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The *Mechanical Problems* in the Corpus of Aristotle

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The Mechanical Problems
in the Corpus of
Aristotle

Thomas N. Winter

Lincoln, Nebraska • 2007

Translator's Preface.

When I was translating the *Mechanical Problems*, which I did from the TLG Greek text, I was still in the fundamentalist authorship mode: that it survives in the corpus of Aristotle was then for me *prima facie* evidence that Aristotle was the author. And at many places I found indications that the date of the work was apt for Aristotle. But eventually, I saw a join in Vitruvius, as in the brief summary below, “Who Wrote the *Mechanical Problems* . . .”

To “cut to the chase,” I conclude that the likeliest author is Archytas of Tarentum.

Thomas N. Winter
May 16, 2007

Who Wrote the *Mechanical Problems* in the Aristotelian Corpus?

This paper will:

- 1) offer the plainest evidence yet that it is not Aristotle, and —
- 2) name an author.¹

That it is not Aristotle does not, so far, rest on evidence. The authority is Ross:

“The *Mechanica* seem to belong to the early Peripatetic School—perhaps to Strato or one of his pupils. They discuss the lever, the pulley, and the balance, and expound with considerable success some of the main principles of statics—the law of virtual velocities, the parallelogram of forces, and the law of inertia.” (Ross, Sir David, *Aristotle*, Methuen, London, 1923, p. 12)

Just “seems to belong;” no evidence. G. E. R. Lloyd repeats this doctrine where he speaks of the *Mechanical Problems*:

“Finally, the author of the *On Mechanics*, a follower of Aristotle rather than Aristotle himself, though the work is found in the Aristotelian corpus

“Throughout the work the author is chiefly interested in the mathematical principles involved in the devices he discusses. His aim is to give a theoretical, geometrical explanation of the phenomena, as when he suggests that the operation of a lever may be accounted for by the properties of a circle, and unlike some later mechanical writers, such as Ctesibius of Alexandria or Archimedes of Syracuse (both third century B.C.) he does not appear himself to be an inventor.” Lloyd, G.E.R., *Early Greek Science: Thales to Aristotle*, Norton, New York, 1970, p.135.)

The most recent writer to address the subject simply repeats prior doctrine: “Ascribed to Aristotle, but probably dating to the third century BC,” (Carl Hoffman, *Archytas of Tarentum*, Cambridge, 2006, p. 77).

¹ I have been using the *Mechanical Problems* as the heart of my Ancient Science and Technology course for 34 years, and eventually, you figure something out.

Though the critics scoff at Aristotle as author, the work has, as one sees in the above citations, earned respect for its achievement.

The evidence about authorship is in Vitruvius. Vitruvius summarizes the *Mechanical Problems* in the setting of his book on machines, book 10, chapter 3. That he has our *Mechanical Problems* is unmistakable. He includes simplified versions of the easier parts of Mechanical Problems 3, 4, 5, 6, 20, 26, 27, and extends the *Mechanical Problems* thesis to the machines of his own time:

“As in all these cases motion is obtained by means of right lines at the center and by circles, so also farm wagons, traveling carriages, [column] drums, mills, screws, scorpiones, ballistae, press-beams, and all other machines produce the results intended on the same principles, by turning about a rectilinear axis and by the revolution of a circle” (10.3.9, Morris Morgan, tr.)

Vitruvius knew our *Mechanical Problems*; Vitruvius knew who the author was. The question becomes, “Who did Vitruvius know was the author?” His list of his sources on machines was earlier, back in book 7.

Aristotle is not in the list, and neither is Ross’s candidate Strato.

Who was the Aristotle known to Vitruvius? Vitruvius knows Aristotle as a writer of guidance to life, for the benefit of the person, and the benefit of the state, and cites him only twice, speaking at one point of the “rules Socrates, Plato, Aristotle, Zeno, Epicurus, and other philosophers laid down for the conduct of human life.” (Vitruvius 7 Introduction 2). Similarly at 9, introduction 2:

“What does it signify to mankind that Milo of Croton and other victors of his class were invincible? Nothing, save that in their lifetime they were famous among their countrymen. But the doctrines of Pythagoras, Democritus, Plato, and Aristotle, and the daily life of other learned men, spent in constant industry, yield fresh and rich fruit, not only to their own countrymen, but to all nations. And they who from their tender years are filled with the plenteous learning which this fruit affords, attain to the highest capacity of knowledge, and can introduce into their states civilized ways, impartial justice, and laws, things without which no state can be sound.”

It remains to consider Vitruvius’ list of named sources on mechanics and to interrogate the list: “. . . others on machinery, such as Diades, Archytas, Archimedes, Ctesibius, Nymphodorus, Philo of Byzantium, Diphilus, Democles, Charias, Polyidus, Pyrrhus, and Agesistratus. (Vitruvius, 7. introduction 14.)

One of these 12 is the author of the *Mechanical Problems*.

Several of these can be dismissed in one stroke: Ross is incorrect in assigning the work to Strato or one of Strato’s pupils.

Why? The history math and the history of technology make Strato’s time untenable. Strato took over from Theophrastus in 288; his successor Lycon headed the Peripatetic School from 260.

Why is our author before this time? Our author is before Philo and Ctesibius, for he addresses pulleys, but does not have not have the principle of mechanical advantage of the pulley. The mechanical advantage of the pulley was correctly, and fully, set forth by Hero of Alexandria (*Mechanics* II, 3, and 23. In Cohen and Drabkin, *Sourcebook in Greek Science*, pp. 224-226, 233) and known to Philo of Byzantium, who flourished in the third century B.C., i.e., in the time of Strato and his successors.

The object of our search knows and seeks the principle behind gear-trains, windlasses, levers, and the slings with which the Greeks threw spears. But our sought author does not know about catapults. In the period wished by Ross, catapults are already old, and the mind that sought the principle behind the simple sling would have been on them.

Our author is pre-Archimedes; he is happy merely to (correctly) state the principle of the lever; Archimedes rigorously proves it. Similarly our author sometimes has a rough and ready, tacit, notion of center of gravity. Archimedes proves it.

Finally, by the time of “Strato or one of his pupils,” geometrical mathematics has advanced in rigor and left behind the offhand illustrative mode of geometry and gone to the form consisting of *protasis*, *ekthesis*, *diorismos*, *kataskheue*, *apodeixis*, and *sumperasma*. This rigorous layout was already traditional before Euclid (T. L. Heath, *Euclid in Greek, Book 1 with introduction and notes*, on proposition 1, 159). Our author, in common with Plato and Aristotle, shows by his style and use of geometry that he is before the tradition in which Euclid writes.

Pace Ross and his followers, an early author is to be sought.

So then, not Pyrrhus, Ctesibius, Philo, Archimedes. Dating thus also eliminates Diades, whom Vitruvius identifies as Alexander's engineer, and his source about catapults. And Vitruvius tells us when he is using Diades.

Agesistratus? Eric Marsden² (21) puts Agesistratus in the late second century B.C. Melampus? Melampus was a hiergrammateus to Ptolemy. Charias? the known ones are the general in the Peloponnesian War, and the thesmothete of 227-226 B.C. The Nymphodorus known to us is in *Paradoxographii Graeci*. Two savants named Diphilus are known, but neither is a candidate.³ The only Democles known to us is an Attic Orator.

Essentially, Archytas is left. What about Archytas?

Our author is direct: he is not an Aristotle discussing and criticizing the merits and failings of prior workers in the field; there is *nothing* between him and the problems he discusses and theorizes from. We have here not something in the line of development, but an archetype from an original.

Who wrote the *Mechanical Problems*? The author we seek is an intellectual giant. His achievement goes unrecognized in the limbo of Pseudo-Aristotle.

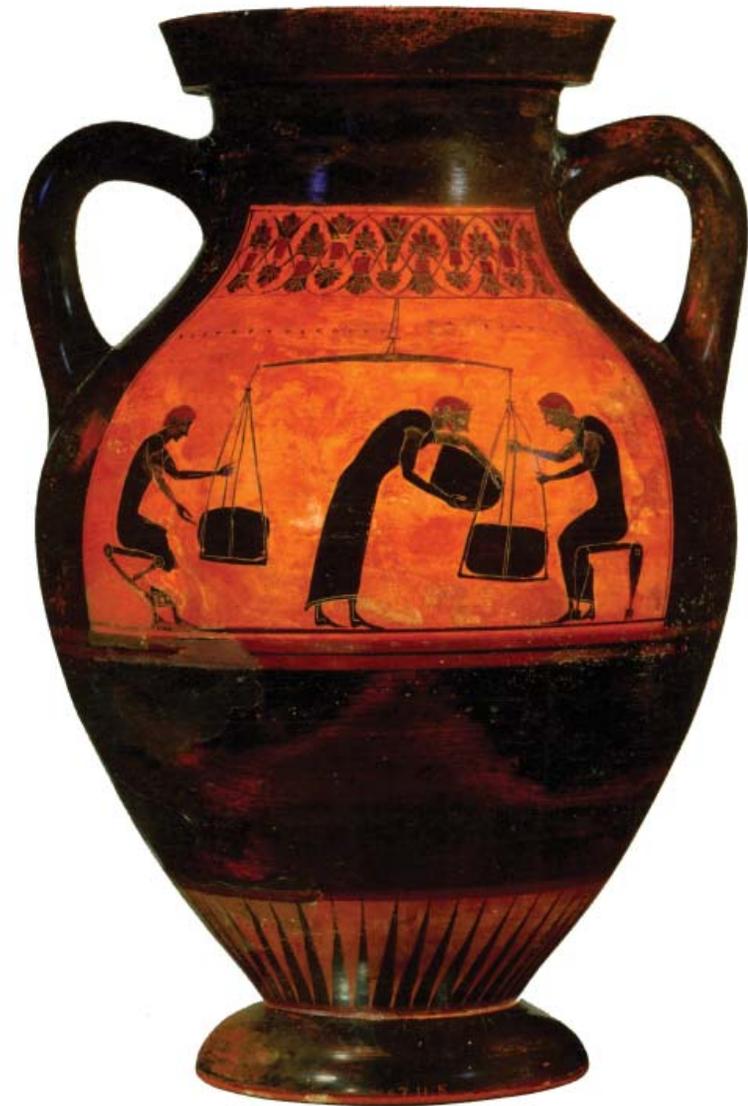
This author is on a quest for what we call inertia; this author manages to separate mass from weight. We still don't know what mass is, but we describe it: Mass is resistance to acceleration. Where others of his time saw bushels in balance pans as items of trade, our author saw the difference between weight and mass. "Why is a balance beam harder to move when laden than when empty?" Since the weight is supported, the question isolates mass.

