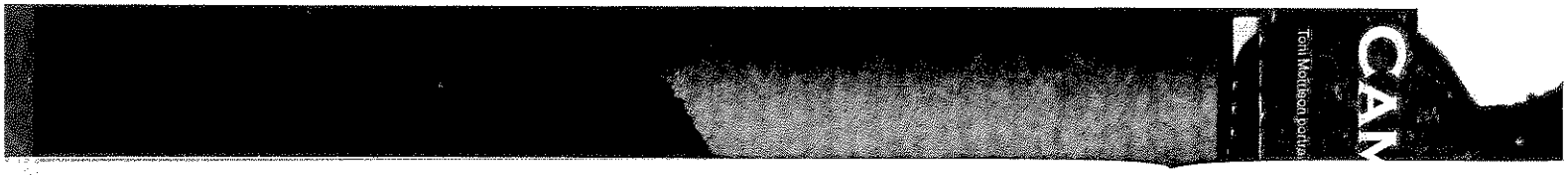
*To glimpse Democritus's radical materialism is to understand why atomistic teachings, physical as well as moral, were subsequently seen as such a threat by proponents both of Platonism and of Christianity. Atomism is reductionist: It reduces things of the soul and the spirit fundamentally to matter in motion. The All, accordingly, is all there is; and there is nothing that is not physical. This is worth remembering when we read, in one of Democritus's fragments, that "Man is a small 'ordered world' [*kosmos*]." Although the idea of the macrocosm and the microcosm became a commonplace of European thought within a Christian context, in Democritus it is founded on an analogy between large and small physical "conglomerations," nothing more.*

EPICURUS (341–270 B.C.)

It was under the name of Epicurus that atomistic physics and especially its accompanying "this-worldly" ethical teaching were bequeathed to subsequent history. Diogenes Laertius quotes at length from a letter by Epicurus himself that summarizes his physics:

Epicurus to Herodotus, greeting.

For those who are unable to study carefully all my physical writings or to go into the longer treatises at all, I have myself prepared an epitome of the



whole system, Herodotus, to preserve in the memory enough of the principal doctrines, to the end that on every occasion they may be able to aid themselves on the most important points, so far as they take up the study of physics. . . .

To begin with, nothing comes into being out of what is non-existent. For in that case anything would have arisen out of anything, standing as it would in no need of its proper germs. And if that which disappears had been destroyed and become nonexistent, everything would have perished, that into which the things were dissolved being nonexistent. Moreover, the sum total of things was always such as it is now, and such it will ever remain. For there is nothing into which it can change. For outside the sum of things there is nothing which could enter into it and bring about the change.

Further, the whole of being consists of bodies and space. For the existence of bodies is everywhere attested by sense itself, and it is upon sensation that reason must rely when it attempts to infer the unknown from the known. And if there were no space (which we call also void and place and intangible nature), bodies would have nothing in which to be and through which to move, as they are plainly seen to move. Beyond bodies and space there is nothing which by mental apprehension or on its analogy we can conceive to exist. When we speak of bodies and space, both are regarded as wholes or separate things, not as the properties or accidents of separate things.

Again, of bodies some are composite, others the elements of which these composite bodies are made. These elements are indivisible ["*atoma*"] and unchangeable, and necessarily so, if things are not all to be destroyed and pass into non-existence, but are to be strong enough to endure when the composite bodies are broken up, because they possess a solid nature and are incapable of being anywhere or anyhow dissolved. It follows that the first beginnings must be indivisible, corporeal entities.

Again, the sum of things is infinite [or boundless]. For what is finite has an extremity, and the extremity of anything is discerned only by comparison with something else. Now the sum of things is not discerned by comparison with anything else. Hence, since it has no extremity, it has no limit. And since it has no limit, it must be unlimited or infinite.

Moreover, the sum of things is unlimited both by reason of the multitude of the atoms and the extent of the void. For if the void were infinite and bodies finite, the bodies would not have stayed anywhere but would have been dispersed in their course through the infinite void, not having any supports or counter-checks to send them back on their upward rebound. Again, if the void were finite, the infinity of bodies would not have anywhere to be.

Furthermore, the atoms, which have no void in them—out of which composite bodies arise and into which they are dissolved—vary indefinitely in

their shapes. For so m
arisen out of a recurren
atoms of each shape are
indefinitely large, is not

The atoms are in cont

LU

The greatest vehicle by
conveyed from Greek t
of Things, *written by L*
not use poems to teach
ing and popularizing at
Empire, but also in the
the last half of the seve
lyn and John Dryden tra
as Lucretius had to for
into Latin, so poets an
gaged in the creation o
cepts. In general this eff
with the Royal Society.
rism played a role that s

Thomas Creech's tra
published in 1682, enca
ize change and order in

I treat of thin
The vast and
The rise of th
The various s
The jarring p
Bring nourish
The Gordian
Of what she
Called "seeds
We use prom

Although in Paradise Lc
to describe the elements
suggests that the term "
The Latin individuum,

ry enough of the principal
may be able to aid them-
hey take up the study of

/hat is non-existent. For in
ng, standing as it would in
ppears had been destroyed
perished, that into which
oreover, the sum total of
ll ever remain. For there is
um of things there is noth-
hange.
ıd space. For the existence
d it is upon sensation that
ıknown from the known.
d and place and intangible
be and through which to
bodies and space there is
nalogy we can conceive to
are regarded as wholes or
ɔf separate things.
e elements of which these
indivisible ["*atoma*"] and
ɔt all to be destroyed and
ough to endure when the
sess a solid nature and are
It follows that the first be-

:]. For what is finite has an
rned only by comparison
t discerned by comparison
, it has no limit. And since

ɔy reason of the multitude
/oid were infinite and bod-
here but would have been
, not having any supports
ard rebound. Again, if the
ave anywhere to be.
them—out of which com-
ılved—vary indefinitely in

their shapes. For so many varieties of things as we see could never have arisen out of a recurrence of a definite number of the same shapes. The like atoms of each shape are absolutely infinite. But the variety of shapes, though indefinitely large, is not absolutely infinite.

The atoms are in continual motion through all eternity.

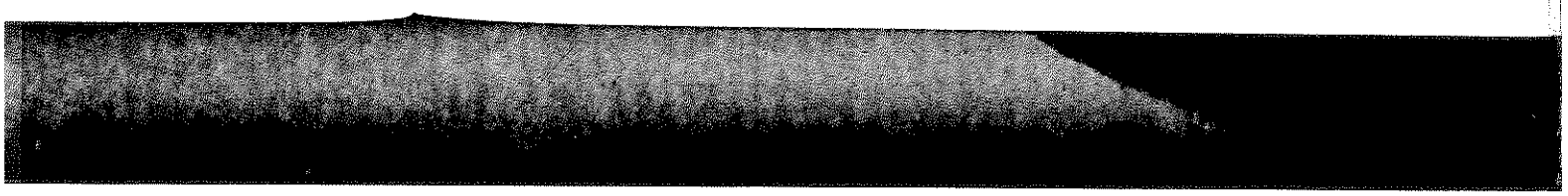
LUCRETIUS (C. 99–C. 55 B.C.)

