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Problems in Epicurean Physics

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Modern interpretations of ancient atomic theory have attributed to Epicurus, and to some extent also to Democritus, some surprising and ingenious propositions. These propositions betray a serious involvement on the part of the atomists with the physical and philosophical implications of their doctrines on matter and the void. In place of commonsensical notions about small hard bodies falling or knocking about in space, we now find such sophisticated ideas as quantized space and time, discontinuous motion, theoretical minima--ideas comparable in their subtlety to the Eleatic paradoxes, which as it seems, they were intended to resolve. The advantage of these new interpretations is that they render a more satisfactory account of difficult arguments and principles in the Epicurean texts; they place the atomists squarely in the tradition of ancient philosophy from Parmenides through Aristotle; and they reveal a degree of philosophical intelligence behind ancient atomism that makes it a stimulating subject for investigation. At the same time, they raise new problems, inconsistencies and paradoxes which demand still further analytical machinery for their solution. Not that there is any cause for consternation in this fact. Even the most refined theories of modern physics produce singularities, limiting cases and other conceptual potholes where the structure breaks down. It is entirely to be expected that a deeper analysis of the premises of ancient atomism should uncover new dilemmas, which in turn make fresh demands on the theory. There is, nevertheless, the real danger that, in pursuing such lines of speculation as far as possible, we may begin to lose touch with the ancient texts, and wander about in intellectual regions which, however fascinating in themselves, have little or nothing to do with the thought of Epicurus and his followers. That is, even if the problems we discover are real ones for the theory, the Epicureans may have been unaware of them or unimpressed by them, and, in either case, not given them much thought. But sometimes engagement with the theoretical issues in their own right points to new significance in familiar texts, or brings together apparently unrelated propositions in such a way as to suggest, strongly a coherent address to the problems posed. At all events, this is the method of exposition which I have adopted: to raise what seem to me problems and paradoxes in Epicurean atomism, to respond to them, as far as I can, using the intellectual apparatus of the ancient theory, and to indicate, where possible, how the texts support the reconstructions which I offer.

I. Collision

There are several words in the Epicurean texts which refer to the process of collision among atoms and the subsequent rebounds which are the exclusive form of interaction between the basic particles. In general, these terms are forms or compounds of kope, krouo, and pallo. The question I shall take up here is the nature of such collisions. We may begin by recalling Epicurus' conception of the nature of atomic motion; the following summary is from David Furley's fundamental essay, "Indivisible Magnitudes."

> Epicurus was unable to accept Aristotle's theory of
> continuity, because it involved the notion of potentiality
> and this was in conflict with his fundamental principles.
> Like Leucippus and Democritus, therefore, he felt it
> necessary to accept the existence of indivisible magnitudes.
> To avoid Aristotle's refutation, he postulated that his in-
> divisibles should be minima--not points without magnitude, but
> units of minimum extension....

Epicurus was now faced with further complications.
Aristotle had demonstrated that indivisible
magnitudes in motion require the assumption of indivisi-
ble units of space, time and motion, and, further, that
there can be no real difference of speed. Epicurus accepted
these conclusions, and worked out a theory of motion which
would incorporate these features and at the same time be consistent
with phenomena. (pp. 128-129)

This theory, again in Furley's account, held that "one unit of motion involves
traversing one unit of space in one unit
of time; and in this case (he agreed with Aristotle) it is never true to say
"it is moving" but only "it has moved" (p. 121).

The problem is this: if Furley is right, and I believe he is, then accord-
ing to Epicurus' theory there is no way in which two atoms can collide, or, what
amounts to the same thing, no way to define the difference between collision and
mere continuity of atoms. For purposes of illustration, let us imagine two cubical
atoms, which we may represent in two dimensions as squares. Suppose that they are
a distance of six minimum units of space apart, and moving toward each other each
at a speed of one minimum unit of space per minimum unit of time. If we represent
the moment at which they are six minima apart as T(1), then clearly at T(2) they
will be four minima apart, each atom having moved a distance of one minimum toward
the other. At T(3) we shall find them separated by a distance of two minima, while
at T(4) they will have traversed these last two units and so be up against one
another. What happens at T(5)? Each atom is presumably inclined to advance another
minimum unit in the direction it has until then been traveling. However, this is
plainly impossible, since each represents an impenetrable obstacle for the other.
For them to continue to move as they had been, they will be obliged to overlap
physically, and this would be inconsistent with Epicurus' conception of matter.
But neither is it the case that one or the other atom can shove its opposite number
out of the way, thereby reversing the other's course and proceeding along its own.
This is because, over a minimum interval, there is no moving, only a condition of
having moved, which describes the position of an atom at any moment with respect
to the moment before. Each atom is not only blocked from completing its motion
across the subsequent interval, it is prevented even from beginning it, because there
is no beginning to such an interval, either in time or in space: there is nothing
smaller than a minimum. How, then, does either atom affect the subsequent motion
of the other?

The same question may be put in a slightly different way. Imagine two atoms
adjacent to each other, and moving at a uniform speed in the same direction. Their
relative positions at T(1), T(2), etc., will be identical: with respect to one an-
other, they are not moving at all. Returning now to our earlier pair, which had
been moving toward each other, in what way can they be said to differ at time T(4),
when they are side by side, from our latter pair at any of the moments T(1), T(2),
and so on. Of course, we can say that at the moment before their positions were
different with respect to one another, but this fact will only be relevant if we
can show that the condition of the pair of atoms at any preceding moment or moments
is in some way necessary to a complete or adequate description of them at the
moment T(4). We may note in passing that Newtonian mechanics is not subject to
this embarrassment because motion at an instant is defined as the limit of motion
over a finite interval. With the Epicurean theory, on the other hand, Zeno's
paradox of the arrow, which the atomists thought they had abolished, seems to have
crept back in, though in a different guise. True, it now makes perfect sense to
say that at any moment an atom is not moving (without recourse to Aristotle's

formula that, at a given instant, a body is neither moving nor not moving, since, for Epicurean minimalism, there are no Aristotelian instants), yet over successive instants it does move, or has moved. Instead, the problem becomes, what is it that distinguishes a moving atom at a given moment from a stationary one? If nothing, then why does the moving atom continue to move (or the stationary atom remain at rest)?

The answer, I believe, is given in the passage by David Furley quoted above: all atoms move always at a uniform speed. There are no stationary atoms. The two approaching atoms, once they are alongside each other, must change course (or at least one of them must), since they cannot proceed further in the direction they had been traveling, and they may not cease from motion. It is essential to take into account the previous history of an atom in describing it at any given moment, because only in this way can we know whether and how it is moving with respect to other bodies (or to some absolute point of reference). In any collisions, the direction of this motion may change, but not its quantity. On this model, the word "collision" seems inappropriate, although it does correspond well with the Greek terms krouo, "to knock," and kope, "a blow." "Deflection" is a better expression. An atom, simply by being there, prevents the progress of any other, which, since it must move, departs along some other trajectory.

We come now to the third stage of the argument: what evidence is there that Epicurus was aware of this problem in his theory, or of its solution? We may begin by examining closely the text of Epicurus at the point where he first discusses atomic collisions (Letter to Herodotus 43):

κινοῦνταί τε συνεχῶς αἱ ἄτομοι τὸν αἰῶνα ... αἱ μὲν εἰς μακρὰν ἀπ' ἀλλήλων διιστάμεναι, αἱ δὲ αὐτὸν τὸν παλμὸν ἴσχουσιν ὅταν τύχωσι τῇ περιπλοκῇ κεκλιμέναι ἢ στεγαζόμεναι παρὰ τῶν πλεκτικῶν.

> The atoms move continually throughout eternity, and while some of them separate from each other to a great distance, others maintain their vibration, when they happen to be supported by their entanglement or closed in by tangled atoms.

As always in Epicurus, there are problems with the text. In the first place, Usener indicated a lacuna between αἰῶνα and αἱ, explaining: "hiatum scholion intrusum procreavit. duplex enim motus distinguendus erat, is quo atomi pondere suo deorsum feruntur et is qui conlisione gignitur, qui nunc solus respicitur." Bignone and Bailey put the lacuna after καὶ αἱ μέν adding that the doctrine of the swerve must also have been mentioned here. I see, however, no reason to assume that Epicurus must have introduced every kind of atomic motion in this paragraph. In the passage immediately preceding, the variety of perceptible phenomena is explained by the various shapes of the atoms. Epicurus then turns, not to motion as such, but to motion in compound bodies. For this, we must know that the atoms are constantly moving: if they are not hindered, they will scatter widely, but if they are—and this is the main clause following the καὶ-- they will continue to oscillate as they did (reading αὐτόν with the MSS., not αὐτοῦ or αὖ, suggested by Brieger and Usener respectively), since there will be nowhere else to go. Once we understand the connection between the necessary motion of the atoms and the process of collision or deflection, the sense of the passage as it stands is manifest.