Further, when you think back on your physics classes, you realize

1. It is exactly parallel to Henry Cavendish's torsion balance with which he determined G to be $F = GmM/r^2$;

² Eric Marsden, *Greek and Roman Artillery; Historical Development*, Oxford, 1969., p. 21

³ Diogenes Laertius has a follower of Stilpo, a reformed dialectician, (sn Stilpo, 2, 113) and a dialectician and follower of Ariston (7.161, sn Ariston)



*Tradesmen measuring merchandise, the Taleides Amphora, 6th century B.C.
Metropolitan Museum of Art.*

2. It parallels the lab equipment first used for Coulomb's measurement of the electromagnetic attraction, and is paralleled by Lorand Eotvos' advanced torsion balance to measure gravitational force between two objects. The question is still at the heart of theoretical physics. In "Inertia as a Zero-Point Field Lorentz Force" (*Phys Review A*, February, 1994), B. Haisch, A Rueda, and H. E. Puthoff ask "What gives an object mass (or inertia) so that it requires an effort to start it moving, and exactly the same effort to restore it to its original state?"⁴

This author has the parallelogram of vectors, which is the first corollary to Sir Isaac Newton's Three Laws of Motion.

This author has a correct statement of the principle of the lever.

This author uses vectors to demonstrate (I use modern terms) that you cannot generate a circle with a first-degree equation.

This author has humility: when he produces a test for his theory of inertia that fails, he admits it. "Or isn't it futile to ask such questions, lacking the central principle."

Archytas "has often been hailed as the founder of mechanics," writes Carl Huffman (*Archytas of Tarentum*, Cambridge, 2006, p. 77.) yet he argues against this, noting "There is little reliable evidence that he founded the discipline of mechanics" (p. 78). Why? Huffman has adopted the reigning dating of our work ("ascribed to Aristotle but probably dating to the third century BC", p.77). His lead-off argument against Archytas being founder of the discipline of mechanics is that "there is no mention of Archytas in the pseudo-Aristotelian *Mechanical Problems*." (p. 78.)

Archytas, in Diogenes Laertius, "was first to put method in mechanics, using mathematical principles." Is this a match-up to our *Mechanical Problems*?

Vitruvius would have said yes. It is when Vitruvius feels the need, before discussing machines, to lay out the underlying principles that he uses our author "Id autem ut intellegatur, exponam," up front (10.3.2), and *iisdem rationibus* for all machines at the close (10.3.9).

The *Mechanical Problems* is a bold attempt to explain all of mechanics in terms of circular motion. It notes that all mechanics depends

⁴ I owe the citation to Arthur C. Clarke, 3001, *The Final Odyssey*, Sources and Acknowledgements, pp. 255, 256.

upon the lever, and that everything about the lever depends upon the circle, and then uses an early form of cartesian coordinates, with motion on what we would now call the x -axis, coupled with motion on the y -axis, to explain why longer radii move farther in the same time than shorter radii. It wrestles with inertia, a concept not tamed until Newton. It is on to vectors. In sum, Diogenes Laertius has Archytas foundational to mechanics; Vitruvius, laying out the foundations of mechanics, uses our extant work.

To the appreciations of Ross and Lloyd cited above, I add a personal note: I have taught the *Mechanical Problems* as the centerpiece of my Ancient Technology course since 1974. In my fundamentalist days, I would argue for Aristotelian authorship, with the line: "If it is not written by Aristotle, it is written by someone smarter than Aristotle." A fourth century genius who could use mechanics to solve cube roots could do it.

In conclusion, first, Aristotle was not the author of the *Mechanical Problems* that Vitruvius had in hand, and so is not the author, period.

Second, of the Vitruvian slate of writers on mechanics, one, Archytas of Tarentum, is a match. Huffman writes "He has, however, often been often hailed as the founder of mechanics" (p. 77). But he doesn't see why, even stating that the *Mechanical Problems*, our earliest source in mechanics, doesn't mention Archytas (!) (p.79).

But if you follow the evidence instead of fighting it, the reason Archytas is the founder of mechanics reason is simple: Archytas of Tarentum is the author of the *Mechanical Problems*.

The Mechanical Problems of Archytas of Terentum

One marvels at things that happen according to nature, to the extent the cause is unknown, and at things happening contrary to nature, done through art for the advantage of humanity. Nature, so far as our benefit is concerned, often works just the opposite to it. For nature always has the same bent, simple, while use gets complex. So whenever it is necessary to do something counter to nature,¹ it presents perplexity on account of the difficulty, and art [*techne*] is required. We call that part of art solving such perplexity a *mechane*.

As the poet Antiphon puts it:

We win through art where we are beaten through nature.

Such it is where the lesser overcomes the greater, and when things having little impetus move great weights. And we term this entire class of problems *mechanics*.

Mechanics isn't just restricted to physical problems, but is common alike to the theorems of mathematics as well as physics: the how is clear through mathematics, the what is clear through physics.

The matter of the lever is concerned in matters of this type, for moving a big weight with a small force seems absurd, and the more so the bigger the weight. What a person cannot move without a lever is moved — even adding the weight of the lever — easily.

¹ This phrase “contrary to nature” is used where we would invoke the term “mechanical advantage.” It is also used below to mean motion diverging from a tangent.

The circle contains the first principle of all such matters. This falls out quite logically: it is nothing absurd for a marvel to stem from something more marvelous still, and most remarkable is for there to be opposites inherent in each other, and the circle is made of opposites. It derives from the moving and the standing,² whose nature is opposite each the other. So in it there is, for those contemplating, less to marvel at, that opposites go together on the subject concerning it.

First, the perimeter which draws the circle, having no breadth, somehow generates opposites: the hollow and the curved. These differ from each other like the big and the small: the midway of one set is the equal of the other, the straight. Therefore, changing into each other they would have to pass through equality before reaching the opposite extreme, and through the straight line when going from curved to hollow, or vice-versa.

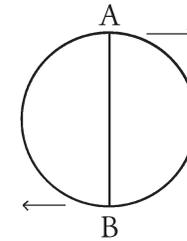
Though one (apparent) absurdity may suffice about the circle, a second is that it moves opposite motions. It moves backwards and forwards at the same time. The line drawing the circle is like this: its limit goes back to the same place from which it started, for with it moving continuously, the last part has again become the first, so it is clear that it has changed from there.

Therefore, as was said earlier, there is no surprise at its being the first principle of all marvels. Everything about the balance is resolved in the circle; everything about the lever is resolved in the balance, and practically everything about mechanical movement is resolved in the lever.

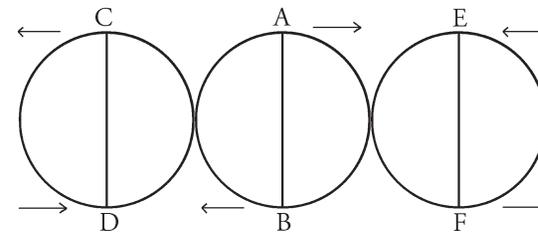
Further, many of the marvels about the motion of circles derive from the fact that, on any one line drawn from the center, no two points are swept at the same pace as another but always the point further from the motionless end is quicker, as will become clear in the following problems.

From the circle going opposite ways at the same time (*e.g.*, one end of the diameter, at A, is moved forward, the other, at B is moved backward) some have set up so that from one movement, many circles are in

² Old geometry is kinetic, not static: a line is the sweep of a moving point; a plane is the sweep of a line; a circle is the sweep of a line when one end is fixed; a solid is the sweep of a plane. (Nowadays a geometer would have to say “a line segment.”)



opposite motions, such as they have dedicated in temples, having made the little wheels out of bronze and steel. For if circle CD touches circle AB, CD will be moved backward when the diameter of AB is moved forward, so long as the diameter is moved in place.³ So the circle CD is moved just the opposite of the circle AB. And that circle again will move its neighboring circle EF just the opposite to itself, and for the same reason. In the same way, if there be more, they will all do this, being moved by one circle alone. So taking this underlying nature of the circle, craftsmen make a machine hiding the cause, so only the marvel of the mechanism is visible while the cause is unseen.

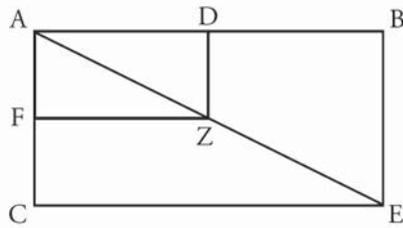


PROBLEM I

When it comes to the balance, why are larger balances more accurate than smaller ones?⁴ The basis of this is to ask why in the circle is the point standing farther from the center moved faster than the one nearer, when the one nearer is moved by the same force. The “faster” has a double meaning. For if in less time it has crossed equal space we

³ *I.e.* rotates rather than rolls.

⁴ Literally “So first the circumstances about the yoke are confusing, through what cause are the larger yokes more accurate than the smaller?”



say it is faster; and likewise if in equal time it has crossed more space. The greater in equal time draws a bigger circle, and the outer is bigger than the inner.

The cause of this is that the point drawing the circle is conveyed two vectors.⁵ Whenever the moving point is carried in some proportion (*logos*), it is necessarily carried in a straight line, and it becomes the diagonal of the scheme that the lines make which are stretched in that proportion.