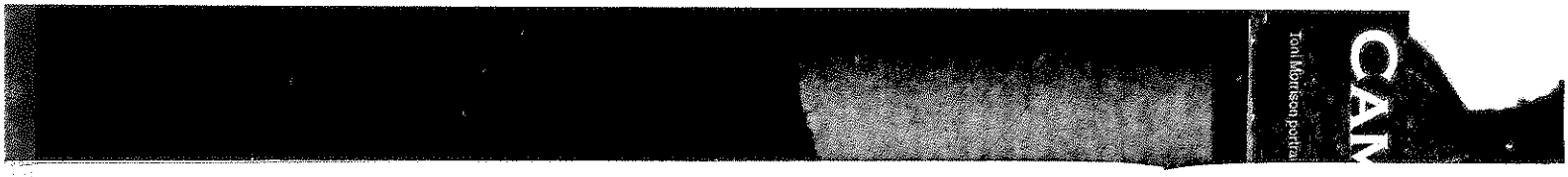
The greatest vehicle by which the atomism of Democritus and Epicurus was conveyed from Greek to Roman culture was a poem entitled On the Nature of Things, *written by Lucretius in about 50* B.C. *Although in our age we do not use poems to teach physics, Lucretius's artistry played a role in introducing and popularizing atomistic thought not only in Latin and in the Roman Empire, but also in the English language at the dawn of modern science. In the last half of the seventeenth century prominent writers such as John Evelyn and John Dryden translated selections of Lucretius into English. And just as Lucretius had to forge a new vocabulary to translate atomistic thought into Latin, so poets and scientists in the late seventeenth century were engaged in the creation of language that would serve and embody new concepts. In general this effort led away from poetry to the plain style associated with the Royal Society. However, poetry's power of word-building and aphorism played a role that should not be overlooked.*

Thomas Creech's translation of all six books of De Rerum Natura, *first published in 1682, encapsulates majestically the mind's effort to conceptualize change and order in the world:*

> I treat of things abstruse, the Deity,
> The vast and steady motions of the sky;
> The rise of things, how curious Nature joins
> The various seed and in one mass combines
> The jarring principles; what new supplies
> Bring nourishment and strength; how she unties
> The Gordian knot, and the poor compound dies;
> Of what she makes, to what she breaks the frame,
> Called "seeds" or "principles," though either name
> We use promiscuously, the thing's the same.

Although in Paradise Lost *(1667) Milton uses the phrase "embryon atoms" to describe the elements of Chaos, Creech's use of "seed" and "principle" suggests that the term* "atom" *was still not yet firmly established in English. The Latin* individuum, *which translated the Greek* atomos, *entered English*





as "individual," a word that has subsequently had a political and psychological rather than physical or chemical history. Nevertheless, seventeenth century "atomic" teaching could still evoke politics or religion. In a verse published with Evelyn's translation of book 1 of De Rerum Natura, *Edmund Waller suggests a parallel between democracy (with a pun on Democritus's name) and the chaos of primordial atoms:*

> Lucretius . . .
> Comes to proclaim in English verse
> No monarch rules the universe;
> But chance and atoms make this All
> In order Democratical,
> Where bodies freely run their course,
> Without design, or fate, or force.

Waller, like many before and since, perceives the antireligious and perhaps politically disruptive tenor of atomistic materialism. (Democritus was the subject of Karl Marx's doctoral thesis). And Lucretius's poetry expresses concisely a common theme—sometimes a prejudice—of historians concerning what Andrew Dixon White, writing in the early twentieth century, calls the warfare of science with theology.

> Long time men lay oppressed with slavish fear,
> Religion's tyranny did domineer,
> Which being placed in Heaven looked proudly down,
> And frighted abject spirits with her frown.
> At length a mighty one of Greece [namely, Epicurus] began
> To assert the natural liberty of Man,
> By senseless terrors and vain fancy led
> To slavery; straight the conquered phantoms fled.
> Not the famed stories of the Deity,
> Not all the thunder of the threatening sky
> Could stop his rising soul. Through all he passed
> The strongest bounds that powerful Nature cast.
> His vigorous and active mind was hurled
> Beyond the flaming limits of this world
> Into the mighty space, and there did see
> How things begin, what can, what cannot be;
> How all must die, all yield to fatal force,
> What steady limits bound their natural course.
> He saw all this, and brought it back to us.

> Wherefore by hi
> Religion is our s

The fabric of the univer ocritus's and Epicurus' empty space. "For if 'tis 'tis space." As Lucretius of space we have no alte

> Yet bodies c
> For besides tl
> A void. This
> Will bring to
> And teach yo
> The greatest
> A void is spa
> For were the
> Because whe
> It still must n
> 'Tis natural t
> So that to mc
> But all would
> Because no yi
> Which first sl
> But every one
> With various
> Which, were
> But the bodie
> Ne'er generat
> With other m

Lucretius's teaching thu space in the age of New "For since the void is in dle place?" Finally, fron triguing contributions i structure: the way in wh recombination of simpl within simplicity, alphab ogy. Derrick de Kerckho

Wherefore by his success our right we gain,
Religion is our subject, and we reign.

The fabric of the universe as envisaged by Lucretius, in keeping with Democritus's and Epicurus's teaching, is strikingly simple: again, atoms and empty space. "For if 'tis tangible, and hath a place, / 'Tis body; if intangible, 'tis space." As Lucretius charmingly argues, unless we presume the existence of space we have no alternative but to imagine universal gridlock.

Yet bodies do not fill up every place:
For besides those there is an empty space,
A void. This known, this notion framed aright
Will bring to my discourse new strength and light,
And teach you plainest methods to descry
The greatest secrets of philosophy.
A void is space intangible, thus proved:
For were there none, no body could be moved;
Because where'er the brisker motion goes,
It still must meet with stops, still meet with foes,
'Tis natural to bodies to oppose.
So that to move would be in vain to try
But all would fixed, stubborn, and moveless lie,
Because no yielding body could be found
Which first should move, and give the other ground.
But every one now sees that things do move
With various turns in earth and heaven above;
Which, were no void, not only we'd not seen,
But the bodies too themselves had never been:
Ne'er generated, for matter all sides pressed
With other matter would for ever rest.

Lucretius's teaching thus not only popularizes the categories of matter and space in the age of Newton but also reinforces the rejection of geocentrism: "For since the void is infinite, the space / Immense, how can there be a middle place?" Finally, from a modern perspective, one of atomism's most intriguing contributions is its attempt to conceptualize what we might call structure: the way in which abounding qualitative variety may arise from the recombination of simple elements. In this attempt to conceive complexity within simplicity, alphabetically structured language itself provides the analogy. Derrick de Kerckhove comments that, "without the slightest shred of ev-

idence, [Democritus] came to his conclusion that the elements of matter must be like the indivisible phonemes of the alphabet, thus inventing the very notion that one day in 1945 threatened to destroy the world" (The Skin of Culture, *1995, p. 35). In Lucretius's words as translated into English:*

> And hence, as we discoursed before, we find
> It matters much with what first seeds are joined,
> Or how, or what position they maintain,
> What motion give, and what receive again:
> And that the seeds remaining still the same,
> Their order changed, of wood are turned to flame.
> Just as the letters little change affords
> *Ignis* and *Lignum* ["fire" and "wood"], two quite different words.

SOURCES: Diogenes Laertius, *Lives of Eminent Philosophers*, trans. R. D. Hicks, 2 vols, London: Heinemann, 1925; fragments from Zeno and Democritus quoted from *The Presocratics*, ed. Philip Wheelwright, New York: The Odyssey Press, 1966; *T. Lucretius Carus . . . De Natura Rerum Done into English Verse*, trans. Thomas Creech, 2nd edition, Oxford, 1683.

Im

Although the Timaeus *is the other dialogues of Pl can attach Plato's autho the work presents. The Timaeus, a Pythagorean that Plato invests in hea questions the* Timaeus's *logues survived in a Lat Ages.*

Recognizing that cosn ogy, and that firm knowl cautiously. Although he of the Republic, *his meth*

Was the heaven or the v
ceptable name . . . alway
having a beginning? Cre
body, and therefore per
opinion and sense are in

Now that which is cr
how can we find out the
have found him, to spea
one more question has t

e elements of matter must
, thus inventing the very
the world" (The Skin of
translated into English:

d,

ame.

uite different words.

phers, trans. R. D. Hicks, 2
and Democritus quoted from
The Odyssey Press, 1966; *T.*
nglish Verse, trans. Thomas