Epicurus continues (sec. 44):

ἥ τε γὰρ τοῦ κενοῦ φύσις ἡ διορίζουσα
ἑκάστην αὐτὴν τοῦτο παρασκευάζει, τὴν ὑπ-
έρεισιν οὐχ οἵα τε οὖσα ποιεῖσθαι, ἥ τε
στερεότης ἡ ὑπάρχουσα αὐτοῖς κατὰ τὴν σύγκρουσιν
τὸν ἀποπαλμὸν ποιεῖ, ἐφ᾽ ὁπόσον ἂν ἡ περιπλοκὴ
τὴν ἀποκατάστασιν ἐκ τῆς συγκρούσεως διδῷ.

> For the nature of the void which delimits each atom provides this,
> since it is unable to offer the resistance; and the solidity which
> belongs to them makes the rebound in the case of collision, to
> whatever distance the entanglement allows the separation from the
> collision.

The argument is straightforward. Atoms must move: if they meet no resistance, they simply advance as they were going; if they do, they move off some other way. We must beware of importing into ancient physics modern notions of billiard-ball mechanics, in which collisions involve transfer of energy or motion. There is no transfer in Epicurus' system; the source of motion is entirely within the individual atoms.

Let us consider the reasoning behind Epicurus' claim that all atoms constantly move, and move at the same speed. David Furley has shown most persuasively the dependence of this part of Epicurus' theory upon book Z of Aristotle's _Physics_. In a nutshell, Aristotle's argument is this. Partless entities must move in a jerk from one position to the next, or else they will be located at some moment partly in one place, partly in another, which contradicts the premise that they have no parts (pp. 111-114). He goes on to argue that if time is continuous, so is space. The proof is to consider bodies moving at different speeds; in a shorter interval of time, the slower must traverse a smaller interval of space, and we may contract the intervals indefinitely (pp. 119-220). Furley concludes, then, that Epicurus "accepted Aristotle's contention that faster and slower motion entails the divisibility of time and distance; he developed the theory that there are no _real_ differences in the speeds of visible moving bodies" (p. 121). Did Epicurus have no other choice? Surely he did: he could have assumed that atoms may linger two or more temporal _minima_ in a given position before making the move to the next. Never, on this conception, could an atom be caught part way across a spatial minimum, which is the heart of Aristotle's criticism. If Epicurus did not elect this option, it was perhaps because there seemed to be no sufficient reason why an atom should take a longer or shorter time to prepare its leap into another place.

But the real reason may be a simpler one: Epicurus admitted the uniform speed of the atoms because it was an essential premise in his theory, not least of all in the account of atomic deflections.

II. Contact

The reason why atoms deflect each other in collisions is that they are impermeable (see section 44 quoted above). In the punning phrase of Lucretius, _officium quod corporis exstat officere_ (1.336-7). How is this impenetrability accounted for? Taking the atomists as a group, four kinds of reasons are indicated

in our sources: smallness of the atoms; their partlessness; their hardness or solidity; and the absence of void in the basic particles. David Furley has suggested that all four reasons may be attributed to Democritus (Two Studies, 94-99). Plainly, they fall into two pairs, smallness being a function of partlessness, hardness is the condition of matter as such--this by definition--and only the presence of void makes possible the division of apparently solid objects. Furley puts the questions: "Why did Democritus stress the hardness and imperviousness of the atoms, and the fact that they contained no void, as causes of their indivisi-bility? He certainly did so; yet to meet the Eleatics' arguments it was a partless unit that was required, rather than a hard one." Furley finds the answer to this problem in De Generatione et Corruptione 1.8. "The Eleatics, says Aristotle, objected to the pluralists that if the universe is divisible in one place and not in another, this seems like a piece of fiction. Why should it be so? We have the atomists answer in the hardness of the atoms. What is, they said, is indivisible (as the Eleatics claimed): each atom is absolutely solid, packed with being and nothing else. There is no void, or not-being, in an atom; hence nothing can pene-trate it, so as to divide it. The universe as a whole is divisible, however, in the sense that there is a plurality of existents separated by void" (p. 99). I am afraid I do not follow Furley's reasoning here. All the atomists needed to answer the Eleatics' conundrum was to posit the reality of empty space. This of course violated the Eleatics' fundamental principle that not-being cannot be used in any way as an analytical concept, but the atomists' attitude on this point was tant pis for the Eleatics. With this postulate alone, Democritus could have concluded that the universe may be divided where there is void, but not where there are atoms, because the atoms, being partless, cannot be further reduced. The hardness of the atoms was necessitated by a different and quite simple requirement, namely, that atoms be incapable of occupying the same place at the same time. For there is nothing in the description of atoms as small or partless which precludes this. However, the postulate that atoms are indivisible because they contain no void is too strong for Democritus' purposes, since it gives us two different causes for the same phenomenon, one of them quite otiose. It would have been sufficient merely to posit the atoms' apatheia; to explain it involved Democritus in a redundancy.

However, the case may be with Democritus' theory, Epicurus decisively separated the two arguments when he lifted from the atom its status as minimum or partless entity, attributing this feature to his (presumably) novel concept of smallest bits (elachista, minima) which themselves cannot have an independent existence (hence cannot be atoms). The atom, then, became simply a body of whatever size (though in actuality limited to imperceptibly small magnitudes), defined by the absence of any admixture of void, in other words, an extended volume bounded by space. Moreover, the solidity (pleres, stereotes, mestos are words used in this connection by Epicurus) of the atom plays a quite distinct role in Epicurean theory from arguments centered on the properties of minima. Solidity is the basis for the ultimate physical stability of the universe, the fact that matter cannot wither away (a) to nothing, or (b) to units indefinitely small. The doctrine of minima, on the other hand, was addressed to rather different considerations, such as the discontinuous nature of space, time and motion. It is this very distinctness which leads me doubt Furley's attempt to fuse the two lines of reasoning in his analysis of sections 56-57 of the Letter to Herodotus (cf. esp. pp. 10-12). The passage reads:

τοῖς δὲ πινοῖς οὐ δεῖ νομίζειν ἐν τῷ ὡρισμένῳ σώματι ἀπείρους ὄγκους εἶναι οὐδ᾽ ὁπηλίκους οὖν, ὥστε ὁ μόνον τὴν εἰς ἄπειρον τομὴν ἐπὶ τοὔλαττον ἀναιρετέον, ἵνα μὴ πάντα ἀσθενῆ

(Greek handwritten text)

"In addition, one must not imagine that there are infinitely many bits in a bounded body, even of indefinite size. So that not only must we eliminate division to infinity into ever smaller (parts), so that we do not make everything weak and, in our conceptions of aggregates, be compelled to crush and squander existing things into nothing, but also one must not imagine that in bounded bodies there is a way to pass to the infinite even (by dividing) into (continuous but non-vanishing) ever smaller (parts)." Furley proposed taking the phrase toi horismenoi somati to mean the atom, and the onkoi, accordingly, as the parts of the atom. Krämer has since restated quite forcefully the reasons why it is preferable to interpret somati as referring to any bounded body, and to understand onkoi in the usual sense of particles (Platonismus und hellenistische Philosophie, pp. 237-239), and there is no need to repeat them here. My point here is that the clause following ou monon affirms the thesis which I labeled (a) above, while the clause following alla kai has reference to thesis (b). Thesis (a) is taken as already demonstrated, as indeed it was, rather summarily, in section 39. Thesis (b) is argued in the following paragraph (57), in the claim that an infinite number of parts, however minuscule, must sum to an infinite volume. Lucretius gives another argument for the proposition: if the atomic constituents of nature could be infinitely small, then it would be impossible to conceive how they might ever recombine into coherent objects on the perceptible or macrocosmic scale.

I have discussed in some detail the differences between Democritus' and Epicurus' treatment of the indivisibility of the atom because I wished to stress that in Epicurus' theory, at least, the explanation of the impenetrability of the atom on the ground of the absence of void is in principle detachable from arguments concerning minima or partless entities. In the analysis presented in sections 56 and 57 of the Letter to Herodotus, it is, I think, assumed that matter free of void is indivisible; the only thing at issue is, how small are the units of pure matter in nature. The answer is, of course, they are of finitely small size. Now one problem we might offer Epicurus' theory is the possibility that atoms are hollow, in which case they might be said to contain void but nevertheless present a solid and impenetrable surface. I suppose that Epicurus excluded this possibility, though I do not know what kind of reasons he might have advanced. In any case, it is not an important omission, so far as I can see. It is an entirely different matter, however, with the following difficulty. Imagine once more two atoms in the shape of boxes, placed alongside each other, face against face (as at the moment of collision discussed in section 1 above). Between the two atoms there is no void. How then can they be separated, if indeed bodies can only be divided by cutting along the space between them, solidity being nothing but the absence of this space? Before proceeding with this inquiry, I had probably better pause to insist that the issue is neither trivial nor a quibble, whether or not the Epicureans conceived of a satisfactory solution to this perplexity. Thus, it might be objected to the dilemma I have posed that Epicurus took as axiomatic the fact that atoms could not change in any way save in position and orientation. But the inalterability of the atoms was presented as a consequence of their solidity, not as an additional premise. Again and again we are told that the two fundamental principles (archai) of the Epicurean philosophy of nature are matter and the void, from which all other properties follow. The atoms are distinguished precisely by the intervening stretches of emptiness. Thus Epicurus speaks of *(Greek)* ("the nature of the void dis-