Let the *logos* the point is carried be the ratio AB has to AC.

Let AC be swept toward B.

Let AB be swept towards CE. Let A be carried up to D, and the line AB up to F.

If the vector ratio is that which AB has to AC, of necessity AD has that ratio to AF. The small four-sider is proportional to the larger since the diagonal⁶ is same for both, and the point A will be at Z. The same thing will be seen no matter where the conveying gets stopped: Point A will always be on the diagonal.

It is clear that the point being born along the diameter in two vectors has to bear the proportion of the sides. If it does not, it will not be born on the diagonal.

⁵ PHORA, the word here rendered “vector,” is the cognate noun to the verb PHEREIN, “to carry.” It was tempting to render with “carriage,” or with the substantive of the verb itself, “a carry” to help the reader see where the Greek was. PHORA is the literal act of carrying in PROBLEM 29, about two men shouldering a weight; it is inertia when A. speaks of a resting weight — on an ax — lacking the force of the PHORA and BIAS of a blow in PROBLEM 19.

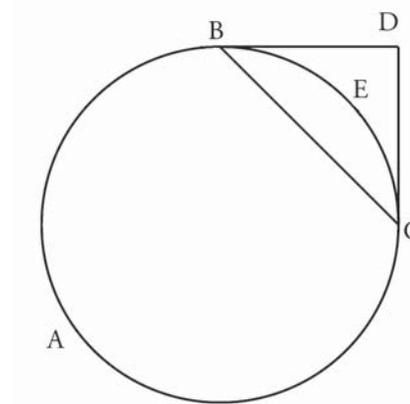
⁶ The Greek for this is interesting: DIAMETER, “measure across.” The word for maximum straight line inside a polygon and maximum straight line inside a circle, and any of its chords, one and the same.

If it is carried two vectors in no proportion and in no fixed time, it is impossible for the resultant travel to be a straight line.⁷

Let it be a straight line. With the straight diagonal being set down, and the sides filled in, the point is carried the ratio of the sides. For this was shown earlier. Therefore the point carried in no ratio in no time will not be straight. For if it is born in a ratio in some time, its travel would be straight, because of the foregoing.

Therefore the point being conveyed along two vectors in no fixed time becomes a curve.⁸

That the line which forms the circle is conveyed in two vectors is clear from the following, and from the fact that as soon as it is born along a straight, it becomes a tangent. Let there be a circle ABC. Let the top point B be carried to D, and then reach C. But if it were carried in the ratio that BD has to DC, it would have been conveyed along the chord-line BC. But since it was carried in no fixed ratio, it was carried along the periphery BEC.



⁷ I refer to this in class as “Aristotle’s proof that a first-degree equation cannot generate a circle.”

⁸ To be exact, a PERIPHERES, a “carry around,” in its component parts much more interesting than our derivative “periphery.” This is usually an arc, but as it includes anything rounded, “curve” is better.

If, of two objects being carried by the same force, one gets more turned aside and the other less, it is reasonable that the one more diverted is slower than the one less diverted.

Of the lines drawing the circles, this seems to hold for the one farther out from the center and the one nearer in. For the end of the lesser radius, through being closer to the non-moving part than the end of the greater one, is carried more slowly, being, as it were, anti-pulled to the opposite direction, to the middle. To every line drawing a circle, this happens: it is both conveyed according to nature along the periphery and carried contrary to nature, to the side and to the center. Being closer to the anti-pulling center, it is overcome by it more. That the lesser circle is moved more contrary to nature than the larger is clear⁹ from the following.

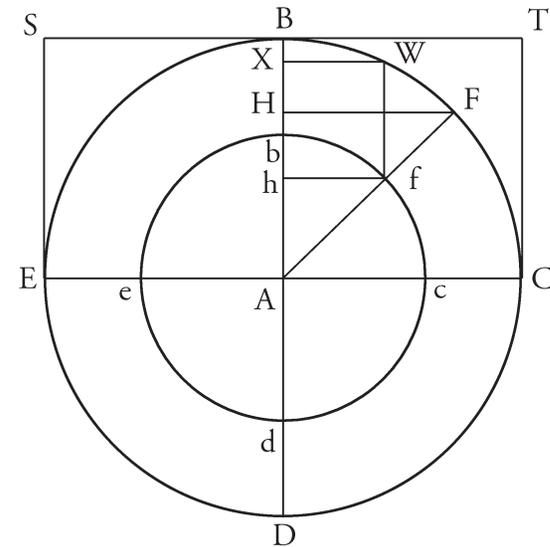
Let there be a circle BCDE, and a smaller one in it, bcde, about the same center A, and the diameters drawn, in the large circle BD and EC, in the small bd and ec. Let the rectangle ESTC¹⁰ be filled in.

If the line drawing the circle, AB will come to the same point it started from, to the position AB, it is obvious that it is carried towards itself. Similarly Ab will have come to Ab. But it is carried slower than AB, as was said, because the diversion and anti-pull were greater than at AB.

Let AfF be drawn, and a perpendicular from f to AB, at fh. From f let fW be drawn parallel to AB, and perpendiculars to AB at XW and HF.

⁹ In modern terms, A. is plotting two circles on the equivalent of the x and y axes. His point is that, when $\Delta x_1 = \Delta x_2$, $\Delta y_1 > \Delta y_2$. This is simpler mechanically than geometrically. Another way to envision the following is that A. is contriving to draw a circle by moving marbles in two slots, one slot horizontal, one slot vertical. Starting at top dead center, motion downwards of the horizontal slot is “contrary to nature.” Motion of the vertical slot is “according to nature.” When a quadrant has been drawn, the motion “contrary” and the motion “according” to nature will be equal, and the sine of the chord will be unity. But in between!!

¹⁰ The unpolished nature of this work can be seen plainly here: this step, surrounding the upper semicircle with a rectangle, is a dead end. It is not used in the geometrical problem. Neither is the line FH. It is like putting two variables at the head of a FORTRAN program that the program itself never uses.

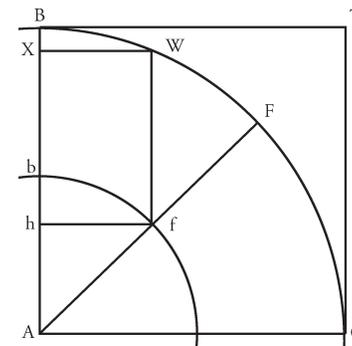


Lines XW and hf are equal, but BX is less than bh,¹¹ since equal lines in unequal circles cut off less diameter in the larger circle.

In such time as Ab has been carried [the arc] bf, the end of AB in the greater circle has been carried more than BW. Why? The vector ac-

¹¹ *I.e.* travel to the right is equal, but travel toward the center is greater in the smaller circle.

A's point mainly needs the upper right quadrant, and the “unnatural motion” (down the y axis) is greater for the smaller circle.



ording to nature [XW for the larger circle, hf for the smaller circle] is equal, but the vector counter to nature is less, BX as against bh.

There has to be a proportion: the according-to-nature in the large is to the according-to-nature in the small as the contrary-to-nature is to the contrary-to-nature.

$$[BH/HF = bh/hf]$$

For it went a greater arc than BW, to BF, and it is necessary that F be reached in the same time. For it will be there if the proportion holds. If indeed the according-to-nature is larger in the larger circle, the contrary-to-nature would fall with it in only one way, if the line AB is carried to F and f simultaneously. This, namely the perpendicular from F, becomes the according-to-nature limit for B, while the contrary-to-nature is BH.

Then HF is to BH as hf is to bh, an obvious thing if B and b are yoked to F and f.

$$[HF/hf = BH/bh]$$

But if the arc which B has been carried is either more or less than to F, it will not be similar, and there will not be a proportion between the contrary and the according, to nature.

For what reason the point further from the center is carried quicker by the same force is clear from the above. And why larger balances are more accurate than smaller ones is obvious from this: for the cord becomes the center, as it is the unmoving part, and each division of the arm becomes the lines from the center.¹² So it is necessary that, from the same weight the end of the arm moves quicker the further off it stands from the cord, and that some weights put onto smaller balances will be unclear to the perception, but clear on larger ones. For nothing prevents it getting tilted¹³ less than is plain to the eye. But on a longer

¹² Radius. A. doesn't have a word for it, but this phrase, instead. Typically, "a line" is merely to the feminine definite article <H, omitting GRAMMH. Similarly, a point is often simply the neuter definite article TO, omitting some such noun as SHMEION. Keeping the geometry in later problems straight is a matter of tracking the genders of adjectives and participles, as the nouns are often not in sight.

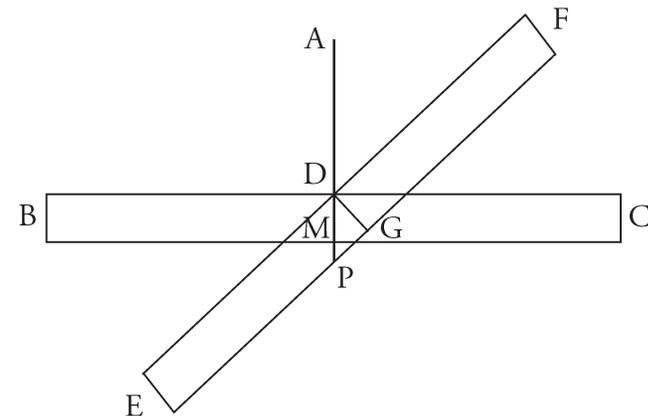
¹³ Literally, "getting moved a size less than is plain to the sight." But in the third occurrence of "size" it is finally defined with a limiting genitive, size "of tilt."

arm the same weight will make a visible size of tilt. Some weights will be plain on both, but much more obvious on the larger, because of the much bigger size of tilt on bigger balances.

PROBLEM 2

Why does a balance beam¹⁴ return when you remove the weight if the string is set from the top, and not return, but stay put when supported from below? Is it because when the string is set above, more of the balance is on the far side of the vertical (letting the string define the vertical)?