5

The Moving Image of Eternity

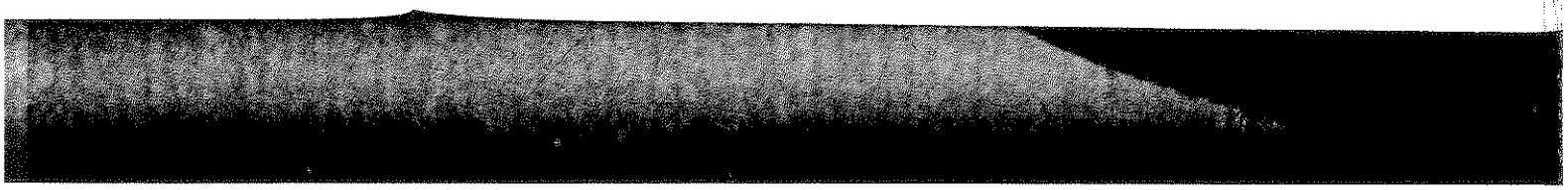
Plato

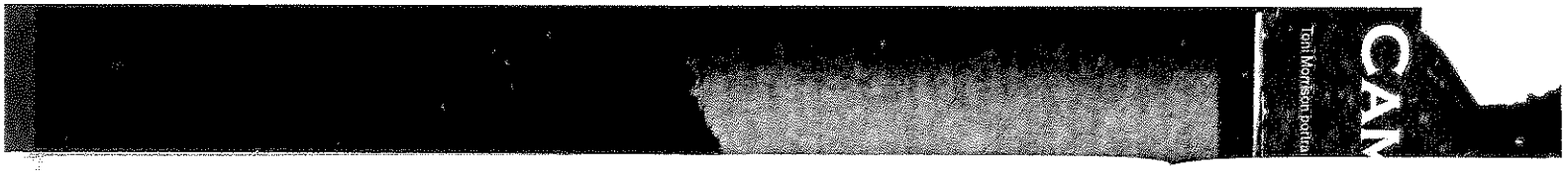
Although the Timaeus *is more conspicuously about cosmology than is any of the other dialogues of Plato (427–347 B.C.), it has been debated whether we can attach Plato's authority or unambiguous assent to the cosmology which the work presents. The main speaker in the dialogue is not Socrates but Timaeus, a Pythagorean philosopher, and physical cosmology is not a subject that Plato invests in heavily elsewhere in the dialogues. Nevertheless, no one questions the* Timaeus's *influence, especially since it alone among the dialogues survived in a Latin translation through late antiquity and the Middle Ages.*

Recognizing that cosmology and cosmogony are directly related to theology, and that firm knowledge in these areas is not to be had, Timaeus sets out cautiously. Although he reasons in the analogical manner familiar to readers of the Republic, *his method explicitly pursues not certainty but probability.*

Was the heaven or the world, whether called by this or any other more acceptable name . . . always in existence and without beginning, or created and having a beginning? Created, I reply, being visible and tangible and having a body, and therefore perceptible; and all perceptible things apprehended by opinion and sense are in a process of creation and created.

Now that which is created must of necessity be created by a cause. But how can we find out the father and maker of all this universe? And when we have found him, to speak of his nature to all men would be impossible. Yet one more question has to be asked about him: Which pattern had the artifi-





cer in view when he made the world—the pattern which is unchangeable, or that which is created? If the world is indeed fair and the artificer good, then plainly he must have looked to that which is eternal. But if what cannot be said without blasphemy were true, then he looked to the created pattern. Every one will see that he must have looked to the eternal, for the world is the fairest of creations and he is the best of causes.

Having been created in this way, the world has been framed with a view to that which is apprehended by reason and mind and is unchangeable, and must (if this is admitted) of necessity be the copy of something. Now that the beginning of everything should be according to nature is a great matter. And in speaking of the copy and original we may assume that words are akin to the matter which they describe: when they relate to the lasting and permanent and intelligible, they ought to be lasting and unfailing, and, as far as their nature permits, irrefutable and immovable—nothing less. But when they express only the copy or image and not the eternal things themselves, they need only be probable and analogous to the real words. As being is to becoming, so is truth to belief. If then, Socrates, amid the many opinions about the gods and the generation of the universe, we are not able to convey notions which are in every way exact and consistent with one another, do not be surprised. It is enough if we adduce probabilities as likely as any others, for we must remember that I who am the speaker, and you who are the judges, are only mortal men, and we ought to accept the tale which is probable and not enquire further.

Although the four elements of earth, air, fire, and water are popularly associated mainly with the teaching of Aristotle, they originated with the teaching Empedocles, and the cosmology of the Timaeus *employs them too, though with a distinctively Pythagorean, geometrical flavor.*

Now that which is created is of necessity corporeal, and also visible and tangible. Now nothing is visible where there is no fire, and nothing is tangible which is not solid, and there is no solidity without earth. Therefore, God in the beginning of creation made the body of the universe to consist of fire and earth. But two things cannot be held together without a third; they must have some bond of union. The fairest bond is that which most completely fuses and is fused into the things which are bound; and geometrical proportion is best adapted to effect such a fusion. . . . If the universal frame had been created a surface only and without depth, one mean would have sufficed to bind together itself and the other terms; but now, as the world must be solid, and solid bodies are always compacted not by one mean but by two, God placed water and air in the mean between fire and earth, and made them to have the same proportion so far as was possible (as fire is to

air, so is air to water; a
bound and put togethe
and out of such elemen
was created in harmor
friendship. And being a
any other than that of t

The creation took up
ator compounded the w
and all the earth, leavin
side. He intended first t
fect whole and of perfec
from which another suc
free from old age and un
figure which was suitab
being which was to con
within itself all other fig
globe, round as from a l
ter to the extremes, the

Already in the Timaeus
concerning the nature of
reasoning is glimpsed in
which functions in the ti
its powers to define time

When the father and cr
and living, the created g
joy determined to confo
eternal, he sought to ma
nature of the intelligible
is impossible. Therefore
which he made when he
while eternity rested in u

This moving image w
months and years befor
heaven he created them a
are created species of tim
eternal being. For we say
truth is that only "he is"
ply to becoming in time, t
same cannot become olde
come, nor hereafter will

which is unchangeable, or
nd the artificer good, then
nal. But if what cannot be
ed to the created pattern.
ıe eternal, for the world is

)een framed with a view to
and is unchangeable, and
)f something. Now that the
ıture is a great matter. And
me that words are akin to
to the lasting and perma-
d unfailing, and, as far as
:—nothing less. But when
eternal things themselves,
real words. As being is to
, amid the many opinions
, we are not able to convey
nt with one another, do not
ies as likely as any others,
ker, and you who are the
ept the tale which is proba-

water are popularly associ-
riginated with the teaching
employs them too, though
or.

ıl, and also visible and tan-
re, and nothing is tangible
ıt earth. Therefore, God in
universe to consist of fire
without a third; they must
ıat which most completely
d; and geometrical propor-
If the universal frame had
one mean would have suf-
)ut now, as the world must
l not by one mean but by
tween fire and earth, and
s was possible (as fire is to

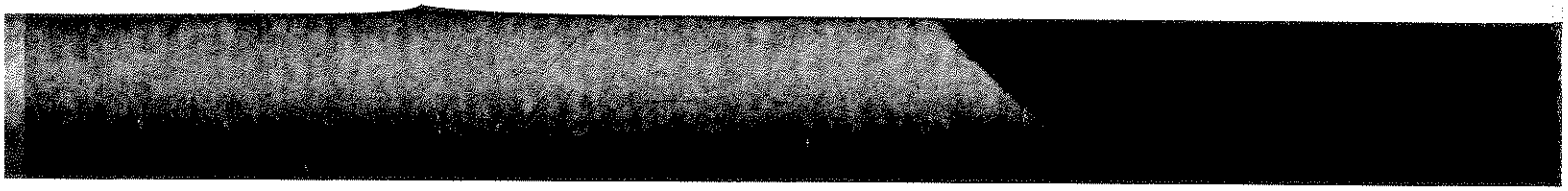
air, so is air to water; and as air is to water, so is water to earth). Thus he bound and put together a visible and palpable heaven. For these reasons, and out of such elements which are four in number, the body of the world was created in harmony and proportion, and so possessing the spirit of friendship. And being at unity with itself, it was indissoluble by the hand of any other than that of the framer.