criminating each [atom]") (sec. 44, Letter to Herod.) The testimony of
Simplicius is unequivocal (in Arist. De Caelo A7 (p. 109b39 Karst), Usener 284):
"For they [the atomists] said that the principles were infinite in number, and
supposed that they were atomic and indivisible and impassive because they were
compact and did not partake of void; they said that division occurred according
to the void in bodies, but these atoms, being separated from one another in the
infinite void and differing in shapes and sizes and position and order, raced in the
void, and, intercepting each other, they collide and some rebound wherever they
chance to, while others are interwoven with each other...." Or Simplicius again
on Arist. phys. D 6, (Usener 274): "They said in fact there was such an
interval, which, existing between bodies, does not permit the bodies to be
continuous, as the followers of Leucippus and Democritus said...." Themistius'
paraphrase of the same passage makes the same point: "For these are the two
types of arrangement of space, either that it is scattered among the bodies, as
Democritus says and Leucippus and many others and finally Epicurus (for all
these give the weaving in and about of void as the reason for the separation of
bodies), or that it is separate and compact in itself, surrounding the
heavens...." (again, Us. 274). Finally, a passage from Aetius (Usener 267):
"It was called an atom not because it is smallest, but because it cannot be
cut, being impassive and without a share in void." I have quoted these
representative citations in order to show that the Epicureans were at least
aware that to explain imperviousness by the absence of void means also to define
atoms by the fact that they are bounded by space rather than more matter.
Continuous matter is indivisible, divisible matter is discontinuous. But when
two atoms are in contact, they are no longer discontinuous; how is their
boundary defined? To find an answer to this question, it is necessary, I
believe, to re-examine once more the reasons why the Epicureans separated the
issues of hardness and partlessness, in other words, to look again at the
question of minimal parts. And that, of course, means Aristotle.

    In his chapter, "Aristotle's Criticisms and Epicurus' Answers," David
Furley demonstrates brilliantly how Epicurus' conceptions of atomic time and
motion were responses to Aristotle's analysis of the doctrine of spatial minima.
Further on, Furley observes: "But this still leaves it undecided why Epicurus
chose to make his minimum units of extension into parts of atoms, and not into
the atoms themselves.... I have not been able to find any direct evidence on
this question; but it is possible to make a reasonable guess. Aristotle's
careful analysis of the geometry of motion made it clear that the distance
traversed by a moving body must be composed of indivisible minima, if there are
indivisible magnitudes at all. So he made it necessary for Epicurus to consider,
not merely the atoms, but the places successively occupied by moving atoms. It
must then have become obvious that the units must all be equal (otherwise
absurd consequences would follow, such as that an indivisible space was too
small or too large for an indivisible atom to fit into it). But if this is so,
then either all atoms must be equal in size, or else some atoms must occupy
more than one unit of spatial extension. The first alternative, so Epicurus
thought, did not square with the phenomena. So he adopted the second." (p. 129)
I leave aside the question of Democritus' conception of space; if it differed
from Epicurus', it must have been fairly primitive, as Krämer makes clear
(p. 277). On the issue of parts, however, there is, unless I am mistaken, an
oversight in Furley's argument. For to prove that "some atoms must occupy more
than one unit of spatial extension" does not entail that no atoms may be
exactly one minimum in magnitude. But it is just this latter, stronger
proposition which we need to demonstrate. This is not a casual distinction.

For just as the essential difference between Democritus and Epicurus on the nature of the atom is that, for the latter, the atom had parts, so the essential difference between them on the nature of minimal or partless entities is that, for Epicurus, they could never subsist independently, but must always exist only as parts of larger bodies. Lucretius' phrase, minimae partes, is in no way redundant: they are not simply partless, they are less than wholes, and thus inseparable in fact or in thought from the atoms they compose. Our question, then, is, why did Epicurus add this feature to the definition of the minima?

The answer, I believe, is to be found, not in Aristotle's analysis of motion, but rather in his analysis of contact and continuity in the opening paragraph of book Z of the Physics. The passage reads as follows: "If there is continuity and contact and consecutiveness, as was defined above that continuous things have their boundaries in common, touching things have them together, and consecutive things have nothing of the same sort between—then it is impossible for continuity to be composed of indivisibles, for example the line out of points, if indeed the line is a continuous thing, and the point is indivisible. For neither are the boundaries of points in common (hen) (for of the indivisible there is not both a boundary and some other part), nor are the boundaries together (for there is no boundary at all of the partless thing; for the boundary is a different thing from that of which it is the boundary). Moreover, it is necessary that the points be either continuous or touching each other, for a continuous thing to be composed of them; and the same argument applies also to all indivisibles. They would not be continuous according to the argument just stated. For everything touches either whole to whole or part to part or part to whole. And, since the indivisible is partless, it is necessary that it touch whole to whole. But whole touching whole will not be continuous. For the continuous has one part here and another there, and is divided into parts that differ in this way and are separated in place. But neither will point be consecutive upon point, nor instantaneous moment upon moment, so that magnitude or time can be composed from these. For consecutive means that there is nothing of the same sort between them, but there is always line between points and time between moments. Furthermore, there would be division into indivisibles, if indeed each (i.e. time and the line) were divided into these things of which they are composed; but no continuities were supposed to be divisible into partless things. And there cannot be another type of thing between. So it will either be indivisible or divisible, and if divisible, either into indivisibles or into forever divisibles; and this is the continuous. Clearly, then, every continuity is divisible into forever divisibles; for if into indivisibles, it will be indivisible touching indivisible; for the boundary of continuous things is in common and touches."

In brief, Aristotle's argument is this: a continuous magnitude cannot be composed of discrete, consecutive elements, because the discreteness violates the very meaning of continuity, that any two distinct points bound a segment of the continuum. On the other hand, it cannot be composed of either continuous or touching partless elements, because partless elements cannot be either continuous or in contact; the reason here is that continuity and contact are defined as relations between boundaries, and partless things cannot have boundaries distinct from some remaining portion. Now, it is very important to be clear about what Aristotle does and does not say here. He does not argue, for example, that points are not part of a line. Quite the contrary, the point is the boundary of the line, and Aristotle is explicit that the boundary is a

part of the whole (objects touching part to part touch precisely at their
boundaries). However, these parts cannot be construed as a collection of free-
standing entities arranged side to side, simply because they have no sides. That
is, the partless entity has no independent existence, but subsists only as a
part (cf. De anima 431b15-17:"so one thinks of mathematical entities, which are
not separated, as though they were separated, whenever one thinks of them").

Simplicius, in his commentary on this passage in the Physics (Usener 268),
suggested (cf. τους) that Aristotle's argument here was directed against the
early atomists, and that Epicurus, in sympathy with the Democritean conceptions
but daunted by the force of Aristotle's logic, abandoned partlessness as a cause
of the atom's indivisibility, though he preserved Democritus' other premise,
that of impassivity (apatheia) as the reason for this quality of matter. But
how, in fact, would Aristotle's reasoning have told against Democritus' theory?
If Democritean atoms were true minima, and if indeed he did not think it necessary
to posit a granular conception of space as well, as modern analysts seem to
agree, then in the Democritean system there were no physical continua, and
therefore there was nothing for Aristotle's critique to challenge. But if we
look, not to Aristotle's conclusion, but to the first stage or lemma of his
theorem, we may, I think, discover the issue that troubled Epicurus. Aristotle
seemed to have shown that Democritus' atoms, being partless, could not touch
each other except as whole to whole, which is to say, by overlapping--which
contradicted the principle of atomic impermeability. And Epicurus found the
solution to this problem, here as often elsewhere, by accommodating his
materialist analysis entirely to Aristotle's requirements.

Epicurus, then, abandoned the notion of a self-subsisting minimum entity.
Every actual body, accordingly, has parts, and among these parts may be
included all surfaces, edges and corners. Thus, the Epicurean atoms answer to
all the conditions imposed by Aristotle's definitions of continuity and
contiguity. Moreover, with the stipulation of minimum parts, Epicurus' atoms
are impervious to Aristotle's whole argument for infinite divisibility in the
passage cited. The only (but crucial) difference is that the extreme or limit
is assumed to be an inconceivably small but nevertheless finite quantity, while
for Aristotle the boundary is of zero magnitude in at least one dimension.