The greater part must slope down until the line evenly dividing the balance returns to the vertical, the weight being in the upraised part of the balance. Let there be a straight balance beam on BC, a string on AD. Extending this let the vertical continue to M.



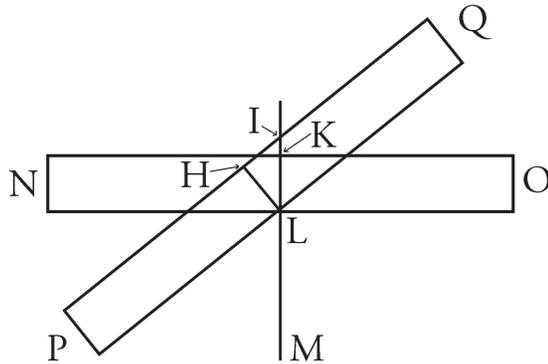
So if a slant is imposed on B, B will be at E and C will be at F. So the dividing line, at the exact vertical DM before, will be at DG during the slant. So the part of beam EF outside the vertical, marked GP, makes that side greater than half.

¹⁴ This is a ZUGOS, basically "yoke," as is also the "capstan" of PROBLEM 13. The Greeks did not really have a word for everything. In this context, it is a balance; in the setting provided by PROBLEM 13, it is a capstan.

If you take the weight from E, F has to swing down, for E is less.

Therefore if the string supports from the top, the beam goes back.

But if the support is from below, it does the opposite: The downward part becomes greater than half the beam as the vertical divides it, so it does not come back up.

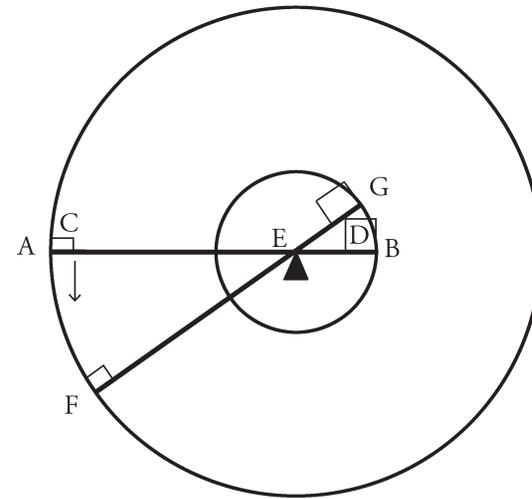


Let the beam lie on NO, and let the vertical be KLM. NO is divided equally. Put a weight on N. N will be at P, O will be at Q, KL will be at HL, so that IP will be greater than IQ by the amount HLI. Remove the weight and the low end will stay down, for the excess overlies on it like a weight.

PROBLEM 3

Why is it that small forces can move big weights with a lever? Even, as was said in the introduction, adding too, the weight of the lever? It is easier to move a smaller weight, and it is smaller without the lever. Is the cause that the lever is a balance beam having a string from below, and dividing into unequals? The fulcrum takes the place of the string. For they both, like a center, do not move.

When the part farther from the center gets moved more quickly by the same weight, there are three things about the lever: the fulcrum—string and center, and two weights, the one moving and the one getting moved. The weight getting moved to the weight moving is the opposite of length to length. And always, the farther from the fulcrum, the easier it will move. The reason is the aforesaid, that the more distant from



the center scribes the larger circle. So by the same force, the mover will manage more the farther from the fulcrum.

Let there be a lever AB, a weight on it C, the motive weight on it D, fulcrum E. The D, moving, goes to F, the weight being moved to G.

PROBLEM 4

Why do the men at the middle of the boat¹⁵ move the boat most? Is it because the oar is a lever? The pin becomes the fulcrum, and stays put. The sea which the oar pushes off is the weight to be moved, and the mover of the lever is the sailor. The one moving the weight always moves more the further he stands off from the fulcrum, for thus he becomes stronger than at the center, *i.e.* at the pin which here serves as fulcrum. It is at the middle of the boat that the greatest part of the oar is inboard, as the ship is widest there, so on both sides more of each oar is within the sidewall. Thus the ship gets moved forward through the forward pull on the inside part of the oar, with the outside end working against the sea. Necessarily, where the oar best pulls the sea, there is

¹⁵ Greek is wonderful: this entire noun phrase, “the men at the middle of the boat” is simply HOI MESONEOI, οἱ μεσόνεοι.

where it most propels. And it best pulls through where the greatest part of the oar is away from the pin, and the greatest part of the oar is in-board at mid-ship.

PROBLEM 5

Why does a steering oar, small as it is, and at the end of the boat¹⁶ have such force that with one little handle¹⁷ and the force of one man, and that gentle, it moves the great bulk of ships?

Is it because the steering oar is a lever, and the steersman levers? Where it is fitted to the ship is the fulcrum, the entire steering oar is the lever, the sea is the weight, the steersman the mover. The steering oar does not take the sea on its breadth like the oar, as it does not move the boat forward, but getting moved, it inclines, receiving the sea edge-wise. When the sea is the weight, the boat, working opposite to it, angles as the fulcrum gets diverted the opposite way — sea inwards, fulcrum outwards. Because of the bindings, the boat follows.¹⁸

¹⁶ Rather than amidship, where the other oars are most effective.

¹⁷ *οἰακος*, the Greek word here rendered “handle,” is not “the handle of the rudder,” as in LSJ; “tiller,” being a rudder handle, is not the choice here either, as it would mislead. The side-mounted steering oar, single or double, is seen from ancient Egyptian through Viking times, and up to the Renaissance. The single rudder is in evidence in the 1400’s, though the Venetian “great galleys” used double sidemounted steering oars for another hundred years. This transition can be seen illustrated in Enrico Scandurra, “The Maritime Republics: Medieval and Renaissance Ships in Italy.” In *A History of Seafaring Based on Underwater Archaeology*, George Bass, ed., Walker and Co., New York, 1972, pp. 206–224. An excellent transition is shown in a 1544 construction drawing, p. 216, showing a center-mounted steering oar. Hinging its paddle to a vertical stern-post would be the final step.

The steering oars are set to rotate, not sweep, and the *οἰακος* is a peg set in a hole drilled through the upper end of the steering oar. It is actually a lever to help turn it.

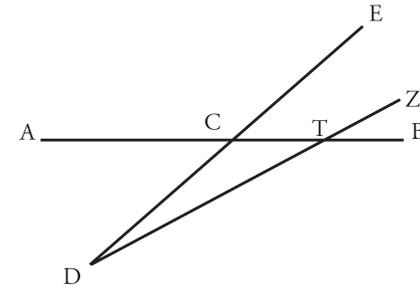
¹⁸ Fascinatingly informative passage: before coming to it, I had wondered if there weren’t a crossbar linkage twixt the two handles, so both oars could be rotated at once. Not at all. Only the steering oar on the outside of the turn is used. We can see here why ancient boatmen went from single side-mount to double: noting that the sidemounted oar was better in a turn to the opposite side, they would have added the second one so all turns could be effectuated from the outside oar.

The oar, pushing weight on its breadth, and being pushed back by it¹⁹ propels straight ahead. But the steering oar, as it is seated sideways makes movement sideways, this way or that. It is at the end [of the boat] not the middle because it is easier to budge a moving object by moving at the end. The first part is most quickly carried as with anything being conveyed, the *carriage* leaves off at the end, so the *carriage*²⁰ is weakest of a connection to the end. If it is weakest, it is easy to divert. Because of this the steering oar is set at the stern, because there at the end the effect of even a small motive force is greater. There follows a much greater difference from even a small motive force. Though the angle be equal, there it is on a longer line, having longer legs.

PROBLEM 5A

It is clear why the boat goes forward more in one direction than the breadth of the oar goes in the other, from this: the same size, moved by the same force, goes farther in air than in water.

Let AB be an oar, C the pin, A the end in the boat. C the end in the water. If A is moved to D, B will not be at E if AD equals BE. Then the change of position will have been equal, but the change of position



¹⁹ Here, it is an admirable perception. In Newton, it’s the law.

²⁰ The Greek word here is a subliminal equivalent to inertia. It is PHORA (*φοράν*), the cognate noun to the verb PHEREIN, to bear, carry, endure. As will be noted again more aptly elsewhere, a moving object in English is, in Greek, an object being carried, or in middle sense, carrying. English uses this middle sense of carry only with sound, e.g., “how far does my voice carry?” “Inert” is a much better base for the essential concept of mechanics, as it does not argue inherently that motion requires a mover to tag along. A change of concept requires, or at least profits from, a change of vocabulary, and vice-versa.

is actually less, say, to Z. It will then connect²¹ AB at T, and not at C, but below it instead: AB won't lie on C [the pin], but down from it, since BZ is less than AD as TZ is less than DT (similar triangles). And the middle, at C will also have changed position, for B changes position in the opposite direction from the end in the sea, so the end in the boat does not shift to D. As the boat will be moved, so there will the inboard end of the oar be moved. [*Back to 5*]

The steering oar does the same thing except it does not help the boat forward at all, as was said above, but only pushes the stern to the side this way or that, the prow verging in the opposite direction. Where the steering oar is yoked to the ship, one has to think of it as the middle of something being moved, and like the pin relative to the oar: it changes position when the handle of the steering oar is moved. If the steering oar drives [the sea] inward, the stern also shifts this way and the prow the opposite. Being in the same thing as its prow, the entire boat shifts direction with it.

PROBLEM 6

Why when the yardarm is higher does the boat sail faster, with the same sail and the same wind? Is it because the mast is a lever, the step in which it is set is a fulcrum and the boat is the weight to be moved? The wind on the sail is the mover. And the further the fulcrum [from the mover] the easier and quicker the same force moves the same weight. So the yardarm being pulled farther up makes the sail farther from its step, which is the fulcrum.