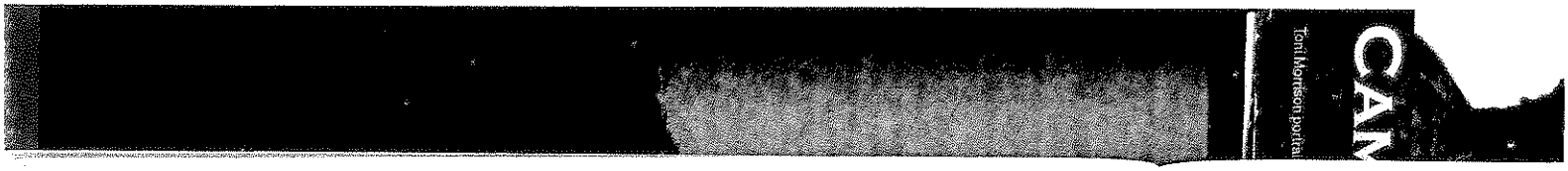
The creation took up the whole of each of the four elements. For the creator compounded the world out of all the fire and all the water and all the air and all the earth, leaving no part of any of them nor any power of them outside. He intended first that the living being should be as far as possible a perfect whole and of perfect parts, and should be one, leaving no remnants over from which another such world might be created, and also that it should be free from old age and unaffected by disease. . . . And he gave to the world the figure which was suitable and also natural. What was suitable to the living being which was to contain all living beings was that figure which contains within itself all other figures. Therefore he made the world in the form of a globe, round as from a lathe, in every direction equally distant from the center to the extremes, the most perfect and the most like itself of all figures.

Already in the Timaeus *questions of cosmology are closely linked to those concerning the nature of time. The profoundly self-reflexive nature of Plato's reasoning is glimpsed in part in the recognition that all human reasoning, which functions in the time-bound medium of language, is severely limited in its powers to define time or, even more so, that which exists beyond time.*

When the father and creator saw the creature which he had made moving and living, the created glory of the eternal gods, he was delighted, and in his joy determined to conform the work to the original still more. As this was eternal, he sought to make the universe eternal, as far as might be. Now the nature of the intelligible being is eternal, but to attach eternity to the creature is impossible. Therefore he resolved to make a moving image of eternity, which he made when he set in order the heaven moving according to number, while eternity rested in unity.

This moving image we call time. For there were no days and nights and months and years before the heaven was created, but when he created the heaven he created them also. They are all parts of time, and the past and future are created species of time, which we unconsciously but wrongly ascribe to the eternal being. For we say indeed "he was," "he is," and "he will be"; but the truth is that only "he is" is truly spoken of him. "Was" and "will be" only apply to becoming in time, for they are motions. But that which is immovably the same cannot become older or younger by time. Nor ever did he, nor has he become, nor hereafter will he grow older; nor is he subject at all to any of those





states of generation which affect the movement of perceptible things. These are the forms that time exhibits as it imitates eternity, moving in a circle measured by number. Moreover, when we say that what has become has become, and what is becoming is becoming, and what will become will become, and that that which is not is not—all these are inaccurate modes of expression. But perhaps this is not the place for us to discuss minutely such matters.

Although generations of "synchretizing" Christian commentators interpreted the creation as depicted by the Timaeus *in conformity with the creation account of Genesis, chapter 1 (and vice versa), the differences between Plato and the Bible are as notable as are the similarities. By contrast with biblical monism and the doctrine of* creatio ex nihilo *which grew from it, the teaching of the* Timaeus *is tied to the analogy of a human architect whose relative success in making something is inevitably limited by the nature of available raw materials that are* not *of the architect's own making. The presence of that "necessity" as a potentially intractable raw material renders Plato's account—for all its Christianizable features—fundamentally dualistic.*

Thus far in what we have been saying, with small exceptions, the works of intelligence have been set forth. Now we must place beside them the things done from necessity. For the creation is mixed, being made up of necessity and mind. Mind, the ruling power, persuaded necessity to bring the greater part of created things to perfection, and thus in the beginning, when the influence of reason got the better of necessity, the universe was created. But if one will truly tell of the way in which the work was accomplished, one must include the other influence of the variable cause as well. Therefore, we must return again and . . . consider the nature of fire, and water, and air, and earth, which were prior to the creation of the heavens, and what happened before they were elements. For no one has explained them, yet we speak of fire and the rest, whatever they really mean, as if people knew their natures, and we treat them as the letters or elements of the whole, when they cannot reasonably be compared to the syllables or first compounds by any sensible person. Moreover, let me say this: I will not speak of the first principle or principles of all things, or by whatever name they should be called, because it is difficult to express my opinion according to the mode of discussion which we are at present employing. . . . Therefore, when I speak of the beginning of each and all, I shall observe the rule of probability with which I began. . . . Once more, then, I call upon God at the beginning of my discourse and beg him to see us safely through a strange and unusual enquiry, and to bring us to probability. So now let us begin again.

This new beginning of our discussion of the universe requires a fuller division than the former. For then we posited two classes; now a third must be

added. The two sufficed
pattern intelligible and al
of the pattern, generated
considering that two wo
quire that we account fo
scure. What powers and
being? We reply that it i
generation.

*Timaeus is of course righ
is a difficult entity to con
material (if abstract) sub
the divine architect looks
apparently akin to the "n
with the forms of creation*

Let me make one more att
a person makes all kinds
them out of one form int
and asks, "What is that?"
not "That is a triangle" o

In the same way, that w
extent the resemblances o
ular form. Therefore, the
perceptible things is not t
their compounds, or any
but is an invisible and for
a mysterious way a portio

*Timaeus summarizes the t
or Imitation, and (3) the "*

The third nature is space,
provides a home for all c
sense, by a kind of spuriou
if in a dream and say that
occupy a space—and that
tence. These and other suc
reality of nature we appre
unable to arouse ourselve
an image, not possessing t
isting as a constantly chan

erceptible things. These are
noving in a circle measured
s become has become, and
ome will become, and that
odes of expression. But per-
such matters.

commentators interpreted
rnity with the creation ac-
differences between Plato
s. By contrast with biblical
ch grew from it, the teach-
an architect whose relative
by the nature of available
making. The presence of
naterial renders Plato's ac-
nentally dualistic.

ll exceptions, the works of
ace beside them the things
eing made up of necessity
cessity to bring the greater
he beginning, when the in-
niverse was created. But if
as accomplished, one must
s well. Therefore, we must
d water, and air, and earth,
and what happened before
n, yet we speak of fire and
new their natures, and we
when they cannot reason-
nds by any sensible person.
first principle or principles
e called, because it is diffi-
of discussion which we are
k of the beginning of each
h which I began. . . . Once
y discourse and beg him to
y, and to bring us to prob-

verse requires a fuller divi-
asses; now a third must be

added. The two sufficed for the former discussion. One (we assumed) was a pattern intelligible and always the same. The second was only the imitation of the pattern, generated and visible. We did not then distinguish a third, considering that two would be enough. But now the argument seems to require that we account for another kind, which is hard to explain and obscure. What powers and what nature shall we attribute to this new kind of being? We reply that it is the receptacle, and in a manner the nurse, of all generation.

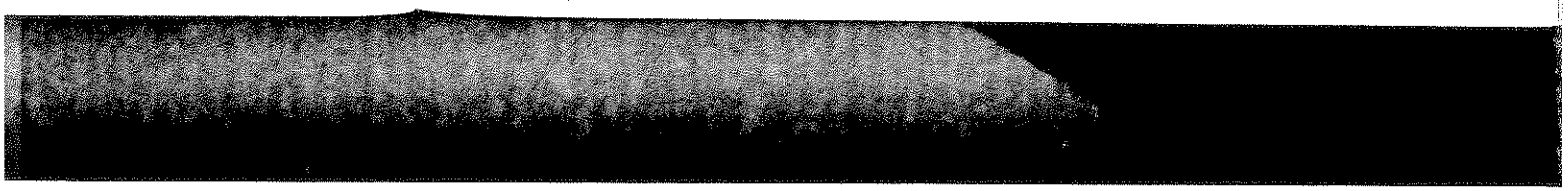
Timaeus is of course right that the third something he wishes to account for is a difficult entity to conceptualize, although in general we can see it as the material (if abstract) substrate of creation, not the formal pattern to which the divine architect looks as he creates, and not the product of creation. It is apparently akin to the "necessity" mentioned earlier, that which is imprinted with the forms of creation.