David Furley, however, has charged Epicurus with one departure from
Aristotle's analysis, a departure so serious as to suggest that Epicurus
altogether abandoned the line of reasoning which Aristotle had developed. In
section 58 of the Letter to Herodotus, Epicurus is speaking of minimum parts
in perceptible objects: "We examine these beginning from the first and not in
the same (spot), nor touching parts to parts, but in their own nature as things
that measure sizes, more of them measuring a greater thing and fewer of them a
lesser." Furley remarks on this sentence (p. 115): "Here Epicurus answers
Aristotle with an echo of his own words. These indivisible units are ranged
in order in the continuum, and their contact is neither of whole with whole
(i.e. 'within the same area') nor of part with part." Furley goes on to observe:
"But Aristotle said that contacts must be either of whole with whole or of part
with part or of part with whole. Epicurus clearly envisages another possibility
altogether. His indivisibles, he explains, are to be units of measure: that is
to say, they are to have extension." If, of course, Epicurus was simply
unimpressed by Aristotle's analysis, and dismissed it casually with the suggestion
that there was some other way in which partless entities may be arranged in a
continuum, then the argument which I have been developing must collapse. To see

that this is not the case, we may put the following question to Aristotle's theory: given that an extremity is part of a whole, how is it attached? The extremity itself has no parts, else there would be an infinite regression, each boundary defined by a further boundary. Thus, the extremity can not be continuous or contiguous with the remaining substance; nor, clearly, will it do to suppose it divided from it by a stretch of some other kind of matter. The answer to this conundrum is that we are not required to explain the connection between body and surface in the same way we must account for the contact between two discrete bodies, because a surface can only be understood as a part; it is not and cannot be discrete; because we cannot conceive of it as a discrete element, there is no sense in inquiring how it might abut another object. Similarly, Epicurus was not obliged to indicate how his minima, which were likewise inconceivable except as parts, were arranged in the larger mass; it was sufficient to say that they did not touch part to part, nor did they overlap. Furley goes on to argue that by identifying the extremity with the indivisible part, the Epicureans "were then left without a word for the edges of the indivisible part; but the existence of its edges was a necessary consequence of their theory...." (p. 116) I can only say that the Epicureans did not, I am sure, believe that the minimum quantity had edges; else there was nothing to prevent its independent existence. Nor is there a hint in the texts of such a doctrine. Furthermore, Furley's suggestion that they "could have pointed out that the extremity is not a part," would not have commended itself to the Epicureans. Could it have worked for the minimum, it would have done for the atom too. I suspect that the notion of a boundary that was neither a part of matter nor physically separable from it would have smacked too much of idealism for Epicurus' comfort.

I have been arguing that the chief reason why Epicurus defined his minima as always and essentially participating in some larger extended bit of matter was to solve the problem of contact among atoms, which is equivalent to the problem of boundary. I believe that a passage in the Letter to Herodotus tends to corroborate this point, if we read it correctly. Reasoning from the observation that sensible objects have perceptible but partless extremes, Epicurus affirms by analogy that the same must hold true for atoms:

$$\text{[Greek text, handwritten]}$$

"further, it is necessary to think of the minimum and partless entities as the limits (or boundaries) of extended masses, providing of themselves the primary measure for greater and smaller things in the rational theory concerning invisible things." (Text as in Furley and Krämer, except that I have preserved the MSS proton for protōn.) My translation of the phrase follows Bailey and Krämer, but differs from Furley's version, which reads: "Further, we must take these minimum partless limits as providing the larger and smaller things...;" that is, Furley takes elachista and amere as adjectives modifying the substantive perata, which serves as the subject of paraskeuazonta (a participial construction with nomizo, for which Furley gives a parallel in Letter to Herod. 74.3). Bailey's interpretation is, Furley contends, unnecessary, and "makes poor sense, because we do not need at this stage to be told that the minima are limits or extremities" (p. 26), since this information had already been provided in sec. 57.

ἄκρον τε ἔχοντος τοῦ πεπερασμένου δια-
ληπτόν, εἰ μὴ καὶ καθ' ἑαυτὸ θεωρητόν, οὐκ
ἔστι μὴ οὐ καὶ τὸ ἑξῆς τούτου τοιοῦτον νοεῖν
καὶ οὕτω κατὰ τὸ ἑξῆς εἰς τοὔμπροσθεν βα-
δίζοντα εἰς τὸ ἄπειρον ὑπάρχειν κατὰ τοιοῦτον
ἀφικνεῖσθαι τῇ ἐννοίᾳ.

The passage is textually problematic, and its significance, moreover, depends
in part on whether we agree with Furley that the reference is restricted to atoms
and minima, or with Krämer and others that it embraces all bounded bodies (see
above, pp. ⌐ ⌐). Either way, however, it is not the case that Epicurus has
already averred that the minima constitute boundaries; all that he has done is to
assume that boundaries are not of no size, and that if bodies are composed of
boundary-like parts, then an infinite number of them must generate a mass of
infinite size.

Krämer, as I have indicated, keeps the phrase   as a unit
(pp. 247-248), but would understand the term perata not as boundary but as limit
in size, i.e. smallest magnitude: "Das gleiche gilt für den Ausdruck πέρατα,
womit nicht etwa 'Grenzen' im Sinne von 'äussersten Gliedern,' sondern Grenz- und
Grundwerte der Ausdehnung, d. h. letzte Elemente der (linearen) Erstreckung
(ἐλάχιστα) gemeint sind, die nicht weiter teilbar sind und so eine letzte
Teilungs'grenze' setzen" (p. 247; so too von Arnim, Bignone, and Bailey). But
this not only renders the passage redundant, it also ignores the feature of
Epicurus' thinking for which section 57 does give evidence, that the concept of
the minimum part is acquired through extrapolation from the notion of an extreme
border, whether a surface, edge or corner. For it is only at the boundary that
we can actually grasp, whether visually or intellectually, the minimum quantity
as a percept or idea, though at the same time there is no way to conceive of it
apart from the substance it delimits. According to Epicurean theory, our
experience of minima is as boundaries. Of course, minima serve several purposes
in the system, such as units of measure (katametremata) and as the basis of the
atomistic reply to the Eleatic paradoxes. But that the minimum could not subsist
independently occurred to Epicurus not in those contexts, but in the investigation
of atomic boundaries.

In the sentence following the one we have been analyzing, Epicurus concludes
his argument. I borrow Furley's translation, and also his emendation of ta
ametabola to ta metabola: "For the similarity between them and changeable things
is sufficient to establish so much; but it is impossible that there should ever
be a process of composition out of these minima having motion." (p. 25) Why is
this process impossible? Not because minima would be incapable of motion, since,
as we have seen, the only argument Aristotle levelled at this (presumably)
Democritean conception of the atom was that it entailed the minimalization of
space and time, and this Epicurus accepted. I suggest that the impossibility
resides in the symphoresis, the coming together, and that the reasons are precisely
Aristotle's: free-standing partless bodies cannot meet, because they are without
surfaces.

I shall conclude my discussion of the present topic with a question to
Epicurus' theory (as I have reconstructed it): does the analysis of atomic
boundaries in terms of minimum parts account satisfactorily for the discreteness
of adjacent atoms? On the whole, it would seem so. The surface of a particle
is inseparable from and inconceivable without the rest. It can only be part of
that to which it has always belonged. To put it another way, the relationship
among minimum parts in an atom is fundamentally different from the relationship

among atoms; the former constitute continuous matter, while the latter, precisely
in that they have the distinct surfaces which minima lack, can be brought into
contact but cannot merge into a common corpuscle. We must concede, however,
that the argument for the indivisibility of matter can no longer rest solely
on the absence of void. That formulation will have to be regarded as part of the
heritage of Democritus, which continues to be valid for Epicurus only in the
sense that there is no void internal to an atom; atomic boundaries, however, are
defined by the principles explicated above. And we may add, indeed, that without
the additional postulate of minimum parts, there is no way that Epicurus could
have solved the problem of continguity and discreteness. For without a deep
structure to matter, it differs from space only as its complement. It is a
purely geometrical conception: we may picture a plane of dark shapes against a
light background; adjacent and continuous forms cannot be distinguished. With
the Aristotelian concept of boundary, made physical by endowing it with actual
if minimal extension in all dimensions, Epicurus drew the line that divided
contiguous substance.

We know, from Diogenes Laertius' life of Epicurus (10.28), that Epicurus
wrote two books entitled On the Corner in the Atom (Περὶ τῆς ἐν τῇ ἀτόμῳ γωνίας)
and On Contact (Περὶ ἁφῆς). Is it too presumptuous to suggest that in these
volumes Epicurus may have taken up in greater detail some of the arguments
concerning boundaries and contact which I have considered here?