PROBLEM 7

Why when out of the wind they wish to run across,²² the wind not being at their back, do they tighten [send, furl] the sail toward the steers-

²¹ ARA is not the connective "ARA, but 'ARA^ (Ἄρα), the alpha-contract future third person singular of AEIRO. Recognizing this makes the violent emendation of the following word TOINUN (τοίνυν) to the participle TEMNON quite unnecessary.

²² Everything in this problem argues against taking DIADRAMEIN as "run before the wind," as in Liddell and Scott s.v. *ourios*, and in Hett, *ad loc.* That reading could work if and only if what's going on is making the sail the equivalent of a

man and, having made it a foot wide, let it out toward the prow? Is it because the steering oar can't counter a big wind, but can a small one, so they partially furl. Thus the wind leads forward and they set the steering oar toward the wind, with it both countering [the wind] and levering the sea. Simultaneously, the sailors fight the wind, leaning against it.

PROBLEM 8

Why are round things easier to move than things of other shapes? A circle receives roll three ways, along the tangent, the center also going, as roll the wheel of a wagon, or about the center only, like pulleys, the center staying in place, or parallel to the ground, as rolls the potter's wheel.

If these are fastest, it is through little touching the ground, like the circle at a [geometrical] point, and through not hitting forward, as the angle has a stand-off from the ground. Always, whatever body it contacts, it touches but little of it. But if it were straight-lined, it would contact the ground on the entire straight.

Always, where the weight tilts, there the mover moves it. When the diameter of the circle is straight up from the ground, touching the ground at that one point, the diameter balances the weight on either side. Then as it is moved instantly there is more towards where it is moved, like a tilt. From there it is easier for the one pushing to move it forward, for everything tilting is easier to move, as it is hard to move against the tilt.²³

Lateen rig, "winged out" on one side, but still going straight downwind, which requires the steering oars to work against the wind's tending to turn the boat abeam to the wind. This would put the boat down on the wing side, which would require the countering lean of the sailors. I believe what is going on is that they are bringing the yardarm of a rectangular sail down almost as far as it goes: (PEDIAION is a dimensional adjective, not the foot of a sail), and then setting it at a tacking angle, drawing one end back (toward the pilot) and loosening the stay on the other end go to have it be closer "toward the prow." This would have the two steering oars trying to work partly like centerboard, partly steering, and would well account for the countering lean of the sailors.

²³ Any non-round body must be partly lifted to tilt. *I.e.*, its center-of-gravity must gain height. It becomes easier only after the CG is past vertical. Once past this point, its own weight works with the mover. Without the Archimedean concept of the center of gravity, A. cannot yet say that pushing any non-round body involves lifting it — unless it will go as a sledge.

Still some say the line of a circle is always in carriage, like the things staying in place through resisting, such as happens with the larger circles relative to the smaller ones. For the larger are moved faster by an equal force, and move weights faster, because of having some tilt at the angle of the greater circle vis-a-vis the smaller one.²⁴ And this is as diameter is to diameter.²⁵ But every circle is greater than some lesser one, and there is an infinity of lesser ones. And if the circle has tilt relative to another, so it is easier to move.

And the circle would have another tilt toward the objects moved by the circle, not only where it touches the ground, but either parallel to it or like pulley wheels. In this way they are moved easily and also move weight easily.

Or not through little touching and veering forward, but through some other cause. This is the one mentioned earlier, that the circle consists of two vectors, so that one of them always has tilt. Also the persons moving it always move it like a thing already being conveyed since [‘OTAN] they move it along the periphery either way. For they are moving a thing being conveyed: The motive force pushes sideways while the circle itself is moved the movement of its diameter.²⁶

PROBLEM 9

Why, with larger circles, whether wheels, pulleys, or rollers, do we move more easily and quickly the things which are lifted or pulled?

²⁴ Circular angles — and mixed angles — were a dead-end of ancient geometry and mechanics. Any two circles whose perimeters touch are either congruent (and tangent everywhere) or not. If not, they form equal circular angles on both sides of the touching point. If they both also touch the ground, the angle made by the larger and the ground is less than the angle of the smaller and the ground. A sees this difference as an advantage making the bigger circle easier to roll, having more tilt than the lesser circle.

²⁵ A marvel. Nowhere else is there an expression of a means of relating circular angles. They are bigger, smaller, the same. They go, however directly with the ratio of the radii, and A perceived this.

²⁶ That is, the circle has a rotatory motion in addition to the linear motion; the push one on side results in the circle’s both moving toward the other side and moving around its own center.

Is it because the further from the center, the greater space is traveled in equal time? So with an equal weight following, it will do the same thing as the larger balances when we noted they are more accurate than smaller ones; there the string [pivot point] was the center, here the lines from the center correspond to the lines from the string of the balance.

PROBLEM 10

Why is an empty balance beam easier to move than a weighted one? In the same way also a wheel or any such thing, the heavier is harder than the smaller and lighter. This is true not only opposite the weight, but sideways. Opposite to its tilt it is harder to move anything, but there is no tilt sideways.²⁷

PROBLEM 11

Why do burdens go easier on rollers than on wagons, despite wagons having large diameter wheels and rollers small? Is it because on rollers the burden has no hit-against?²⁸ But the burden on the wagon has the axle, and it hits against that,²⁹ for it pinches it from above and from the sides.

But the burden on rollers moves at two of these, underneath at the ground and above at the burden. The circle gets rolled on both of these places and is pushed whilst already being conveyed.

²⁷ Mass is resistance to acceleration; our author is so observant of the world around him that he was able, in the 4th century, to separate mass and weight. This question pinpoints inertia, the unknown object of the quest. He consciously places it in “tilt” in PROBLEM 8, and tacitly has it in some of his uses of PHORA. He has a theory, and in this question, finds a test for it, and finds that his theory does not fit. In the words of retired Math professor Gary Meisters “He’s doing Science!” He does not supply an answer to this question, but instead admits that his theory falls short.

²⁸ The word is PROSKOPSIS [=to, towards + hit + abstract noun], too choice a Greek word to leave unshared with the reader. Our English-from-Latin word “resistance” [=back+stand/set+abstract noun] wasn’t even tempting. I have reserved “resist” for the Greek verb ANTEREIDO.

²⁹ PROS KOPTEI, the cognate verb.

PROBLEM 12

Why are spears or pellets carried farther from the sling than from the hand? Indeed, the thrower is more able with the hand before fitting the weight to it, for then he moves two weights, that of the sling as well as that of the spear or the pellet, but the other way, he moves the weapon only. Is it because with the sling he throws an object which is already being moved? For the slinger flings only after leading it around in a circle several times.

But out of the bare hand, the beginning is from rest. All things are easier to move if they are already being moved than if they are at rest.

Either because of this, or because in the slinging, the hand becomes a center, and the sling the line from the center. The farther from the center, the quicker anything is moved. The throw from the hand is short compared to the sling.

PROBLEM 13

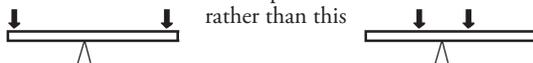
Why, around the same capstan, are longer spikes moved more easily? And likewise, thinner winches, by the same force?³⁰ Is it because the capstan and the winch are centers and the distances from them are the lines from center? And lines of larger circles are moved more easily than the lines of smaller ones by the same force. Given the same force, the end changes position faster the further it is from the center. This is why they make spikes for capstans, to wind up more easily. As for slender-barreled winches, there is more outside the wood, and this becomes the line away from center.

PROBLEM 14

Why is wood the same length broken over the knee more easily if you break it while holding it having set it equidistant from the ends³¹ rather

³⁰ In a non-mechanical context, an ONOS (*ὄνος*) is a donkey; in this context, a winch.

³¹ This extremely curious phrasing seems to stem from avoiding the word “center” and talking around it, since center is the point of his answer. The contrast appears to be this



than being close alongside the knee? And if you set it on the ground and step into it, you break it farther from the hand rather than near?

Is it because in the first instance the hand, in the second, the foot is the center? Everything is easier to move the further from the center, and movement has to come before breakage.

PROBLEM 15

Why are pebbles at the seashore rounded? At the start, they were oblong stones and shells.

Is it because the parts more distant from the middle are carried faster in any movement? For the middle is essentially the center, and the stand-off is essentially a line from center. Always the longer line describes a greater circle from an equal movement.

And whatever is carried faster over an equal distance hits harder. Whatever hits harder gets hit harder itself.

Therefore the greater stand-off from the center must always get more worn, and with this happening to them they must become round. Through the pushing of the sea, through being moved in its midst, they are always in movement, and being rolled, they hit forward. And this has to happen most at the extremities.

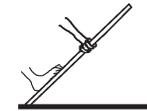
PROBLEM 16

Why is it that the longer a board is, the weaker it gets? and, lifted, bends more, even if the short one — say, two cubits — is thin, and the long one — say, 100 cubits — is thick? Because in the lifting, the length becomes lever, weight, and fulcrum? The part in the hand practically becomes a fulcrum, the part at the end becomes the weight, so that the further it is from the fulcrum, the farther it must bend [repeated]. As it is necessary to raise the ends of the lever, so if the lever be bent, it has to bend more on being lifted, which happens with longer boards. With shorter ones, the end is near the unmoving fulcrum.

and this

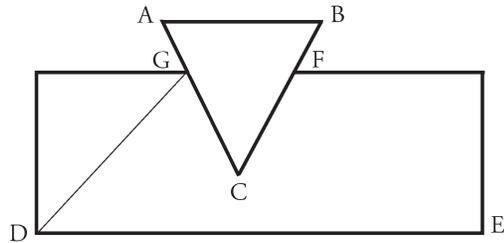


rather than this.



PROBLEM 17

Why are big heavy bodies split by little wedges? Why does the pressure get strong? Is it because the wedge is two levers opposite each other? and each has both weight and fulcrum, and so both pulls up and presses? Also the carriage of the blow³² which hits and pushes makes the weight big, and it becomes stronger still by moving a moving object with speed, and we don't appreciate how its effect is way out of proportion to its size. Great force is behind something quite small. Let ABC be the wedge; the item being wedged³³ DEFG. AB is a lever, right under B is the weight, DG the fulcrum. And opposite, BC is a lever. AC, when hit, uses each lever; B pulls apart.

