The Origins and Growth of the Physical Science I

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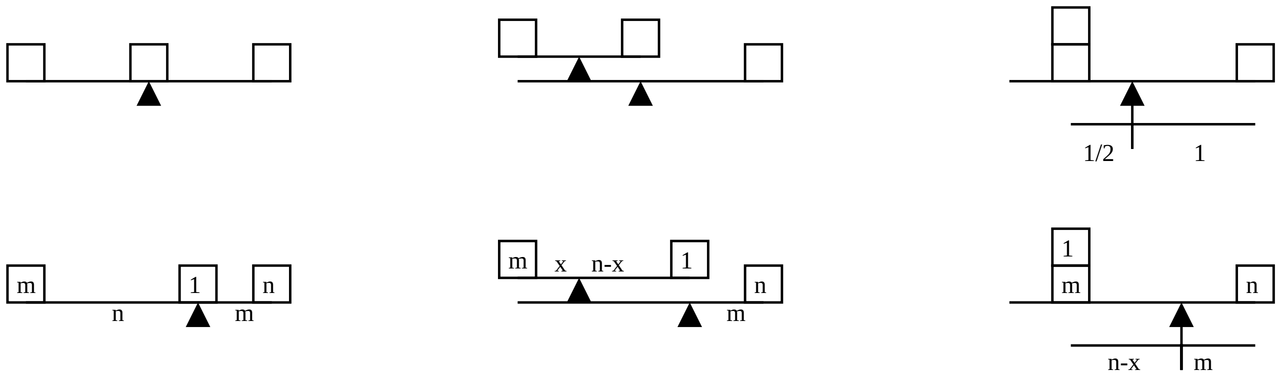
This is an anthology of fragments of scientific writing from Aristotle to Lavoisier, accompanied by short commentaries by the editors. It is the first volume of two, published in two blue Pelicans stemming from the 1960's and which I found in my library, possibly originally acquired by my father. Following my ambition of systematic sampling of all the unread and forgotten books to be found on my shelves I decided to dip into.

The book starts with some homilies on the nature of science, emphasizing its empirical aspects, supposedly absent among the speculating Greek, not to mention the Medieval scholastic thinkers. However they have the sense to admit that the methodology of Francis Bacon is a bit too simplistic, it is not so easy to rely on observation alone, Nature is not a book which is easy to read. In fact Bacon implicitly assumes, I would say, that there is some universal pattern which observation specifies and allows us to read (to put it crudely, observation allows us to specify the parameters in a universal scheme). Instead we have to come up with *ad hoc* patterns all the time, that is what meant by forming hypotheses and theories, which then can be checked with observations. Creativity in science consists in coming up with explanatory theories.

Aristotle starts out on cosmology, which, considering his great width of his study, unmatched by any scientist before or after, is hardly representative and does him slight justice. More interesting is the contribution by Archimedes and how he can from some very simple principles, in the spirit of Euclid's elements derive the condition of equilibrium of a lever. More precisely given weights A, B with distances a, b respectively from the fulcrum, equilibrium holds iff $Ab = Ba$ or to put it differently, given two point masses there center of gravity is positioned on the line segment drawn between the points with the proportions thus distributed. The axioms are that 1a) equilibrium occurs in the case $A = B$ exactly when $a = b$ 1b) or A, B arbitrary and $a = b = 0$. and 2) that two point masses can be replaced by a point mass centered at the center of gravity and with mass the sum of the two masses. From those two principles we see that three masses A, B, A are in equilibrium of they are equally distanced with B in the middle and placed on the fulcrum (as the extreme weights can be replaced by the double weight centered on the fulcrum and as in this case $a = b = 0$). To see how the argument works, set $B = A$ and normalize the distances to $a = b = 1$ look at the two left masses, which can be replaced by $2A$ with $a = \frac{1}{2}$ and hence $b = 1$. This can be stepped up to any fraction, and thus we are done when the weights A, B are commensurable. Then Archimedes adds a simple but rigorous limiting argument for the general case.

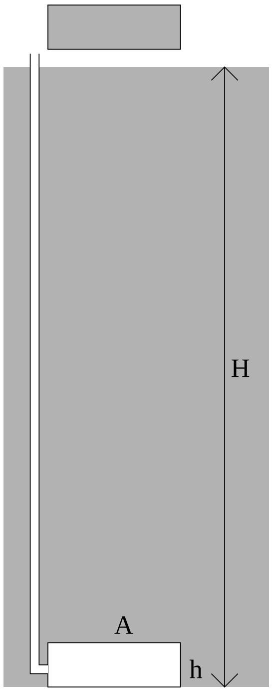


Assume that the condition has been proved for m, n (and fractions with smaller numerators and denominators) we can replace the weights of mass m and 1 by a mass of $m+1$ situated at position x that satisfies $mx = (n-x)$ by the inductive hypothesis. Solving for x we get $x = \frac{n}{m+1}$ thus $n - x = n(1 - \frac{1}{m+1})$ and hence we check $(m+1)(n(1-\frac{1}{m+1}) = mn$ and we are done. (In order to fix m and raise n by one, we simply combine the masses n and 1).

The measuring of the circumference of the Earth by Eratosthenes is too well-known to be dwelt upon, suffices it to say that Erathostenes measures the distance between two points (Alexandria and Siene) one in terms of intrinsic units (degrees of arcs) and one in terms of terrestrial units (stades). The first is easy based on two simple observations (angles of rays) and geometry, the other far more involved.