III. Weight

Plutarch, in The Opinions of the Philosophers, tells us: "these bodies
(i.e., atoms) have the following three attributes, shape, size and weight.
Democritus, indeed, mentioned two, size and shape; but Epicurus added weight
to these as a third" (Us. 275; DK 68 A 47, cited as Aetius). There is no doubt,
of course, about Epicurus' position, but in the case of Democritus there is room
for considerable controversy. On the one hand, there are several other
testimonies to the effect that Democritus did not acknowledge weight as one of
the fundamental features of atoms [citations in DK 47; by implication also else-
where, as in Aristotle Physics A 5 188a22 (DK 45): "Democritus says that there
is the solid and void, of which the one is as being, the other as not being;
further by position, shape and order"--no mention of weight; so also Cicero,
De nat.deor. 1.26.73 (DK 51), De fin. 1.6.17 (DK 56)]. On the other hand,
Aristotle states explicitly that in the case of atoms, Democritus held that
weight varies directly with size, a relationship which does not hold for compound
bodies because they contain greater or lesser quantities of void (Arist. De gen.
et corr. A 8 326a9; De caelo D 2 309a1, cit. DK 60). Moreover, Democritus
certainly provided an account of the phenomenon of weight, of bodies relatively
lighter and heavier, in the perceptible world. How is the conflicting evidence
of our sources to be reconciled? David Furley, in a recent investigation of the
atomists' theory of motion ("Aristotle and the Atomists on Motion in a Void,"
in P.K. Machamer and R.J. Turnbull, edd., Motion and Time, Space and Matter,
Columbus, Ohio, 1976), describes the current consensus as follows: "Faced with
this contradiction, modern interpreters have propounded a clever solution. So
long as atoms are not involved in a cosmic vortex, they are weightless, and
collision is the only factor that explains their motion. The vortex, however,
drives larger atoms to the center, and this tendency to move toward the center
is what 'weight' means. So, he adds wrily, "this cake can be had and eaten"
(p. 86). As will shortly become clear, I do not myself believe that the notion
of atomic weight functions in quite this way in the Democritean system, but
before addressing this issue, and its implications for Epicurus' concept of

weight, in greater detail, I must pause to consider Furley's claim, advanced in this same paper, that the vortex played no role at all in Democritus' account of why things fall. Furley puts forward two objections to the modern solution. The first is that vortices do not have a punctual center: "the center of a vortex is a line, not a point, and although it may account for the motion of bodies towards the central axis, it does not yield an explanation of why bodies should congregate at the midpoint of the central axis...." (p. 87). I believe that Furley is in error here. Vortices do indeed have an axis; this they have in common with the mere centrifugal rotation of a column of fluid. But vortices also have a vertical vector, which is much in evidence in the action of a tornado or maelstrom. In fact, the centripetal force in the vortex is inseparable from the vertical motion at the axis, for the mechanics of the vortex are based on a drag effect, in which the speed of rotation, and therefore the centrifugal force, at one end of the column is less than that at the other. The result of this differential is a rotary flow along the axis of the funnel, with dispersion of the fluid at one end and a pressure toward the axis at the other. The following diagram illustrates both the horizontal and the vertical flow patterns of the vortex:
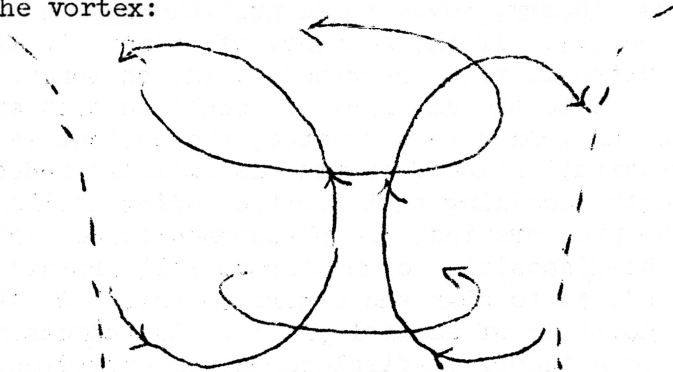
Moreover, since a vortex necessarily occur in a medium, the effects of floating and sinking, that is, of differential densities, will also play a part in the distribution of any particles within the swirl. Light particles may, for example, be scattered at the top of the column, while heavy ones are concentrated at the bottom; objects of the appropriate density and shape (flat and wide, say) may even float suspended for a while at some point along the axial center. (I am indebted for this description of the dynamics of the vortex to Steven Tigner, who summarized the basic principles in his article, "Empedocles' Twirled Ladle and the Vortex-Supported Earth," Isis 65 (1974) 440 (cited by Furley, p. 98, note 9). Tigner gave a much fuller account in an unpublished paper, "Vortex Action in Pre-Platonic Cosmology," in which he took as a point of departure Albert Einstein's "admirably brief and lucid explanation" of one kind of vortex in "The Cause of the Formation of Meanders in the Courses of Rivers and of the So-called Beer's Law," Essays in Science New York, 1934, p. 86.) Thus the vortex is a fairly complex system, and can provide a model for several different physical phenomena, including dispersal and congregation of particles, suspension at different levels along the axis, and vertical motion either upward or downward in the axial vacuum. In a cosmological theory, it could serve quite nicely as an explanation both for the differential distribution of substances varying in size, shape and density, and also for a downward tendency in particles at or near the axis of the whirlpool. We do not have the evidence, so far as I know, to reconstruct even the broad outlines of Democritus' theory concerning this process, but it is easy to imagine how a constant atomic rain could be invoked to explain why heavy objects are disposed to fall, or, when hurled upward, to slow down and ultimately reverse their course under such an imperceptible but massive bombardment.

[Could this be the sense of Cic. De fato 20.46, where Dem's plaga is equated with Ep's gravitas and pondus? Cit Us. 281]

Furley's second objection to the vortex theory is that "the Aristotelian view of weight as a tendency to move toward the midpoint of the cosmic sphere entails that the earth itself is spherical..., but Democritus believed the earth to be flat..." (p. 87). Here too, a clearer conception of the operation of the vortex provides us with a different image. An object caught at the bottom of an eddy is more likely to have the shape of a disk or drum; or perhaps we ought to imagine it resting like a metal plate on updrafts from below (cf. Aristotle, De caelo cf. Poe's "Maelstrom" D 6 313a21ff., cit DK 68 A 62). However this may be, I cannot agree with Furley that "the vortex seems totally inadequate to explain weight," and therefore I do not feel "forced back on the interpretation that weight, meaning a tendency to fall vertically, is a primary, irreducible property of the atoms." I continue to believe that it was an innovation of Epicurus to include weight in this sense among the fundamental attributes of the atom.

Before leaving Democritus' theory, however, we must examine one consequence of endorsing the role of the vortex: if the tendency of objects to fall--that is, the terrestrial effect of gravity--is to be ascribed to the action of the cosmic swirl, then what function is left to the category of weight in this system? I do not believe it is the case, as some have suggested, that weight is merely a redundant expression for a gravitational effect that is entirely reducible to the vortical mechanism. It is worth recalling that for the ancient philosophers in general, and above all for the presocratics, the phenomenon to be explained was not, in the first instance, the disposition of matter to fall; rather, it was the twin tendencies of some objects to sink and others to rise. Aristotle attacked this issue with the doctrine of natural places. The atomists, though not they alone, had recourse to a theory of displacement or extrusion, ekthlipsis in Greek, according to which heavier or denser objects had the capacity to drive lighter ones out and upward. The fact that air bubbles rise in water, or tongues of flame in air, was explained not in terms of the natural motion of the rarer elements, but as an effect caused by the superior downward thrust of the particles constituting the heavier medium. We have explicit testimony in Simplicius that Democritus, like Epicurus, posited this effect (on De caelo, cit. DK 61; the supposition in DK that Epicurus' position differed substantially from Democritus' because Epicurus ascribed uniform speed to the atoms seems unwarranted, since it is not clear that the relative velocity of the atoms has anything to do with the process of extrusion). Now, I submit that this power of atoms to jostle their lighter neighbors out of the way was precisely the property to which Democritus attached the name weight. We may observe that weight in this sense has nothing whatever to do with tendency of atoms or compound bodies to fall; whenever a group of atoms is moving, for whatever reason, in a uniform direction and encounters a resisting surface or texture of corpuscles, the heavier, if they are atoms, or the denser, if they are compounds, will force their way further in the given line of progress and displace the lighter. To be sure, this process will only yield the regular contrariety of direction exhibited in the perceived motion of lighter and heavier substances when the random atomic movements are organized into a more or less uniform current, and such a current was assumed by Democritus to arise out of chance turbulences evolving into vortices. That is, the vortex is a necessary condition of the observed phenomena of displacement. But, in the first place, the vortex is not a sufficient condition: it must be supplemented by the power associated with weight. And, in the second place--but no less important--weight is not even a necessary condition for the formation of

the vortex and the tendency of matter to fall. Against the hypothesis that
Democritus saw any connection between weight and some priviledged direction in
the universe, I may add that I see no reason at all to suppose that, according
to his theory, the vortices in different cosmoi necessarily had the same orienta-
tion.

Why did Democritus not elevate weight to the rank of one of the primary
qualities of the atom, along with size and shape? Perhaps it was because weight
was, for Democritus, simply a function of size (Arist. De gen. et corr. A 8 326a9;
De caelo D 2 309a1, cit. DK 60), which was certainly not the case for Epicurus.
More likely, though, is the fact that weight could only manifest itself as a
relation among atoms and under certain specified conditions; a single atom,
considered in isolation, would present itself only as a geometric form. If this
is so, then we can see that, at least with respect to the atomists, there was some
justice in Aristotle's claim that his predecessors had not accounted for weight
as such, but only for the heavier and the lighter (Arist. De caelo D. 1. 308 a11).
[Furley, p. 96, uses this remark to a different effect.] In the Democritean
conception, it does not make sense to speak of the weight of an atom as such, but
only with respect to other atoms heavier or lighter than itself.