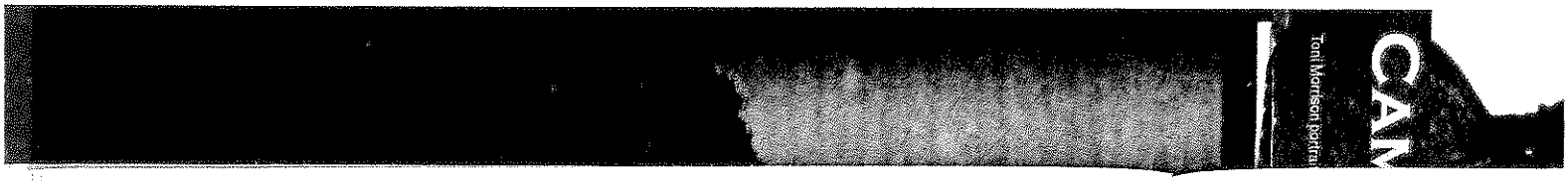
Let me make one more attempt to explain my meaning more clearly. Suppose a person makes all kinds of figures of gold and never stops transforming them out of one form into all the others. Somebody points to one of them and asks, "What is that?" We answer most truly and safely, "That is gold"—not "That is a triangle" or any other figure formed in the gold. . . .

In the same way, that which is to receive perpetually and through its whole extent the resemblances of eternal beings ought to be destitute of any particular form. Therefore, the mother and receptacle of all created and visible and perceptible things is not to be termed earth, or air, or fire, or water, or any of their compounds, or any of the elements out of which they are composed, but is an invisible and formless being which receives all things and attains in a mysterious way a portion of the intelligible.

Timaeus summarizes the three classes, which we can call (1) Form, (2) Copy or Imitation, and (3) the "Nurse" or Receptacle, which is now called space:

The third nature is space, and is eternal, and admits not of destruction, and provides a home for all created things, and is perceived without the help of sense, by a kind of spurious reason, and is hard to believe in. We behold it as if in a dream and say that all existence must of necessity be in some place and occupy a space—and that what is neither in heaven nor in earth has no existence. These and other such things which are related to the true and waking reality of nature we apprehend only in such a dreamlike manner that we are unable to arouse ourselves to describe them or to determine them truly. But an image, not possessing the essence of that of which it is an image, and existing as a constantly changing shadow of something else, must inhere in that





third nature, space, if it is to participate in reality to any degree at all—if it is not to be nothing.

The poetic pinnacle of Timaeus's account comes with the description—which includes an almost Homeric epic simile—of the elements in their chaotic pre-creational state. It is not surprising that interpreters of Genesis 1:2, with its parsimonious description of the earth "without form and void," should turn to this account for an imaginative amplification of the narrative of creation. One may emphasize again, however, that Plato's dualism entails a quite different theodicy—a contrasting account of the origin of evil in the world—from the monistic and largely moral picture presented by Genesis. The God of the Timaeus *is simply not almighty in any biblical sense: In the face of necessity, he made things good only "as far as possible."*

Thus I have given concisely the results of my thinking. My opinion is that being and space and generation, these three realities, existed before the heaven. The nurse of generation, moistened by water and inflamed by fire, and receiving the various forms of earth and air, and experiencing all the other accidents that attach to them, took a variety of shapes. But there was in it no equilibrium or homogeneity of powers, nowhere any state of equipoise. Thus it swayed unevenly to and fro, shaken by them, and by its motion it shook them in turn. And the elements when moved were divided like the grain shaken and winnowed by fans and other instruments used in the threshing of corn, when the close and heavy particles are borne away and settle in one direction while the loose and light particles are blown away in another. In this manner the four kinds or elements were shaken by the recipient vessel, which, moving like a winnowing machine, scattered far away from one another the elements most unlike, and forced the most similar elements into the closest contact. The elements too, therefore, had different places before the universe that was formed out of them came into being.

At first all things were without reason and measure. But when the world began to become ordered, first fire and water and earth and air, having only certain faint traces of themselves, and being altogether such as everything may be expected to be in the absence of God—this being their nature—then God fashioned them by form and number. Let us always, in all that we say, affirm that God made things as far as possible most fair and good out of things which were not fair and good.

SOURCE: Adapted from Plato, *Timaeus*, in *The Dialogues of Plato*, trans. B. Jowett, 2nd ed., vol. 3, Oxford, 1875.

The

No thinker or writer e
of cosmology than did
about place, space, mat
Ptolemaic system, whi
years. The plainness an
give us a glimpse into
authority.

In the following wid
how, for Aristotle, defi
counter the notion—a s
or post-Newtonian—th
themselves are qualitati

The physicist must hav
such a thing or not, an
cause all suppose that t
nowhere—where is the
its most general and pr
motion." . . .

Further, the typical l
fire, earth and the like,
exerts a certain influen
dered, the one up, the o
up and down and the r
and down and right an

to any degree at all—if it is

vith the description—which
lements in their chaotic pre-
ters of Genesis 1:2, with its
orm and void," should turn
of the narrative of creation.
dualism entails a quite dif-
rigin of evil in the world—
ented by Genesis. The God
ical sense: In the face of ne-
ble."

king. My opinion is that be-
, existed before the heaven.
d inflamed by fire, and re-
periencing all the other acci-
pes. But there was in it no
any state of equipoise. Thus
and by its motion it shook
vere divided like the grain
ents used in the threshing of
e away and settle in one di-
wn away in another. In this
en by the recipient vessel,
ered far away from one an-
ost similar elements into the
different places before the
being.
easure. But when the world
d earth and air, having only
ogether such as everything
is being their nature—then
s always, in all that we say,
most fair and good out of

ues of Plato, trans. B. Jowett,

6

The Potency of Place

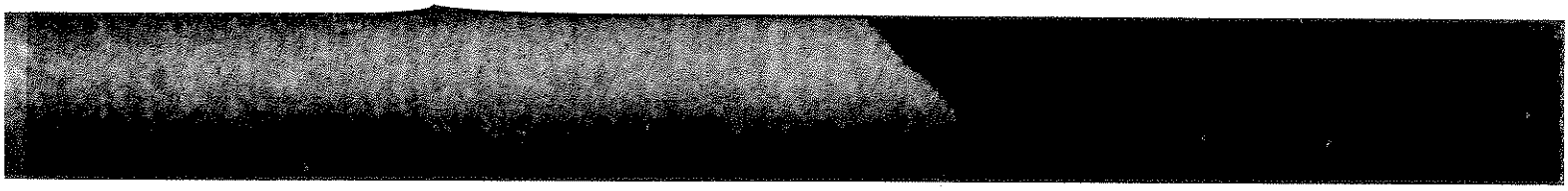
Aristotle

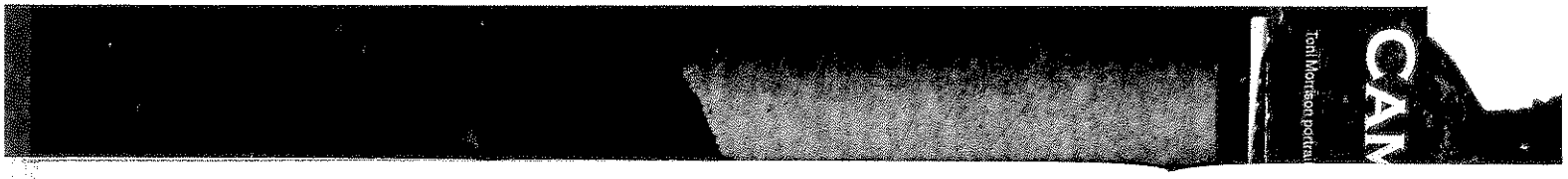
No thinker or writer exerted a greater influence on pre-Copernican notions of cosmology than did Aristotle (384–322 B.C.). Aristotelian assumptions about place, space, matter, motion, and time served as the foundation for the Ptolemaic system, which held sway in the west for more than a thousand years. The plainness and unstrained authoritativeness of Aristotle's style may give us a glimpse into the sources, both rhetorical and philosophical, of his authority.