**PROBLEM 18**

Why, if someone makes two pulleys working together on two blocks, and puts a rope around them in a circle, one block hanging, the other getting lifted up/let down, and hauls on the end of the rope, does he draw up great weights, even if the lifting force is small? Is it because the same weight is raised by less force if by a lever rather than by the bare hand? For the pulley does the same thing as a lever; even one draws easier, and from one pull draws much more than by hand. And two pulleys will lift it with more than double speed, for the second pulley, when the rope is thrown over it from the other, is drawing even less than if it were pulling by itself, because that one made the weight

³² PHORA again, the abstract noun cognate to the verb PHEREIN, to bear or carry, serves here again where a modern would say "inertia." In the parallelogram of velocities illustration, it was used where a modern would say "vector."

³³ The Greek goes from the noun "wedge" to the verb "wedge" as easily as English does.

even less. So, if the rope is set around more, a great difference occurs in a few pulleys, so that if under³⁴ one pulley the hauling weight is four minas, under the last, it is pulled with much less.

PROBLEM 19

Why, if you put a large ax on wood, and a large burden on that, doesn't it pull apart the wood, no matter how considerable the burden is? But if you raise the ax and hit with it, you split the wood even if you have less weight than you put on the ax in the first place?

Is it because everything works through moving-power³⁵? And the weight receives the moving-power of the weight more upon being moved than while at rest? So lying [on the wood] it doesn't get moved the moving power of the weight, but receives it, and that of the striker, upon being carried.

Also the ax is essentially a wedge, and a wedge, though small, pulls apart large objects because of being two levers set in opposition.

PROBLEM 20

Why is it that phalanxes³⁶ balance big heavy meats hanging from a stub? The whole kit being half a balance scales, since from one side, where you put the object, there just hangs the pan, from the other, there is just the phalanx. Is it because the phalanx is both balance scales and lever? It is a balance in that each of its strings becomes the

³⁴ HYPON plus genitive is an agent phrase typically, though not usually with an active verb form, and a material object for an agent. "Under" fills the bill, and makes the Greek happier.

³⁵ KINESIS. Remembering the essentially transitive nature of the verb of which this is the abstraction, I rendered it with this hyphenation. The English word "movement," though seemingly an obvious choice, is not at all causative of motion, but is the motion itself.

³⁶ Having never met a person for whom "steelyard" was in regular use or comprehension, it seemed just as well to keep the Greek word, the more so for another concept: the *sarissa*, the extra long spear of Alexander's phalanx had the long free end, the pointed one, counterbalanced. The counterweight made it possible for the soldiers to have the business end far out in front of them. This technological advance, making use of the material expressed in this work, was the A-bomb of its time, a weapon with which to conquer the world.

center³⁷ of the phalanx. One side holds the pan; the other instead of a pan has a ball, which is set in the beam, as if one were to put another pan and the standard weight at the end of the arm, for it is clear that it balances such weight as lies on the other pan.

Resultantly the one balance becomes many balances, as many as this kind of balance has strings set on it, at each of which this side and the side toward the ball are half of the phalanx. The standard weight is through the equality of them, each of the other, [arrived at] through the strings being moved. Measuring how much weight the load in the pan balances is knowing, when the phalanx has become perpendicular, whatever string it hangs from, that's the weight in the pan, as has been said.

On the whole, it is a balance with one pan, the pan in which the object is weighed, and with, on the other side, the standard measure on the phalanx. The phalanx is a ball at the other end. And being like this, it is many balances, as many as it has strings. Always, the string nearer to the pan — and nearer to the object being weighed — hauls [the balance point of] a greater weight³⁸ because of the entire phalanx essentially being a suspended lever. Its counterpart to the fulcrum is the string from above; its counterpart to the weight is the load on the pan.³⁹

The farther the length of the lever from the center, the easier things are to move there. There it makes a standard weight, and the weight of the phalanx toward the ball balances.

PROBLEM 21

Why do doctors pull out teeth more easily even adding weight — that of the tooth-puller — than with the bare hand? Is it because the tool slips out of the hand more than out of the tooth-puller? Or rather does steel slip more readily than flesh, and not grasp around encircling it, for the flesh of the fingers is soft and fits itself with gripping. Is it in-

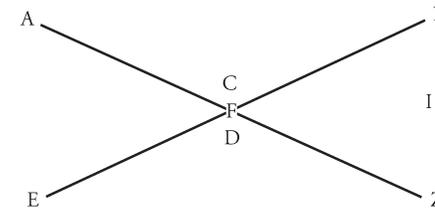
³⁷ Center of gravity of the meat and phalanx combined.

³⁸ *I.e.*, the closer the set-up is suspended to the pan, the more the phalanx sticks out to counter-balance.

³⁹ It is apparent that two drafts of the same paragraph have been both installed in the text. This paragraph is a better expression of the same thing as was covered in the one immediately above it.

stead because the tooth-puller is two opposed levers with one fulcrum, [namely] the connection of the tongs? So for easier loosening, they use this tool for extractions.

Let one end of the tooth-puller be A the other, which pulls out, B. Let one lever be ADZ, the other BCE, and let the fulcrum be CFD. Let the tooth (corresponding to the weight) be at the touch together I. So he grips and loosens with B and Z each, and will then pull it out easily with either the hand or the tool.



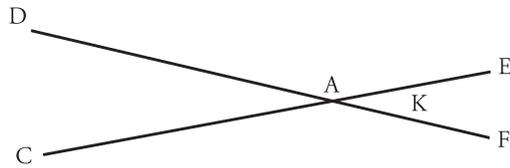
PROBLEM 22

How do they crack nuts easily, without even hitting, in the tools which they make for cracking them?⁴⁰ For the great force of the conveying and of violence is removed. And still, wouldn't someone pressing with the hard and the heavy crack it quicker than with a tool light and wooden?

Is it because in this way, the nut is squeezed by two levers, and weights are easily shifted by a lever? For the tool consists of two levers, having the same fulcrum, the rivet A. So if ends EF have been opened out by moving ends DC, the EF ends are easily brought together with little force. EC and DF, being levers, as much force as, or more force than, a weight makes in a hit.

They grasp with the opposite end, and squeeze until they crack it at K. The closer K is to A, the quicker it is cracked, since the farther the lever stands off from the fulcrum the easier and the more it moves with the same force.

⁴⁰ The circumlocution is curious: if there is a standard Greek word for nut-cracker, we do not learn it from Aristotle's discussion of it. It is "the tool they make for cracking," and then "the tool."



So A is the fulcrum, and DAF is a lever, and so is CAE. The closer K is to the angle at A, the closer it is to the rivet A. This is the fulcrum. Therefore of necessity it grips more from the same force. Therefore when the lifting is opposite to this, it must squeeze more, and what is squeezed more cracks faster.

PROBLEM 23

Why, when both terminal points of a parallelogram carry two vectors, don't they go an equal straight line, but instead one goes many times the other? It is the same story as to ask why does the point swept along the side go less than the side?

For the point generating the diagonal is carried two vectors, but the line going the side is carried one.

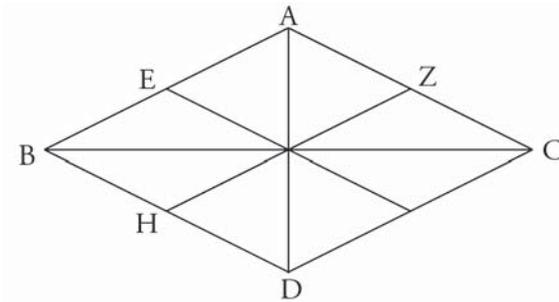
Let point A go to B on AB and at the same speed let point B go to D. At the same speed as these, let line AB go up to CD along AC.

Necessarily, point A is carried on the diagonal AD and point B is carried on BC, and each has been carried simultaneously with the side AB along AC. For let point A be carried the line AE and let the line AB be carried as far as AZ. Let the line ZH be extended parallel to AB and let it be filled in from point E.

This resultant parallelogram is similar to the larger one: line AZ equals AE as point A has been carried on AE. Line AB would have been carried to AZ. It will be on the diagonal at point G.

And always, of necessity, it will be carried on the diagonal. Side AB will go along the side AC simultaneously as point A will go the diagonal AD. Similarly point B will be seen to have been carried on the diagonal BC since BE = BH.

When filled in from H, the figure inside is similar to the whole, and point B will be on the diagonal at the connection of the sides.



The side will be carried to side in the same time as point A will be carried the diagonal BC. B will go many times line AB at the same time as the side will be carried a lesser length, being carried at the same speed, and the side, being carried on one vector, has gone more than A.

For the sharper the rhombus, the less the one diagonal, the greater the other, and the side is less than BC

For it is absurd, as has been said, for the point carried two vectors sometimes to be shorter than the one carried a single vector, and, given two points at equal speed, for one to be carried more than the other.

The cause is this: Both vectors (a) the one it is carried, and (b) the side under which it is subcarried, of the point carried from the obtuse, are practically opposite. But of the point from the acute, both are carried towards the same, as the side helps give a tailwind⁴¹ to the diagonal.

The sharper one makes the angle, and the more obtuse, the more one will be slower and the other faster: because of the obtuseness, one pair will be more opposite, and the other pair will be the more driven together toward the same. B is essentially carried the same direction down each vector. One tailwinds the other, and the more so the sharper the angle.

Just the opposite with point A. It is itself carried to point B, but the side sub-carries it toward D. The more obtuse the angle, the more

⁴¹ This metaphor is inherent in the verb SYNEPOYRIZEI, and it seemed best the reader know it was there, rather than to render with more formal but less picturing words.

nearly opposite the vectors become: the figure approximates a line. If the figure became altogether a line, the vectors would be altogether opposite. But the side getting carried along a vector is impeded by nothing — quite reasonably then it goes a longer line.