In the physical theory of Epicurus, the role of ecthlipsis is every bit as
important as it was for Democritus, if not more so. The pseudo-Plutarchan
treatise On the Opinions of the Philosophers preserves a fairly detailed account
of the distribution of the elements during the creation of the cosmos based
entirely on the operation of this principle (Usener 308), and Simplicius too, as
I have indicated above, makes clear the connection between weight and displacement
in Epicurus' system (the passages from his commentary on De caelo are quoted in
Usener 276). Plainly, the Democritean concept of weight, that heavier, which is
to say larger, atoms have the capacity to displace smaller and lighter ones, is
essential also to Epicurus' view, and there can be little doubt that he simply
adopted this function along with the doctrine of extrusion. Epicurus' own
contribution was to make the category of weight serve a second purpose as well,
that of accounting for the uniform flow of the atoms, without which, as we have
seen, it was impossible to explain the phenomena of sinking and floating. For
reasons that are still somewhat obscure to me, the vortex fell out of favor as a
paradigm of the cosmological process in the time of Plato and Aristotle. I
suspect that the vortex came to be considered a complex motion, which itself
demanded an explanation in terms of simpler forces such as linear and rotary
translation; in the pseudo-Aristotelian Mechanica, for example, the action of a
vortex in collecting particles at the center (meson) is presented as a problem,
and the solution is given in terms of circular motions (Problem 35, 858b3 ff.).
Epicurus, at any rate, abandoned it as a cause of gravitational phenomena, and
posited in its place an inherent disposition of the atom to move in a single
privileged direction. Such an assumption was undoubtedly facilitated by the
doctrines of natural motion propounded by Plato and Aristotle, despite the great
differences between the theories. In any case, Epicurus was also responsible,
again, I am sure, under the influence of Aristotle, for assigning the name of
weight to this power. At first sight, this appears to be a perfectly reasonable
move, but I must again emphasize that in fact two quite different concepts or
functions are cohabiting under the cover of a single term in the Epicurean
interpretation. We are apt to overlook this fact because in the modern,
Newtonian analysis of gravitational attraction the force varies directly with
the mass of the bodies involved, and hence the same formula that defines the
attraction also accounts for its greater magnitude in the case of heavier

substances. There is no such relationship in the ancient system. As a property of the atom in itself--that third characteristic which Epicurus posited in addition to the Democritean two--weight is only the tendency of atoms to move down in preference to some other direction (I shall indicate shortly how I understand this law to work). All atoms do this at a uniform speed, smaller and larger ones exhibiting no distinctions in this respect. Thus, if we look only to this feature, it cannot be said that weight implies any notion of heavier and lighter; it is an absolute property, not admitting of gradations. In the theory of extrusion, on the other hand, weight is a function of the size of the atom, and remains, as it was with Democritus, essentially a relative concept (cf. Letter to Herod. sec. 61).

It is worth noting that, as an explanation of the observed phenomena of terrestrial gravitation, the Epicurean notion of atomic weight is not an obvious candidate. To say that all atoms fall uniformly downward does not explain why solid and liquid masses plummet to the earth, since the earth itself should, on this reasoning, be sinking as fast as any other body. The Epicurean explanation was that the earth's downward course is retarded by the resistance of a relatively thick or viscous atomic medium which surrounds it; the smaller, narrower objects on its surface more easily penetrate this fluid, which on the upper side of the disk may be recognized as the atmosphere. In this account, however, it seems to me that the Epicurean principle of isotacheia or uniform atomic velocity is a necessary premise, since it explains why the relatively compact aggregate of atoms that constitutes a cosmos must fall more slowly than free particles: collisions introduce a horizontal component to the atomic motions which reduces in a proportional degree the vertical or downward speed. I do not, however, know of any evidence that the Epicureans actually thought the problem through in this way.

I have argued that the Epicurean conception of weight may be understood as a disposition of the atoms to move in a privileged direction, which is defined as down. (Strictly speaking, I ought to discriminate between the two senses of weight in Epicurus' theory, employing some such convention as $weight_g$ for the gravitational property, and $weight_e$ for the feature relevant to extrusion or ecthlipsis; but in all that follows I shall be concerned only with the former quality, that is to say, with Epicurus' distinctive contribution.) Furley puts it well when he writes: "Epicurus defended and revised the Atomist theory of motion by introducing something like the concept of a vector" (Aristotle and the Atomists...," p. 96; cf. also my article, "Epicurus on 'Up' and 'Down' (Letter to Herodotus sec. 60)", Phronesis 17 (1972) 269-278, esp. pp. 274-275). But how did the Epicureans imagine this process to occur in the case of individual atoms? David Furley, commenting on section 61 of the Letter to Herodotus, explains it as follows:

> Two kinds of motion are mentioned here: motion downward, which is due to weight, and motion upward or sideways, which is due to collision. The last sentence of this passage may need explanation. Epicurus says that motion due to either one of these causes will go on at the same speed until it is countered. If it is downward motion, it can only be countered by collision with another atom coming up or across; if it is upward or sideways motion, it can be countered by collision or by the reassertion of weight. In the latter case one would expect a slow deceleration, followed by acceleration in another direction, but this is ruled out.

> Motion at full speed in one direction is followed instantaneously
> by motion at full speed in the other direction. Of course,
> variations in weight must cause variations in motion (Arrighetti
> is right to stress this). Variations may be of two kinds, in
> direction or in distance. If a falling heavy atom collides with
> a light atom, then the heavy atom may perhaps be only slightly
> deflected, or else it may be turned directly about but move
> upward through only a few space units before its weight
> reasserts itself. (Two Studies, pp. 122-123)

The nub of the issue is the picture which Furley presents of the "reassertion of
weight." The behavior of objects in the phenomenal world does, of course,
provide a fair analogue to this description, although continuous deceleration to
the apogee followed by gradual acceleration downward is a feature that is not
preserved on the atomic scale (the acceleration of falling bodies was well known
to Aristotle, and could not be ignored by Epicurus). As I suggested above in the
case of Democritus, this behavior could be explained as a result of continual
collisions between the rising object and the stream of descending atoms, here
propelled by their own gravity rather than by the vortex. But what about the
reassertion of weight on the atomic level? In the first place, let us recall the
mordant derision with which Cicero greeted the doctrine of the swerve, on the
grounds that it was an arbitrary and uncaused occurrence (Cic. De fato 10.22,
20.46, etc.; cit. Usener 281). Is it likely that Cicero and other critics of
Epicurus would have passed over in silence the far more startling spectacle of an
atom hurtling at full tilt upward, only to reverse itself for no apparent reason
and at no fixed time or place in an equally precipitous descent? But this
argument, which has the double fault of being both of the eikos form and ex
silentio, will not bear much weight.

    The texts themselves, however, suggest a different story. The last sentence
of the passage from the Letter to Herodotus, which, as Furley says, calls for
explanation, reads as follows:

$$ \dot{\epsilon}\dot{\phi}\ \dot{o}\pi\dot{o}\sigma o\nu\ \gamma\dot{\alpha}\rho\ \ddot{\alpha}\nu\ \varkappa\alpha\tau\dot{\iota}\sigma\chi\eta\ \dot{\epsilon}\varkappa\dot{\alpha}\tau\epsilon\rho o\nu,\ \dot{\epsilon}\pi\dot{\iota}\ \tau o - \\ \sigma o\tilde{\upsilon}\tau o\nu\ \ddot{\alpha}\mu\alpha\ \nu o\dot{\eta}\mu\alpha\tau\iota\ \tau\dot{\eta}\nu\ \varphi o\rho\dot{\alpha}\nu\ \dot{\iota}\sigma\chi\epsilon\iota,\ \ddot{\epsilon}\omega\varsigma\\ \dot{\alpha}\nu\tau\iota\varkappa\dot{o}\psi\eta\ \ddot{\eta}\ \ddot{\epsilon}\xi\omega\theta\epsilon\nu\ \ddot{\eta}\ \dot{\epsilon}\varkappa\ \tau o\tilde{\upsilon}\ \dot{\iota}\delta\dot{\iota}o\upsilon\ \beta\dot{\alpha}\rho o\upsilon\varsigma\\ \pi\rho\dot{o}\varsigma\ \tau\dot{\eta}\nu\ \tau o\tilde{\upsilon}\ \pi\lambda\dot{\eta}\xi\alpha\nu\tau o\varsigma\ \delta\dot{\upsilon}\nu\alpha\mu\iota\nu. $$

This is Furley's translation: "For as long as one of these two motions is in
force the atom will move as quick as thought, until there is a counterblow,
either from something outside, or else from its own weight acting against the
force of the object which hit it." (p. 122). What is the meaning of the final
clause? Usener excised it from the text as a gloss, while other commentators,
though not indulging in so drastic a revision, appear simply to ignore its
significance. Yet it plainly suggests that the proper weight of an atom asserts
itself only upon collision with another body. There seem to be two kinds of
counterblow described here, one purely external (exothen), the other involving
also the action of the atom's own characteristic weight (ek tou idiou barous).
There is another piece of evidence, moreover, in the passage in Plutarch's On the
Opinions of the Philosophers in which is recorded the information that Epicurus
added weight as a third atomic quality to Democritus' other two (Us. 275). The
relevant lines read:

ὁ δὲ Ἐπίκουρος πλάτος καὶ τρίτον βάρος προσ-
έθηκεν· ἀνάγκη γὰρ, φησί, κινεῖσθαι τὰ
σώματα τῇ τοῦ βάρους πληγῇ· ἐπεὶ οὐ
κινηθήσεται

I translate: "But Epicurus added weight as a third to these; for he said it is
necessary that bodies move by means of the blow of the weight, since they will
not be moved [sc. by some other force or agency]." Now, for the word plegei,
"blow," Usener substituted holkei, "attraction" or "pull." This is consistent
with his emendation of the Letter to Herodotus. But the manuscript reading points
once again, albeit in an abbreviated and confused way, to a connection between
weight and collision.