In the following widely cited passage from book 4 of the Physics *we see how, for Aristotle, definitions of place precede those of space; and we encounter the notion—a startling one for those whose education is Newtonian or post-Newtonian—that place itself has "potency," and that places in and of themselves are qualitatively different from each other.*

The physicist must have a knowledge of Place . . . namely, whether there is such a thing or not, and the manner of its existence and what it is, both because all suppose that things which exist are *somewhere* (the non-existent is nowhere—where is the goat-stag or the sphinx?), and because "motion" in its most general and primary sense is change of place, which we call "locomotion." . . .

Further, the typical locomotions of the elementary natural bodies, namely fire, earth and the like, show not only that place is something, but also that it exerts a certain influence. Each is carried to its own place, if it is not hindered, the one up, the other down. Now these are regions or kinds of place—up and down and the rest of the six directions. Nor do such distinctions (up and down and right and left, etc.) hold only in relation to us. To *us* they are





not always the same but change with the direction in which we are turned: that is why the same thing may be both right *and* left, up *and* down, before *and* behind. But in *nature* each is distinct, taken apart from itself. It is not every chance direction which is "up," but where fire and what is light are carried; similarly, too, "down" is not any chance direction but where what has weight and what is made of earth are carried—the implication being that these places do not differ merely in relative position, but also as possessing distinct potencies. . . .

These considerations then would lead us to suppose that place is something distinct from bodies, and that every sensible body is in place. Hesiod too might be held to have given a correct account of it when he made chaos first. At least he says, "First of all things came chaos to being, then broad-breasted earth," implying that things need to have space first, because he thought, with most people, that everything is somewhere and in place. If this is its nature, the potency of place must be a marvelous thing, and take precedence of all other things. For that without which nothing else can exist, while it can exist without the others, must needs be first; for place does not pass out of existence when the things in it are annihilated.

Accordingly, for Aristotle place is not isotropic (identical in all directions) as it is for Newton; however, it is *absolute and independent of matter in the same way that it is for Newton (but not for Einstein). Time, by contrast, is relative to things, to matter, in a way that place is not:*

Not only do we measure the movement by the time, but also the time by the movement, because they define each other. The time marks the movement, since it is its number, and the movement the time. We describe the time as much or little, measuring it by the movement, just as we know the number by what is numbered, e.g. the number of the horses by one horse as the unit. For we know how many horses there are by the use of the number; and again by using the one horse as unit we know the number of the horses itself. So it is with the time and the movement; for we measure the movement by the time and vice versa. It is natural that this should happen; for the movement goes with the distance and the time with the movement, because they are quanta and continuous and divisible. The movement has these attributes because the distance is of this nature, and the time has them because of the movement. And we measure both the distance by the movement and the movement by the distance; for we say that the road is long, if the journey is long, and that this is long, if the road is long—the time, too, if the movement, and the movement, if the time.

Time is a measure of motion and of being moved.

The principles laid out
of place and the explan
tain substances naturall
self in On the Heavens.

First, however, we mus
many senses we use the
quiry. (a) In one sense, t
circumference of the wl
treme circumference. W
"heaven" in the extremi
all that is divine. (b) In a
ous with the extreme ci
some of the stars; these
we give the name to al
since we habitually call
is used in three senses.

Now the whole incluc
posed of *all* physical and
into being any body outs
includes all its appropri
body. So that neither ar
ever be formed more he
unique and complete.

It is therefore evident
heaven. For in every pla
which the presence of b
number of movement. B
ment.

Aristotle turns his attent
rest or motion within th
philosophical vacuum b
with his own. The line o
the old cliché according
earth in the place of grea

As to earth's *position* th
in fact, who regard the
the Italian philosophers
the center, they say, is fi

ɔn in which we are turned:
d left, up *and* down, before
apart from itself. It is not
ɛ fire and what is light are
ɛ direction but where what
—the implication being that
tion, but also as possessing

uppose that place is some-
le body is in place. Hesiod
t of it when he made chaos
haos to being, then broad-
ave space first, because he
ɪewhere and in place. If this
elous thing, and take prece-
ɪothing else can exist, while
rst; for place does not pass
ted.

dentical in all directions) as
dependent of matter in the
stein). Time, by contrast, is
not:

ne, but also the time by the
time marks the movement,
ɪe. We describe the time as
ɪst as we know the number
ɛs by one horse as the unit.
ɜe of the number; and again
ɔer of the horses itself. So it
ɪsure the movement by the
happen; for the movement
ovement, because they are
ɪent has these attributes be-
ɪe has them because of the
by the movement and the
ɪad is long, if the journey is
time, too, if the movement,

ɛd.

The principles laid out in the Physics, *especially concerning the importance of place and the explanation it provides for what we call gravity—why certain substances naturally seek certain places—are applied to the universe itself in* On the Heavens.

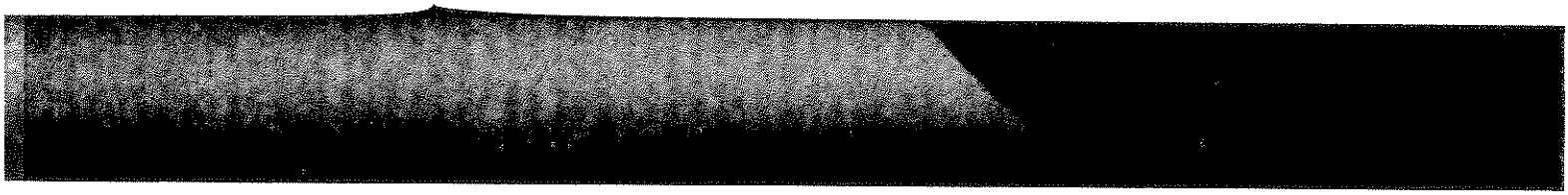
First, however, we must explain what we mean by "heaven" and in how many senses we use the word, in order to make clearer the object of our inquiry. (a) In one sense, then, we call "heaven" the substance of the extreme circumference of the whole, or that natural body whose place is at the extreme circumference. We recognize habitually a special right to the name "heaven" in the extremity or upper regions, which we take to be the seat of all that is divine. (b) In another sense, we use this name for the body continuous with the extreme circumference, which contains the moon, the sun, and some of the stars; these we say are "in the heaven." (c) In yet another sense we give the name to all body included within the extreme circumference, since we habitually call the whole or totality "the heaven." The word, then, is used in three senses.

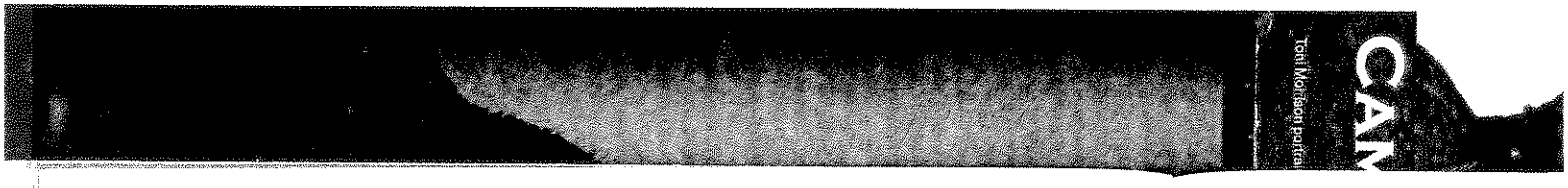
Now the whole included within the extreme circumference must be composed of *all* physical and sensible body, because there neither is nor can come into being any body outside the heaven. . . . The world as a whole, therefore, includes all its appropriate matter, which is, as we saw, natural perceptible body. So that neither are there now, nor have there ever been, nor can there ever be formed more heavens than one, but this heaven of ours is one and unique and complete.

It is therefore evident that there is also no place or void or time outside the heaven. For in every place body can be present; and void is said to be that in which the presence of body, though not actual, is possible; and time is the number of movement. But in the absence of natural body there is no movement.