PROBLEM 24

It is confusing why the larger circle describes a line equal to a smaller circle's when they have been put on the same center. Rolled separately, size to size is line to line. Yet given one center for the two, sometimes the line is like what the lesser circle would describe by itself, sometimes like the larger. Yet it is obvious the larger circle rolls out a larger line.

It is obvious that the bigger circle rolls out a bigger line, as the angle of the bigger circle at perimeter and diameter, is perceptibly bigger, and the angle of the smaller circle is smaller. Therefore the lines they roll out perceptibly have the same ratio.

Yet they clearly roll out an equal line when they lie on the same center. And thus it happens that sometimes it is equal to the line the large circle rolls out, sometimes to the smaller.

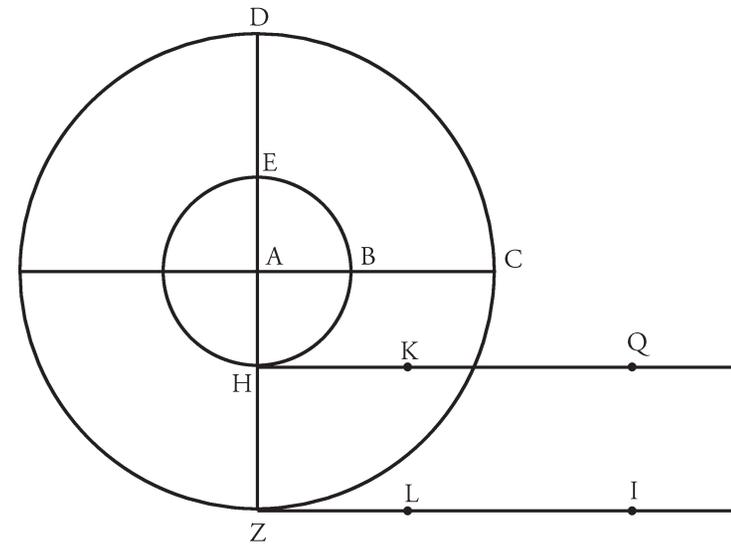
Let the large circle be DZC , and the lesser one EHB , and A be center for both. Let the line the larger rolls out by itself be ZI , while the lesser by itself rolls out HK , equal to ZL .

If I move the lesser circle I move the same center A . But let the large circle be fixed to it. Then when AB becomes perpendicular to HK also AC becomes perpendicular to ZL .

Therefore it will always have gone an equal line, HK , on which the periphery HB [has rolled], and ZL , on which periphery ZC . And if the fourth part has rolled out an equal line, it is clear that the whole circle will roll a line equal to the whole circle, so that when line BH goes to K , periphery ZC will be on ZL as the entire assembly has rolled.

Similarly, if I move the large circle, having affixed the small one, both on the same center, AB will be vertical and perpendicular at the same time as AC , one to ZI , the other to HQ .

Therefore when the one [AC] has gone an extent equal to HQ and the other an amount equal to ZI , ZA will again be perpendicular to



ZI ⁴² and AH ⁴³ will again be perpendicular, as at the start, but at points Q and I , there having been no stop or standing in place, the large vis-a-vis the small, at any time, for they were both moved constantly with each other.

It is absurd, with the smaller one not leaping any point, for the larger to have gone out an equal extent to the smaller and the smaller and equal extent to the greater. Further, it is marvelous that, with always but one moving force, the center getting moved sometimes rolls out like the large circle, sometimes like the small one. For the thing getting moved at the same speed inherently goes an equal line. And at the same speed it is possible to move it equally either way.

As for the cause of this, the principle to be taken is that the same or equal power [DYNAMIS] moves one mass slower, another faster.

If there be an object not inherently moved by itself, if this moves that which is inherently moved, it will get moved more slowly than if

⁴² Corrected here from the ZL of Bekker.

⁴³ Corrected here from the AC of Bekker.

alone it were moved by itself. And if it is inherently moved, and nothing gets moved with it, it will come out the same way. It is in fact impossible for an object to get moved more than what is moving it,⁴⁴ because it is not getting moved the extent of its own motive force, but the extent of the motive force of what is moving it.

Let there be a circle A and one smaller, B. If the smaller pushes the larger, without it rolling,⁴⁵ it is clear that it goes a straight line just as far as it can be pushed by the lesser, and it was pushed as far as the smaller was moved — they have gone an equal line.

Necessarily also, if the lesser pushes the larger while rolling, it is rolled together with the push, only as much as the lesser is rolled it if it is moved to no extent with its own movement.⁴⁶

So far as the one moves, just so far, necessarily, is moved the one moved by it.

But the circle has moved the same extent—say—a foot, and the large has therefore been moved that much.

Similarly if the large circle moves the small one, the small circle will get moved as the larger; whichever one of them gets moved by itself, fast or slow, it goes such a line as the greater one inherently rolls out.⁴⁷

There is where the difficulty lies, because they no longer behave as when they were affixed to each other. *I.e.*, if one gets moved by the other, not its inherent or its own motion. Whether you surround one with another or affix one to the other or set on the other makes no difference at all. It's the same: when one moves and the other is moved by it, so far as one moves, just so far the other gets moved.

Whenever somebody moves a circle leaning on another or leaned on, one doesn't always roll it. But when he affixes it to the same center, it is necessary that the one is continuously being rolled by the other. But the second is moved nothing less, not its own motion, but as if it

⁴⁴ A promising statement we might classify as “conservation of energy” trails off into a denial of inertia.

⁴⁵ A requirement outlawing inertia: the moved ball is forbidden to keep rolling once the motive force stops. Some thought experiments prevent further thought!

⁴⁶ “its own movement:” this would seem to be inertia.

⁴⁷ A repetition of the preceding clause, yet elliptical omitting but implying “[the smaller will always roll out] exactly . . .”

had no motion. And if it has, but does not use [its own motion] the same thing happens.

So when the big circle moves an attached smaller one, the smaller circle gets moved the same. But when the smaller circle moves, again the big one gets moved the same. Separated, each one moves itself.⁴⁸

Someone philosophizing over this would err to say that with the same center and the same speed they roll out an line unequally. There *is* the same center for each, but incidentally, like “related to the Muses,” and “colored white.” Thought there's the same center, they don't *use* the same center: when the small circle is the mover, then the center and origin are its. So the same center doesn't move simply, but relatively.⁴⁹

PROBLEM 25⁵⁰

Why do they make beds the way they do, sides two-to-one — one side six feet and little more, the other three? And why don't they web them on the diagonal? As for the shape, it is for symmetry with the body, roughly two-to-one, four cubits in length, two in width. And they web it not on the diagonal, but criss-cross so the wood is less pulled through.

It splits most quickly being pulled through along the grain, and suffers more being pulled.

Further, when the webbing has to be able to bear weight, this way, when the weight is put on,⁵¹ it will suffer less at the holes for the strings than edgewise.

⁴⁸ Thus the text. One expects it to say — or mean — “each one rolls out its own perimeter.” Perhaps the <AUTON [reflexive pronoun, αὐτόν] was originally <AUTHN [“its own line”]. Or perhaps in the neighborhood of the <AUTON, the <AUTHN was omitted from the text.

⁴⁹ The Greek word here rendered “relatively” is <OS (ὥς), the adverb from the relative pronoun, whose identity depends on its antecedent.

⁵⁰ This problem is an attempt which didn't work, definitely the sort that an author who oversaw the publication of his own work would have suppressed. Even more than in the third figure of PROBLEM 1, where a rectangle is drawn which is never used, we have here developed material which is abandoned in the leaping conclusion, and a drawing which should have been done but was not.

⁵¹ Another instance of the author's appreciation of vectors or lines of force.

Further, this way it costs less cord.⁵²

Let there be a bed, AZHI and let ZH be taken in half at B.

Same number of holes in ZB and in ZA.

Sides ZB and ZA are equal, since the whole, ZH, was double.

They web as was noted, from A to B, then to C then to D then to Q, then to E, and so on until they turn another corner, as the two corners have the ends of the cord.

The cords are equal through the turns:

$AB + BC = CD + DQ$, and others likewise, with the same demonstration:

$AB = EQ$,

for the sides of the area BHKA are equal and the holes stand equal.

$BH = KA$,

for the angle B = the angle H,

for they are in equals, one inside, one outside.

And angle B is half of a right angle,

for $ZB = ZA$.

And the angle at Z is right, for the opposite sides were double and halved.

Therefore $AC = EH = KQ$, for they are parallel.

Therefore $BC = KQ$.

Similarly it can be shown that the others are equal through the turns, twos to twos.

Therefore it is clear that there are four such cords as AB in the bed,⁵³ and as many as the number of holes in side ZH, and half that in the half ZB.

Therefore in the half bed there are such lengths of cord as are in BA and the number of them equals the number of holes in BH. That is the same thing as saying as in AZ so in BZ, the pair together.

⁵² The first webbing described, criss-cross, involves the square root of 2, the second, based on the diagonal, involves the square root of 5.

⁵³ The geometry is fine through to this point. He has demonstrated that the cords starting in one long side and ending in the other are all equal to each other, but has done nothing about cords that go from side to end.

But if the cords were set along the diagonal as in bed ABCD,⁵⁴ the halves are not such as the two sides, AZ, ZH. The equals will be as the number of holes in ZB, ZA.⁵⁵ And the ZB and ZA, being two, are greater than AB.⁵⁶

Therefore also the cord is as much greater as both sides are greater than the diagonal.⁵⁷

PROBLEM 26

Why, given that the weight is the same in each case, is it more difficult to carry long boards at the end on one's shoulder than by the middle? Is it because the end, once it starts wobbling, prevents carrying? In fact, works against carrying?⁵⁸

But even if it flexes not at all and has not much length, it is harder to carry by the end anyway. Yet it is easier to lift from the end than

⁵⁴ If A. had even drawn out this bed, he would have seen something remarkable. Rewebbing a bed with all evenly spaced holes diagonally is not an option! Try it. Keep the holes the same as in bed No. 1, put in the first string on the diagonal, the next string through the next two holes, the third string through the one remaining end hole, and the three remaining holes on the long side have nowhere to go to! To use all the holes in the long sides would require doubling the number of holes in the short sides, *i.e.* twice the hole-spacing of the long sides, probably the real and practical reason.