I submit that for Epicurus, all changes in the direction of atomic motion,
including those which result in a downward course and occur under the influence
of atomic weight, are consequences of atomic collisions. I suggest accordingly
that we interpret the gravitational property of atoms as a tendency to emerge
from collisions in a preferred direction, a direction which is, by definition,
down. Once more, it is important to be wary of carrying modern notions over into
the analysis of ancient mechanics. I know of no evidence in Epicurus that even
hints at a rule such as the conservation of momentum, which would entail that
the direction of atomic rebounds bear some lawful relation to the shape of the
particles and their direction of motion preceding the impact. There are no
propositions to the effect, for example, that an equality between the angle of
incidence and the angle of reflection governs the ricochet of atomic projectiles.
In the first section of this paper I argued that atomic collisions in the
Epicurean system are in fact rather deflections, that atoms blocked from pro-
ceeding in a given course by the presence of an opposing particle and under the
necessity of maintaining an unvarying velocity simply take off in another
direction. There is nothing, however, to indicate that this is a determinate
direction. Nothing, that is, except the principle that I am now advancing, that
the motion of an atom following a collision is most likely to be downward. The
cause of this disposition is, I believe, what Epicurus called weight.

Is Epicurus' conception of weight a coherent one? Critics from antiquity
down through the present have heaped scorn upon Epicurus for supposing that in an
infinite homogeneous space (that is, with no global anomalies in the distribution
of atoms), one could rationally define the directions up and down. Consider the
view of Felix Cleve, in The Giants of Pre-Sophistic Greek Philosophy, who writes:
"Adopting Democritean atomism without real understanding and out of ulterior
motives that have nothing to do with any genuine interest in natural philosophy,
Epicurus just bowdlerizes the theories of Democritus." As a case in point, Cleve
cites "Epicurus' assumption of atoms of different sizes that are 'falling' with
equal velocity parallel 'downwards' (when there is not yet an earth, even!)..."
(vol. 2, p. 414). While the tone is perhaps more vituperative than is customary
in contemporary criticism, the point which Cleve makes is commonplace. Even so
excellent a student of Epicurean physics as Jürgen Mau could say: "Im
unendlichen Raum gibt es kein absolute Oben und Unten, demnach auch keine Mitte"
("Raum und Bewegung: Zu Epikurs Brief an Herodot sec. 60," Hermes 82 (1954) 20).
I must insist that this kind of objection to Epicurus' doctrine of weight and
cosmic orientation is really quite vacuous. Of course there is no top and bottom
to an infinite universe. But the hypothesis that atoms tend to rebound

preponderantly in a single direction, or even that they merely favor one direction slightly more than others, affords a perfectly rigorous and intelligible definition of a vertical orientation in space. The issue is entirely analogous to the modern theory of a distinction in nature between left and right (the abolition of parity): the spin of particles emerging from certain reactions does not exhibit the expected symmetry, but rather a statistical preference for one direction over the other. The theory may of course be wrong, due to faulty measurements or invisible factors; but it is not nonsense. (Cf. "Epicurus on 'Up' and 'Down'..., p. 277). Similarly with Epicurus' doctrine: whatever its faults or virtues as an explanation of the phenomena of gravity and displacement, there is no problem whatsoever concerning the logical status of his fundamental premise of a directional vector in the universe determined by the preferential course of weighted atoms.

There is a difficulty, however, with the notion of absolute space, with respect to which all atoms are said to be in motion. In an unbounded universe, we are free to choose our frame of reference. There is no reason, for example, why we cannot imagine ourselves moving along with a freefalling atom; with respect to the coordinate system in which such an atom served as the origin, all atoms descending under the influence of weight would appear stationary, while rising atoms would appear to be ascending with twice the velocity that Epicurus assigns them. On this matter, two things may be said. In the first place, I have no doubt that Epicurus believed intuitively in an absolute frame of reference, a fixed spatial grid, in terms of which falling atoms could be said to have real motion, and no atoms could be said to be at rest. This is not surprising. As Arnold Koslow has shown, Newton too held such a view, and it has persisted into this century. Koslow quotes H. Feigl, "The Origin and Spirit of Logical Positivism," (in P. Achinstein and S. Barker, edd., The Legacy of Logical Positivism, Studies in the Philosophy of Science, Baltimore, 1969, p. 7): "Once (in 1920) I heard a disciple of Franz Brentano's--Oskar Kraus at the University of Prague--debate Einstein with great excitement. He maintained that the following was a synthetic a priori truth: 'If two bodies move relatively to each other, then at least one of them moves with respect to absolute space.'" Feigl goes on to remark that "this illustrates beautifully the intrusion of the pictorial appeal of the Platonic 'receptacle' notion of space or a confusion of a purely definitional truth (regarding three coordinate systems) with genuinely factual and empirically testable statements regarding the motion of bodies" (Koslow, "Ontological and Ideological Issues of the Classical Theory of Space and Time," in Matter, Time Motion and Space p.   ). I may remark that the critique of the notion of absolute rest and motion is quite independent of relativity theory, although relativity theory is in fact incompatible with such an assumption. The second point is that the relativity of frames of reference introduces no practical difficulty into Epicurus' system. One may be tempted to suppose, for instance, that in the absence of a fixed frame, it makes no sense to speak of atoms having uniform velocity, since, as we have seen, we may select another set of coordinates, in motion with respect to the first, in terms of which such a statement will be false. However, provided we do not contemplate a relativistic geometry, it suffices to assert that there exists some frame of reference in which all atoms are moving at uniform speed; we may call this the absolute frame. Naturally, I do not mean to imply that Epicurus contemplated such a view. I wish only to indicate that, contrary to opinions of some impressive scholars, there is nothing incoherent or inconsistent in Epicurus' postulates concerning weight and motion in infinite space.

IV. Orders of Magnitude

In section 41 of the Letter to Herodotus, Epicurus writes:

$$\text{καὶ μὴν καὶ τῷ πλήθει τῶν σωμάτων ἄπειρόν ἐστι τὸ πᾶν καὶ τῷ μεγέθει τοῦ κενοῦ.}$$

A literal translation: "And in fact the all is infinite both in the quantity of the bodies and in the size of the void." Also infinite, in the Epicurean system, are, a fortiori, all phenomena or events in which atoms participate, e.g. the number of cosmoi (section 45). Time has no beginning and no end, but I am not sure that Epicurus would have called it "infinitely extended" (D.J. Furley, "Aristotle and the Atomists on Infinity," in Naturphilosophie bei Aristoteles und Theophrast (Heidelberg, 1969) 85), since I am inclined to doubt that he conceived of time as a dimension. The text is chapters 72-73 of the Letter to Herodotus, but I reserve discussion of this problem for another occasion. Here I should like to call attention to another class of phenomena which, while they are not infinite in number, are described as being incalculably or inconceivably large. The clearest instance of this class is the variety of atomic shapes, expounded in section 42:

> Besides this, those bodies that are indivisible and solid, out
> of which the compounds arise and into which they are dissolved,
> are incomprehensible in the varieties of their shapes; for it is
> not possible that so many varieties should arise out of the same shapes,
> if their number is comprehended. With respect to each shape-type,
> then, the like kinds are strictly infinite, while in the varieties
> they are not strictly infinite but only incomprehensible.

This passage suggests that Epicurus distinguished between three degrees or orders of magnitude, that is, denumerable, inconceivable, and infinite quantities. I believe that this distinction is deliberate and technical. In what follows, I shall examine some passages in which I think the concept of an inconceivably large but nevertheless finite magnitude is operative; then I shall offer some general remarks on its significance for Epicurus' physical theory.