Those two fragments stand out as they are in a sense the most modern and accessible, the arguments clear and logical as opposed to rhetorical. The worst writings are by those of the Medieval alchemists, which are almost incomprehensible, even those by the foremost 18th century chemists Black, Priestley, Scheele, Cavendish and Lavoisier are hard to make sense of, due to the fact that they are descriptive with no indication of why that and that experiment is fashioned in that and that way. If one did not know that there is such a gas as oxygen, and that was not known to the pioneers, many of the phenomena described would not be understandable. One does infer though that they correctly deduced that this mysterious air in which things burn so brightly make up a fifth of ordinary air, the remaining not fit for respiration. Priestley notes that the gas could be breathed by humans (although he cautiously applies it only to mice) but that it would probably shorten life, as life would be lived at an increased rate. The great contribution by Lavoisier is that he gave the modern explanation of combustion doing away with the notion of phlogiston going back to the late 17th century by Stahl (who also gets to contribute on that issue). Instead of phlogiston being removed from a substance, oxygen was added. Thus doing away with the negative mass of the hypothesized phlogiston.

The contribution by Boyle is intermediate between the mathematical reasoning of Archimedes and Erathostenes and the descriptions of the chemists. Boyle's law is very simple, but to establish it not entirely trivial but requiring some ingeniously set up apparatus. Pascal on pressure on the other hand, descriptive in execution, yet clear and very pedagogical. As one example he discusses the problem of opening up a bellow submerged at the bottom of a tank. To do so means that you have to displace a certain volume of water equal to the achieved volume of the bellow. But what does that water go? It can only go to the top, thus its center of gravity has to been lifted from the bottom of the tank to the surface. (Whether it is the 'same' water that gets lifted is of no consequence, you need only to compare the position of the center of gravity before and after) . If you differentiate you see that the force needed is actually the force of the gravitation on weight of the water above the bellow, in other words the total pressure.



Consider a disc of area A lifted up a distance of h thus deplacing a volume of water with mass $Ah\rho$ a vertical distance of H. The work done is given by Fh where F is the force that the water exerts on the disc (i.e. Ap where p is the pressure). We thus get $(Ah\rho)Hg = Fh$, or $F = AH\rho g$ (and the pressure p given by $p = H\rho g$ where g is the gravitational constant. To this we should also add the pressure exerted by the atmosphere above, but if we let the bellow be connected to a hose reaching above the water, air will freely enter into the hollow and the atmospheric pressure can be disregarded. But if the water also would have free access to the bellow, the water pressure could also be removed, as water now can be displaced locally. We also note that it does not matter in what direction we move, the pressure is the same only depending on the height of the water. Also the famous experiments of bursting a barrel can be similarly explained. This means enclosing the water and adding a tall narrow tube. The overall pressure in the barrel will depend on the height of that tube, and thus an arbitrarily small volume of water (or other liquid) can effect any given increase in pressure. The principle is the same. The displayed water has to go somewhere, and the only possibility is the top of the tube

Those contributions, unlike most of them, induces fruitful ideas to the reader, which he or she could develop further as we have just done. The chemical fragments do not in the same way introduce suggestions that you can develop at the desk but would need an apparatus. But one suggestion they do provide is the following. Let a burning candle float on some liquid, preferably water (the old chemists seemed to have preferred mercury) then cap it by some flask and let the candle burn out. What will happen to the water? Will some of it seep into the flask, and if so how much? The idea being that some of the air is consumed by the flame. Then the pressure of the air inside would diminish, but as the pressure of the liquid is constant through the process (namely that one given by the atmospheric pressure) it stands to reason that it would seep into the flask and rise to such a height as to reduce the volume of the gas proportionality in accordance with Boyle's law.

Now the contributions from Copernicus, Kepler, Halley and the first one by Galileo are essentially descriptive. And so is of course that by Brahe on the new star, although he does give an argument to show that the phenomenon, like that of comets were not sub-lunar. Galileo's dialogue is of course entertaining, and it is noteworthy that the one argument that goes against the Earth being fixed, is that it seems unlikely that all celestial objects would rotate at such a high speed, because their distance to the Earth was known to dwarf terrestrial measures. Newton on the other hand, as his contribution illustrates, argues that rotation is intrinsic because of centripetal forces which can be observed on a rotating bucket containing water, and as to the Earth it does exhibit a pronounced bulge. (Then of course what about Focault's pendulum? Does that not provide tangible proof?)

Finally Galileo's description of reinventing the telescope, improving on it as to effect a magnification of thirty times is indeed fascinating. He directed it at the Moon and could observe the shadows at the border between the dark and the light, a border which is highly irregular, and even disconnected, as he can see on the dark side bright spots, which increase in area until they join the lighted part. His interpretation of those observations is of course correct. The Moon, as does the Earth, does not present a smooth polished surface, but has mountains and valleys, just like the Earth, and is hence not a perfect body, but an irregular rock in space. He also discovers the four satellites to Jupiter, which he first takes as stars, and it takes a sequence of observations to convince him that it is not Jupiter which passes across stars until now never observed, but that the stars revolve, like satellites around Jupiter itself, thus the Earth is not the only body in the universe which has bodies moving around it. Although not a proof, this was a strong case for Copernicus, strongly suggesting a new mindset with which to interpret cosmos. It is well-known that the men of the church, who were no fools, refused to look through the telescope.

`July 14-15, 2020` **Ulf Persson:** *Prof.em, Chalmers U.of Tech., Göteborg Sweden* ulfp@chalmers.se