⁵⁵ In a diagonal webbing, the number of holes in the ends must equal, not the number of holes in half the length, but the number of holes in the full length. Thus this sentence becomes comprehensible if the text were to be corrected to read "The equals will be as the number of holes in AD, AB [in the new bed]. But this simply shifts the nonsense to the next sentence, which is more satisfactory without the change.

⁵⁶ This expression and the one immediately following are a plain demonstration that the author cannot yet conceive of using the radical as a unit.

⁵⁷ *I.e.*, as $(1+2/\sqrt{5})$ is greater than $(1+1/\sqrt{2})$. Not exact. It would use more string as $\sqrt{5}$ is to $\sqrt{2}$, simply. As for the question of authorship, this geometry leaves one aching for the clean and polished style of Aristarchus, and makes several eliminations possible: the author is not Archimedes, not Aristarchus, and not Euclid, though the problem here is as almost as gappy and unsatisfying as one or two in Archimedes, *e.g.*, *Measurement of the Circle*, No. 3.

⁵⁸ Here we see the basic meaning of PHORA, the word which in other contexts A. uses where we would use inertia, vector, or trajectory or impetus: a person shouldering a burden and carrying it.

from the middle, but the reason is that, when it is raised from the middle, the ends always lighten each other, and the part on one side lifts the part on the other.

Therefore, the middle is essentially a center, where it has the lift of the carry. Each side lightens towards “up” the slope towards “down.”

But being lifted or carried from the end, it doesn’t do that. Instead, the whole weight of it tilts on one middle, towards which it is lifted or carried.



Let the middle be A, ends B, C. When lifted or carried at A, the B down-tilt lifts the C up, and correspondingly the C down-tilt lifts the B up. The ends do this simultaneously on being lifted up.

PROBLEM 27

Why, given two burdens of equal weight, is the one too long harder to carry on the shoulder — even if one carries it at the middle — than if it were shorter? It was said long ago that wobble was not the cause, but in this case, it is. When the burden is too long, the ends wobble: Result: it becomes rather more difficult for the carrier to continue carrying.

The cause of the wobble? Given the same moving force, the longer the board, the more the ends change position.

The shoulder is the center A, as it is at rest [relative to the burden] and AB and AC the lines from center. The longer AB and AC extend from the center, the greater the size of the motion. This was demonstrated earlier.

PROBLEM 28

Why at water wells do they make shadoofs as they do? For they ADD WEIGHT of lead on the beam, the bucket already being one weight, whether empty or full. Is it because the hauling work is done at two times, once dipping, once drawing up? Letting down empty is easy, but pulling up full is hard? Letting down a bit slower is more

than made up for by easing the drawing up. So they affix either lead or rock. For the operator, the weight is heavier than if letting down only the empty bucket, but when it is full, the lead — or whatever the added weight is, draws it up. So the two together are easier this way than that.

PROBLEM 29

Why, when two men carry an equal weight on a board or some such, do they not labor the same unless the weight be at the middle, but it is more work for the one of the carriers who is closer? Is it because the board becomes a lever, the weight a fulcrum, the carrier near to the burden becomes the weight being moved, the other becomes the mover?

For the farther he is from the weight, the easier he moves it. And he more burdens the other, as if the resting weight resisted and became a fulcrum. But with the weight resting in the middle, the one does not add burden to the other, nor move him, but each becomes a like weight for the other.

PROBLEM 30

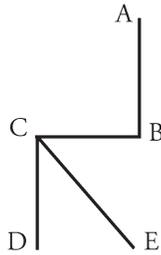
Why, standing up, do we all first make an acute angle with calf and thigh, and with thigh and torso, and if we don’t we cannot arise? Is it because the equal balance⁵⁹ is everywhere a cause of rest? And the right angle is made of the equal, and makes stasis? So [the person getting up] is carried towards⁶⁰ like angles with the surface of the earth. He won’t just *be* perpendicular to the ground: in the act of rising, he *approaches* the vertical. Only when the act of standing is complete is he vertical to the ground. So if one is going to get vertical, this is to have the head and the feet in line and to become as one is when standing,

⁵⁹ A substantized adjective, “the equal.”

⁶⁰ Two points: here the verb of movement is the middle-passive of PHEREIN, just like the verb of carrying the burden on the shoulder in PROBLEM 27. The contrast of this sentence with the next is the *process* of the movement — in the progressive of PHERETAI — with the *state* of its completion in the future ESTAI. Not to see this is to have the next clause be the contradiction of this one, as in the prior translators. This becomes the more plain when one gets to the perfect participle — with its aspect of present state from completed past action — <ESTOTA.

But when you are seated, you have the head and the feet parallel and not on one line.

Let the head be A, the torso AB, thigh BC, calf CD.



For one seated like this, the torso becomes in effect, at a right angle to the thigh and the thigh to the calf, and getting up is impossible. You have to slope in the calf and get the feet under your head. *I.e.*, shift CD to CE, an acute angle, and at once, you have the feet and head on the same vertical, and you can get up.

PROBLEM 31

Why is it easier to move something moving than something at rest? As for instance, they pull wagons faster moving than starting. Because it is most difficult to move a weight which is moving the opposite way? For some of the mover's power is taken away even if it is going much faster, for it is necessary for the thrust of the one pushing against to become slower. Less if it is still. An object resists even if still. But the object moving in the same direction does the same thing as if one were to increase the power and the speed of the mover, for what occurs in this case is the same thing as happens to the object already moving forward down the road.

PROBLEM 32

Why do objects thrown stop? Is it because the projective force leaves off? Counter-pull? Slope, if it be greater than the throwing force? Or is it foolish to mull such an impasse, absent the principle?

PROBLEM 33

Why does anything get carried its own course when the propulsion does not follow along and keep pushing? Perhaps it is clear that the first has done such as to push another, and that another, but it stops when what is propelling the carried object is no longer able to push, and when the weight of the object being carried slopes more than the forward force of the pushing.

PROBLEM 34⁶¹

Why, when thrown, do neither smaller nor larger objects go further, but always must have some symmetry to the one throwing? Is it because the thing thrown and propelled must resist the propelling? For neither the non-yielding through size nor the non-resisting through weakness make a throw or a propelling. The object much exceeding the propelling force yields not at all, and that much weaker [than the propelling force] is non-resistant. Or is it that the object being carried carries only into depth⁶² as far as it moves air? What is not being moved would move nothing. Both go together: the really large and the really small object are alike not moved. The one itself moves nothing; the other cannot be moved.

⁶¹ A good example of words limiting as well as enabling thought, PROBLEM 34 exhibits a handicap that Greek imposed upon what we now call "Classical Physics." Our English verb "move" is indifferently transitive or intransitive:

I move the chesspiece

The air moves.

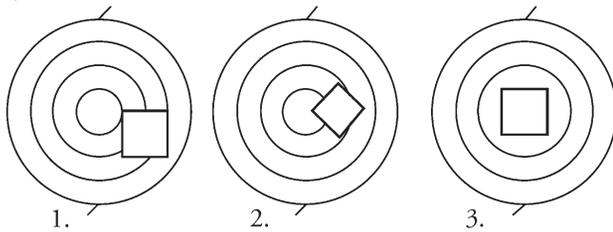
The Greek word KINEIN is transitive only. I move the chesspiece or the chesspiece is moved by me, exclusively. An object moving or in motion (intransitive) is passive in Greek: *to pheromenon*, the thing being {borne, conveyed, carried}. The language thus pictures — and enforces — the concept of continued motion only occurring through continued application of force. This is an idea difficult enough to escape, and still infects us, as in both generations of Star Trek, where deceleration is always a matter of reducing power!

⁶² This prepositional phrase shows we have here the Aristotle who, on the subject of motion, is very concerned with the medium.

PROBLEM 35⁶³

Why in eddying water does everything end up getting carried into the middle? Is it because the object being carried has some size, and is in two circles, one lesser, one greater, at each of its ends? The bigger circle, because it is going faster, pulls the object around, and this pushes it into the lesser. Since the object has some breadth, this too does the same thing, and pushes inward until it goes to the middle, where it stays, having the same relationship to all the circles, for the center is equidistant from all the circles.

Or perhaps whatever the force of the eddying stream can't master because of size, and excels with weight the speed of the water, has to be left behind, and go slower. But the lesser circle is going slower, since the big circle rotates the same in equal time as the small one. Thus the object has to be left in the lesser circle until it gets to the middle.



Whatever object the force of the eddying stream does master, ends up doing the same thing, for each successive circle must overpower it with its speed; each circle will continually leave it more inward.

The object not overmastered must move inward or outward: it is impossible for such object to be carried in the circle where it is, still less

⁶³ This problem approximates a standard format of a geometrical proof:

- I. Either the proposition is true or it is false.
- II. If true, we need go no further.
- III. If false, it either (a) goes too far, or (b) it falls short.
- IV. (a) leads to an absurdity.
- V. (b) leads to an absurdity.
- VI. Therefore the proposition is correct.

in the outer, for the current of the outer circle is faster. It remains for the object not overpowered to switch to the inward.

Each thing always shifts towards the not being overpowered. Since arriving at the middle makes the boundary of not being overpowered, it comes to rest there only, at the center, where everything must collect.⁶⁴

⁶⁴ The conservation of angular momentum means that the inner circles are actually moving faster than the outer circles; the reader may confirm this by stirring a tumbler of water and dropping dye into the whirlpool. The whirlpool makes a cone, and the floating objects fall down into the center of it. But small objects that sink do in fact collect at the center of your tumbler, where they simply are not disturbed any more. There are two different reasons at top and bottom. The author appears to have the correct explanation at the bottom of the tumbler.