The first passage, from sections 46-47 of the Letter to Herodotus, is both a lengthy one and among the most difficult in the entire epistle. This is the text:

$$\text{τούτους δὲ τοὺς τύπους ἐθώλι πρὸς -}$$
$$\text{ἀγρεώμεν. καὶ μὴν καὶ ἡ διὰ τῇ κενῷ}$$
$$\text{φορὰ κατὰ μηδεμίαν ἀπάντησιν τῶν}$$
$$\text{ἀντικοψάντων γινομένη πᾶν μῆκος}$$
$$\text{περιληπτὸν ἐν ἀπερινοήτῳ χρόνῳ}$$
$$\text{συντελεῖ. βράδους γὰρ καὶ τάχους}$$
$$\text{ἀντικοπῇ καὶ οὐκ ἀντικοπῇ ὁμοίωμα}$$

Considerations of space oblige me to forego a review of the many extraordinary interpretations to which this paragraph has given rise. Suffice it to note that Usener emends drastically, Bailey, following Giussani, transposes the better part of it to sections 61-62, and Hicks, in the Loeb translation, goes a good way toward rewriting the original. I propose to offer my own translation and explanatory comments, invoking the distinctions drawn above between categories of magnitude, and I shall be content if my reading makes plausible sense of the passage. First, then, the translation:

(1) We call these forms idols. (2) Furthermore, the course through the void, coming against no opposition of deflecting (atoms), accomplishes every comprehensible distance in an unimaginable time. (3) For deflection and the absence of deflection take the likeness of slowness and speed. (4) Nor, indeed, with respect to the times visible through reason does the moving body also arrive together at the many places (for this is unintelligible), (5) and this body arriving together in perceptible time from somewhere in the infinite will not have set out from just any place whose course we may comprehend. (6) For it will be like deflection, even if to a certain degree we take the speed of the course as not deflected. (7) It is important to posit this factor too.

The first stage of the argument (#2) I take to run like this: in the absence of collisions, atoms (or idols) will traverse all comprehensible, which is to say, denumerable distances in an imperceptibly brief interval of time. It should be noted that my analysis depends upon a rigorous use both of the term _perilepton_ and its cognates, for the translation of which I employ forms of the

word "comprehensible," and of the term aperinoetoi, which I have rendered as "unimaginable" and which I understand to refer to the limits of mental representation; in the next sentence but one (#4) Epicurus drives home the point that these limits are identical to those of perception, and must be sharply distinguished from the limits of theoretical cognition. On this interpretation, the phrase "every comprehensible distance" excludes the category of measures that are incomprehensibly large. When two points on the trajectory of a particle are separated by a distance of incomprehensible magnitude, the interval between the times of arrival at the two positions would, I take it, be perceptible. This proposition is coordinate with the next, that on the level of theoretically discrete temporal intervals no object may be said to arrive simultaneously at two separate points along its path (#4). If our gauge is that of temporal minima, we can distinguish the moments of arrival at any two points. If the measure is perceptible units of time, then it is not possible to discriminate times of arrival when the distance between points is calculable, but if that distance should be incalculably great, the temporal interval should be a sensible one. To put the same hypothesis in different terms, if two particles set out from points of departure that are a calculable or comprehensible distance apart, it is not possible to distinguish in perception the times at which they reach an observer. If, however, they were to originate at positions separated by an incomprehensible distance, then their time of arrival would be discernibly different.

Epicurus then introduces a further qualification (#5): that even on the level of perceptible intervals of time, an object or idol arriving from a given point of departure in the universe will not have set out from any place at all that happens to be at a comprehensible distance from the observer (ex hou an perilabomen ten phoran topou: phoran is the course or trajectory; the relative hou with an and the subjunctive is a relative clause with indefinite antecedent (Smyth 2506); the ouk goes with aphistamenon). That is to say, some distances are excluded, even though they are not incomprehensibly large (perilabomen is interpreted strictly, as the verbal correlate to the adjective perilepton). The reason for this is given in the following sentence (#6): idols do not in fact behave like atoms which meet no obstacles in their course; to treat them so is merely a convenient approximation. Thus, for very large, though still comprehensible distances, the time required for an idol to traverse them may be perceptible.

The final text I wish to examine is Epicurus' discussion of the minimum parts of the atom. In section 56 of the Letter to Herodotus, Epicurus affirms that atoms cannot be subdivided indefinitely (ten eis apeiron tomen). Such division would result in an infinite number of parts, and if these parts have any dimension at all, as they must, then the body they constitute must be of infinite size (sec. 57; see above, pages 5 - 6). He then adds a further argument: ἄκρον τε ἔχοντος τοῦ πεπερασμένου δια-

ληπτόν, εἰ μὴ καὶ καθ' ἑαυτὸ θεωρητόν, οὐκ
ἔστι μὴ οὐ καὶ τὸ ἑξῆς τούτου τοιοῦτον νοεῖν
καὶ οὕτω κατὰ τὸ ἑξῆς εἰς τοὔμπροσθεν βαδίζοντα
εἰς τὸ ἄπειρον ὑπάρχειν κατὰ τὸ τοιοῦτον ἀφικνεῖσθαι τῇ ἐννοίᾳ.

Since a bounded body has an intelligible extremity, even if it
is not imaginable in itself, there is no way not to think of
the same kind (of part) following this, and thus for one
proceeding to the next in succession to be able to arrive in
thought by such a method at infinity.

Epicurus' reasoning is based on the Zenonian notion that to traverse, whether
physically or mentally, a divisible stretch of territory, one must have
accomplished individually each of the potentially separable units into which
the distance can ultimately be resolved. If division could go on without
limit, then the mind, in scanning the dimensions of a finite body, would have
to perform an infinite number of discrete operations, which is, for Epicurus,
impossible. But if an atom is not composed of an infinite number of parts,
is it necessarily the case that we are able to specify the precise number of
parts comprised in any given atom? If so, we encounter the minimalist paradox
in its most blatant form. For we should then be able to equate the size of
the minimum part with a finite specifiable fraction of an atomic particle, and
be obliged to deny the possible existence of a quantity half that size. All
the problems which Gregory Vlastos has pointed out in connection with
geometrical figures, such as a cube with sides of finite measure and
incommensurable diagonals ("Minimal Parts in Ep. Atomism," 126-128), would
immediately controvert the plausibility of Epicurus' theory. Vlastos' own
solution, which is to take the minimum not as a mathematical or theoretical
limit, but as a natural unit of volume, empirically verified, of which all
atoms happen to be integral multiples, ignores, among other things, the
essential relationship between minima and boundaries: a bit of matter whose
edges in one way or another are equal to the natural unit could certainly be
said to have definable boundaries of its own, nor is there any reason at all
why it could not be imagined as an independently subsisting entity. Moreover,
the connection, if any, between the minima of distance, time, and the angle
of swerve would be quite arbitrary. Furley's observation, on the other hand,
that the minima, while assumed to be finite, nevertheless partake in some
respects of the qualities of points, is offered as a statement of the paradox,
not an answer to it. If the above discussion is right, however, there is a
middle ground in Epicurean theory between the dimensionless point and the
measurably small interval of Vlastos' account, that is, the inconceivably small
quantity. Epicurus has given us all the elements necessary to define such a
unit: when we scan the breadth of an atom, proceeding from part to minimal
part, we accomplish neither an infinite number of steps (which is impossible),
nor a denumerably finite number (which, I submit, leads to insupportable
inconsistencies), but inconceivably many steps, not strictly infinite, but
incalculably large in quantity, exactly like the varieties of atomic shapes.
The minimum is, as it were, the inverse of this magnitude. Its property is to
be smaller than any fraction we can name.

The idea of a positive quantity smaller than any specifiable number is
not unrelated to the mathematics of Epicurus' time. The method of proof by
exhaustion, which is similar to the modern reformulation of the calculus in
terms limits (for every delta, there exists an epsilon such that...), naturally
gives rise to the intuition that all areas or volumes may be treated as
multiples of some minuscule unit, too small to tag a number to but greater
than zero. As Mau and others have pointed out, Archimedes' Method acknowledged
the utility of such an assumption as a means of identifying, if not rigorously
demonstrating, provable theorems. It seems to me that, given the Epicurean
criterion of conceivability, there would be no obstacle to accepting such an
intuitive notion as corresponding to an objective property of nature. Further-
more, on this interpretation the doctrine of minima eliminates the need for a
strictly finitistic geometry, such as Vlastos demanded. For any measurable
figure, all the laws of ordinary geometry will obtain. They fail only at the

level of the minimum itself, which has no parts, and therefore does not offer, for example, a diagonal to be measured against a side. As for the purely arithmetical relations or proportions at this order of magnitude, the Epicureans could argue that, if any numbers can be specified, then we are ipso facto above the realm of the true minimum.

I have argued in this section that Epicurus posited a distinct order of magnitude larger than any denumerable quantity but not infinite, whose inverse is, correspondingly, smaller than any specifiable quantity but not zero. What is the logical status of such a conception according to modern mathematical theory? It is not entirely implausible. For today the idea of the infinitesimal has been vindicated in mathematics, and it has been shown that the entire calculus can be consistently derived on the assumption of infinitesimal differentials (see A. Robinson, Non-Standard Analysis, 1966). Now, Epicurus' minima are not infinitesimals, since in finite, though inconceivably large, multiples they sum to finite quantities (e.g., the unit integer). The distinction between denumerable and non-denumerable infinities has been rigorously drawn, but, to the best of my knowledge, the class of finite non-denumerable quantities has not been defined in a useful or coherent way. Nevertheless, it was a good try on Epicurus' part. His third order of magnitude enabled him to evade the paradoxes of infinity, which plagues all Greek minds, without denying the validity of geometry for all calculable operations.

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Notes to follow.