Aristotle turns his attention subsequently to the earth's position, shape, and rest or motion within the universe. His discussion by no means operates in a philosophical vacuum but accounts briefly for other views in competition with his own. The line of argument is instructive for any who have imbibed the old cliché according to which geocentric cosmology is said to locate the earth in the place of greatest importance in the universe.

As to earth's *position* there is some difference of opinion. Most people—all, in fact, who regard the whole heaven as finite—say it lies at the center. But the Italian philosophers known as Pythagoreans take the contrary view. At the center, they say, is fire, and the earth is one of the stars, creating night





and day by its circular motion about the center. . . . There are many others who would agree that it is wrong to give the earth the central position, looking for confirmation rather to theory than to the facts of observation. Their view is that the most precious place befits the most precious thing. But fire, they say, is more precious than earth, and the limit than the intermediate, and the circumference and the center are limits. Reasoning on this basis they take the view that it is not earth that lies at the center of the sphere, but rather fire. The Pythagoreans have a further reason. They hold that the most important part of the world, which is the center, should be most strictly guarded, and name it, or rather the fire which occupies that place, the "Guard-house of Zeus," as if the word "center" were quite unequivocal, and the center of the mathematical figure were always the same with that of the thing or the natural center.

But it is better to conceive of the case of the whole heaven as analogous to that of animals, in which the center of the animal and that of the body are different. For this reason they have no need to be so disturbed about the world, or to call in a guard for its center. Rather, let them look for the center in the other sense and tell us what it is like and where nature has set it. That center will be something primary and precious; but to the mere position we should give the last place rather than the first. For the middle is what is defined, and what defines it is the limit, and that which contains or limits is more precious than that which is limited, seeing that the latter is the matter and the former the essence of the system. . . .

There are similar disputes about the *shape* of the earth. Some think it is spherical, others that it is flat and drum-shaped. For evidence they bring the fact that, as the sun rises and sets, the part concealed by the earth shows a straight and not a curved edge, whereas if the earth were spherical the line of section would have to be circular. In this they leave out of account the great distance of the sun from the earth and the great size of the circumference, which, seen from a distance on these apparently small circles, appears straight. Such an appearance ought not to make them doubt the circular shape of the earth. . . .

Some have been led to assert that the earth below us is infinite, saying, with Xenophanes of Colophon, that it has "pushed its roots to infinity"—in order to save the trouble of seeking for the cause. Hence the sharp rebuke of Empedocles, in the words "If the deeps of the earth are endless and endless the ample ether—such is the vain tale told by many a tongue, poured from the mouths of those who have seen but little of the whole." Others say the earth rests upon water. This indeed is the oldest theory that has been preserved, and is attributed to Thales of Miletus. It was supposed to stay still because it floated like wood and other similar substances, which are so

constituted as to rest u
had not to be given of t
It is not the nature of
must have something t
water than earth. How
stance lies below the he

Aristotle's continuous a
substances seek their p
concerning both the sh
current popular notion
universe (as distinct fro
center) dissolves before

Further, the natural mo
center of the whole—w
center. But it might be
center it is that portions
goal because it is the c
whole? The goal, surely
light things move to th
happens, however, that
Thus they do move to th
fact that the earth's cent

From what we have s
apparent. If it is the nat
point to the center . . . t
move away from the cer
gle movement, and a si
can move away from th
so move. For it is the na
part naturally moves. Si
move it, it must needs st

Earth's shape must ne
weight until it reaches th
would bring about not a
gence of part and part u
ceived by supposing the
natural philosophers de
to constraint, and it is b
this motion is that a thi

. . . There are many others
earth the central position,
to the facts of observation.
:s the most precious thing.
nd the limit than the inter-
:e limits. Reasoning on this
at lies at the center of the
. further reason. They hold
ch is the center, should be
ıe fire which occupies that
rd "center" were quite un-
gure were always the same

ıole heaven as analogous to
ıl and that of the body are
be so disturbed about the
let them look for the center
here nature has set it. That
ıut to the mere position we
ır the middle is what is de-
which contains or limits is
that the latter is the matter

the earth. Some think it is
For evidence they bring the
ealed by the earth shows a
h were spherical the line of
ve out of account the great
size of the circumference,
tly small circles, appears
e them doubt the circular

elow us is infinite, saying,
:d its roots to infinity"—in
Hence the sharp rebuke of
:th are endless and endless
ny a tongue, poured from
he whole." Others say the
theory that has been pre-
ıs supposed to stay still be-
ıubstances, which are so

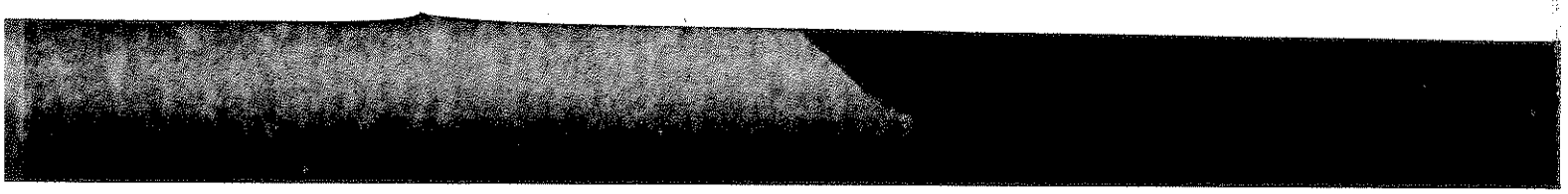
constituted as to rest upon water but not upon air. As if the same account had not to be given of the water which carries the earth as of the earth itself! It is not the nature of water, any more than of earth, to stay in mid-air: it must have something to rest upon. Again, as air is lighter than water, so is water than earth. How then can they think that the naturally lighter substance lies below the heavier?

Aristotle's continuous assumption concerning the potency of place, whereby substances seek their proper or natural location, underlies his conclusions concerning both the shape and the movement or rest of the earth. The still-current popular notion that geocentrism identifies earth as the center of the universe (as distinct from placing it, on account of its mere heaviness, at *the center) dissolves before the sophisticated clarity of Aristotle's account.*

Further, the natural movement of the earth, part and whole alike, is to the center of the whole—whence the fact that it is now actually situated at the center. But it might be questioned, since both centers are the same, which center it is that portions of earth and other heavy things move to. Is this their goal because it is the center of the earth or because it is the center of the whole? The goal, surely, must be the center of the whole. For fire and other light things move to the extremity of the area which contains the center. It happens, however, that the center of the earth and of the whole is the same. Thus they do move to the center of the earth, but accidentally, in virtue of the fact that the earth's center lies at the center of the whole. . . .

From what we have said, the explanation of the earth's immobility is also apparent. If it is the nature of earth, as observation shows, to move from any point to the center . . . then it is impossible that any portion of earth should move away from the center except by constraint. For a single thing has a single movement, and a simple thing a simple. . . . If then no portion of earth can move away from the center, obviously still less can the earth as a whole so move. For it is the nature of the whole to move to the point to which the part naturally moves. Since then it would require a force greater than itself to move it, it must needs stay at the center. . . .

Earth's shape must necessarily be spherical. For every portion of earth has weight until it reaches the center, and the jostling of parts greater and smaller would bring about not a waved surface, but rather compression and convergence of part and part until the center is reached. The process should be conceived by supposing the earth to come into being in the way that some of the natural philosophers describe. Only they attribute the downward movement to constraint, and it is better to keep to the truth and say that the reason of this motion is that a thing which possesses weight is naturally endowed with



a centripetal movement. When the mixture, then, was merely potential, the things that were separated off moved similarly from every side towards the center. Whether the parts which came together at the center were distributed at the extremities evenly, or in some other way, makes no difference. If there were a similar movement from each quarter of the extremity to the single center, it is obvious that the resulting mass would be similar on every side. For if an equal amount is added on every side the extremity of the mass will be everywhere equidistant from its center, i.e., the figure will be spherical.

Given the commonplace picture of Aristotle as anti-empirical, one is perhaps surprised at how often he appeals to experience, as he does in supporting his contention that the earth is spherical.

Again, our observations of the stars make it evident not only that the earth is circular, but also that it is a circle of no great size. For quite a small change of position to south or north causes a manifest alteration of the horizon. . . . Indeed there are some stars seen in Egypt and in the neighborhood of Cyprus which are not seen in the northerly regions; and stars, which in the north are never beyond the range of observation, in those regions rise and set. All of which goes to show not only that the earth is circular in shape, but also that it is a sphere of no great size: for otherwise the effect of so slight a change of place would not be so quickly apparent. Hence one should not be too sure of the incredibility of the view of those who conceive that there is continuity between the parts about the pillars of Hercules and the parts about India, and that in this way the ocean is one.

As further evidence in favor of this they quote the case of elephants, a species occurring in each of these extreme regions, suggesting that the common characteristic of these extremes is explained by their continuity. Also, those mathematicians who try to calculate the size of the earth's circumference arrive at the figure of 400,000 stades [perhaps 40,000 miles]. This indicates not only that the earth's mass is spherical in shape, but also that as compared with the stars it is not of great size.

SOURCE: Aristotle, *Physics* and *On the Heavens*, in *The Works of Aristotle*, ed. vol. 2, W. D. Ross, Oxford: Clarendon Press, 1930.

was merely potential, the
om every side towards the
the center were distributed
akes no difference. If there
he extremity to the single
l be similar on every side.
extremity of the mass will
figure will be spherical.

i-empirical, one is perhaps
s he does in supporting his

it not only that the earth is
For quite a small change of
tion of the horizon. . . . In-
e neighborhood of Cyprus
ars, which in the north are
egions rise and set. All of
ılar in shape, but also that
ect of so slight a change of
e should not be too sure of
that there is continuity be-
the parts about India, and

e the case of elephants, a
, suggesting that the com-
by their continuity. Also,
e of the earth's circumfer-
s 40,000 miles]. This indi-
in shape, but also that as

Works of Aristotle, ed. vol. 2,

7

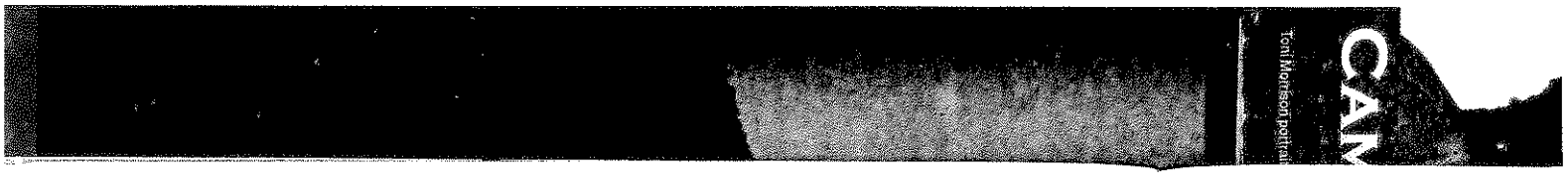
He Supposes the Earth to Revolve

Aristarchus and Archimedes

Not everyone before Copernicus believed that the planets and the sun revolved around the earth. The first astronomer known to have proposed a heliocentric rather than a geocentric model was Aristarchus of Samos (c. 310–c. 230 B.C.). Heliocentrism appears nowhere in his extant works, but we have authoritative attributions of the idea to him in other ancient sources. For example, Plutarch mentions Aristarchus's "attempt to save the phenomena by supposing the heaven to remain at rest, and the earth to revolve in an oblique circle, while it rotates, at the same time, about its own axis."

The most detailed reference, however, appears in the writings of Aristarchus's younger contemporary Archimedes (287–212 B.C.). The work in which Archimedes mentions Aristarchus's ideas is interesting for two further reasons. In it Archimedes is applying his development of an exponential system to express very large numbers—numbers which we quite naturally refer to as "astronomical" and which, without an exponential system, we would be at a loss to express. Archimedes asks, in what modern scientists would call a "thought experiment," how many grains of sand the universe itself might hold. The discussion also provides an occasion for worrying about the size and very definition of the term universe.

There are some . . . who think that the number of the sand is infinite in multitude; and I mean by the sand not only that which exists about Syracuse and the rest of Sicily, but also that which is found in every region, whether inhabited or uninhabited. Again, there are some who, without regarding it as infi-



nite, yet think that no number has been named which is great enough to exceed its multitude. And it is clear that they who hold this view, if they imagined a mass made up of sand as large in size as the mass of the earth, including in it all the seas and the hollows of the earth filled up to a height equal to that of the highest mountain, would be many times further still from recognizing that any number could be expressed which exceeded the multitude of the sand so taken.

But I will try to show you, by means of geometrical proofs, which you will be able to follow, that of the numbers named by me . . . some exceed not only the number of the mass of sand equal in size to the earth filled up in the way described, but also that of a mass equal in size to the universe.

Now you are aware that "universe" is the name given by most astronomers to the sphere the center of which is equal to the straight line between the center of the sun and the center of the earth. This you have seen in the treatises written by astronomers.

But Aristarchus of Samos brought out a book consisting of certain hypotheses, in which the premises lead to the conclusion that the universe is many times greater than that now so called. His hypotheses are that the fixed stars and the sun remain motionless, that the earth revolves about the sun in the circumference of a circle, the sun lying in the middle of the orbit, and that the sphere of the fixed stars, situated about the same center as the sun, is so great that the circle in which he supposes the earth to revolve bears such a proportion to the distance of the fixed stars as the center of the sphere bears to its surface.

Archimedes rightly objects that the ratio of a point to a circumference is no ratio at all, for a point has no dimension whatsoever. Therefore he adjusts the parallel thus: Aristarchus must mean that the ratio of the size of the earth to the size of the universe *as Archimedes has defined it must be equal to* the ratio of the size of the sphere of earth's orbit to the size of the universe *as Aristarchus defines it. In short, the Aristarchan theory entails an increase in the size of the universe by many orders of magnitude.*

Now it is easy to see that this is impossible; for since the center of the sphere has no magnitude, we cannot conceive it to bear any ratio whatever to the surface of the sphere. We must, however, take Aristarchus to mean this: since we conceive the earth to be, as it were, the center of the universe, the ratio which the earth bears to what we describe as the "universe" is the same as the ratio which the sphere containing the circle in which he supposes the earth to revolve bears to the sphere of the fixed stars. For he adapts the proofs of the phenomena to a hypothesis of this kind, and in particular he

appears to suppose the si
moving to be equal to wh

I say then, that, even if
Aristarchus supposes the
prove that . . . some [nur
which is equal in size to t

As T. L. Heath commen
calculation" Archimedes
be contained in a sphere
number which we should

SOURCE: Thomas L. Heath,

vhich is great enough to ex-
hold this view, if they imag-
as the mass of the earth,
e earth filled up to a height
nany times further still from
l which exceeded the multi-

:rical proofs, which you will
ne . . . some exceed not only
he earth filled up in the way
the universe.
: name given by most as-
qual to the straight line be-
earth. This you have seen in

)k consisting of certain hy-
clusion that the universe is
ıypotheses are that the fixed
th revolves about the sun in
middle of the orbit, and that
ame center as the sun, is so
ırth to revolve bears such a
ıe center of the sphere bears

int to a circumference is no
soever. Therefore he adjusts
ratio of the size of the earth
ined it must be equal to the
) the size of the universe *as*
theory entails an increase in
tude.

ince the center of the sphere
r any ratio whatever to the
istarchus to mean this: since
er of the universe, the ratio
ıe "universe" is the same as
: in which he supposes the
ed stars. For he adapts the
s kind, and in particular he

appears to suppose the size of the sphere in which he represents the earth as moving to be equal to what we call the "universe."

I say then, that, even if a sphere were made up of sand to a size as great as Aristarchus supposes the sphere of the fixed stars to be, I shall still be able to prove that . . . some [numbers] exceed in multitude the number of the sand which is equal in size to the sphere referred to.

As T. L. Heath comments in Greek Astonomy *(p. 108), after much "sheer calculation" Archimedes finds "that the number of grains of sand that would be contained in a sphere of the size attributed to the universe is less than the number which we should express as* 10^{63}*."*

SOURCE: Thomas L. Heath, *Greek Astronomy,* London: J. M. Dent, 1932.