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Research Article

From Water to the Stars: A Reinterpretation of Galileo's Style*

Louis Caruana SJ

Faculty of Philosophy, Pontificia Università Gregoriana, 00187 Rome, Italy
E-mail: caruana@unigre.it

Abstract. Galileo Galilei's contribution during the early stages of the scientific revolution and his clash with the Catholic Church have been discussed, studied, and written about for many decades. There are indications however that recent work in this area has tended to underestimate the fact that Galileo had a particular style. By style here I mean a particular combination of behavioural features that are specific to a person or a historical period. Style of course can be related to behaviour in general, but what is relevant in this paper is the combination of dispositions that determine a particular way of engaging in science, as discussed by scholars like A.C. Crombie.[1] Galileo, I will argue, had a scientific style marked by overconfidence. He tended to downplay the importance of obvious contradictory evidence that undermined his claims, and he did this by producing auxiliary hypotheses that sometimes verged on the extravagant. If we focus on this somewhat neglected aspect of his style, some interesting new questions emerge: To what extent did Galileo depend on such auxiliary hypotheses? How insecure did they render his position? And how *ad hoc* were they? In this paper, I explore these questions by comparing two important debates: one about the nature of water and buoyancy, the other about cosmology. Since the main features of the cosmology debate, the one involving Galileo's defence of heliocentrism, are well known, I will dedicate more time to the water debate, before proceeding to highlight the elements of style that are common to both debates, and to evaluate the relevance of these elements for current understanding of scientific practice.

Keywords. Galileo, auxiliary hypotheses, ice, buoyancy

1. THE BUOYANCY DEBATE

First, a word about Galileo's social and cultural situation. The way empirical inquiry used to be motivated and propagated at that time, when what we now call the scientific revolution was at its infancy, differed considerably from the way it is today. In that context, the driving force used to originate mainly not from scientific questioning as such but from what the major patrons of individual scholars regarded as marvels and curiosities, from what these patrons

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considered worthy of exciting debates and controversy. The question "Why does ice float on water?" was one clear example of an exciting question because we all know that ice is in fact nothing more than water. The overall social, political, and cultural context in the seventeenth century was such that science was dependent to a very large extent on what patrons wanted, and this meant that natural philosophers, or anyone we would now recognize as a scientist, could never be fully in control of their research. Patron-dependence was crucial: through financial support, it made the scientist's work possible. But it produced a number of difficulties as well, mainly because the general habitat for science, where science happened, was not the isolated laboratory but pubic disputation, and this mode of scientific practice usually drew attention not to careful and technical understanding but to quick, publicly accessible answers. Moreover, during the period when Galileo flourished, mathematics was still considered a discipline that was less important than Aristotelian philosophy within the overall hierarchy of knowledge. Galileo had to struggle hard against this mindset. The only way he could gain a hearing was to make himself philosophically versatile enough to engage with the Aristotelians on the same level.[2]

With this background in mind, we can now appreciate better the various forces at work during the debate that concerns us here, the one concerning water and buoyancy. This was launched in the summer of 1611, a session that took three days. It started with a dispute about the nature of cold as a quality, but then shifted into one about buoyancy. The major contention arose when the Aristotelians among those present were shocked to learn that, for Galileo, ice was not condensed water, as they had always assumed. They had to admit that the issue was not completely clear in the classic texts. Although Aristotle had indeed indicated that ice was condensed water, his reflections on this point were rather sketchy. For instance, in his *Metaphysics* he discussed the different senses in which the word "is" can be used, and the examples he offers include ice. He writes: "[the word] 'is' has [a] number of senses; for a thing 'is' a threshold because it is situated in a particular way, and 'to be a threshold' means to be situated in this particular way, and 'to be ice' means to be condensed in this particular way. Some things have their being defined in all these ways: by being partly mixed, partly blended, partly bound, partly condensed."[7,8] Aristotle here takes the idea that ice is condensed water as obvious. Why? We find no clear answer in Aristotle's own works, but his followers filled up the reasoning behind this in the following way. He must have started not from the fact that ice floats on water but from the fact that it is colder than water. Since ice is colder than water, it must be water minus something, minus some amount of heat, and this lack leads to a condensation. It is water with a deficiency, as it were, not with something extra. And as regards the question why ice floats, Aristotelians considered this fact as just one example of buoyancy in general. For them, buoyancy is a matter of shape only. It had nothing to do with density. On this issue, they were certainly following their master who had explained this point quite carefully. In his book *De Caelo*, he argued that shape matters because the determining factor in buoyancy is the difference that the various materials we consider show as regards penetrability. For instance, air is more penetrable than water, and water is more penetrable than earth. He adds: "the reason why broad things keep their place [e.g. a plank of wood afloat on water] is because they cover so wide a surface, and the greater quantity [i.e. the water] is less easily disrupted. Bodies of the opposite shape sink down because they occupy so little of the surface, which is therefore easily parted."[9] It is good for us to recall here that, in Galileo's times, Aristotelians used to feel obliged to defend Aristotle, be it on buoyancy or geocentrism, or any other issue, not only because his positions were justified, as indeed they thought they were, but also because they considered these various positions important individual bricks that held an entire worldview in place. For them, removing one brick could have devastating consequences that would destabilize the entire conceptual scheme.

What was Galileo's reaction to this? For him, Aristotelians were seeing the entire issue the wrong way round. They had started from the observation that ice is colder than water and had sidelined the fact that ice floats on water. What they should have done was to start from the fact that ice floats on water. For Galileo, since ice floats on water, it must be rarified water, not condensed water. And as regards buoyancy, Galileo resorted to another ancient source: Archimedes. While Aristotle had developed a shape-theory of buoyancy, Archimedes had developed a density-theory, according to which a thing in water experiences a buoyant force equal to the weight of water displaced. Galileo did not deny that shape matters. He conceded that the shape of a body affected the speed with which it sinks or rises, but was convinced that shape does not affect *whether* it sinks or rises.

Up to this point, the debate seemed well balanced. Both sides presented interesting insights, and both had a heavyweight from Ancient Greece as support. The decisive factor came when Galileo's main opponent, Lodovico delle Colombe, devised a simple but spectacular and decisive experiment. He did not want to resort to Aristotelian deductive reasoning or anything like that. He appealed instead to direct evidence, just like Galileo. He made all the participants gather round the demonstrating table and he showed them how a sphere of ebony, whose density is higher than that of water, sinks when placed on water, while a thin piece of the same material remains afloat even with some weights on it. So the determining factor was shape, not density – full stop.

Galileo must have been quite astounded by this, but he did not give up. He tried to come up with some way of explaining this experiment in his own terms. This was not easy at all, because according to his worldview there should not be any special effect at the surface of a liquid which does not arise elsewhere within liquid. In other words, his view of liquids ruled out what we now call surface tension. He took therefore another line of argument and tried to bring in the relevance of wetness, but this lead to no convincing conclusion. Since the dispute itself became noisy and inconclusive, the meeting was brought to a close, and the main protagonists left with the intention of producing a full written version of their position. Galileo, encouraged to proceed with this by his patron, Duke Cosimo II, took his task seriously, and produced his written text within a year. For him, maintaining the duke's favour was obviously important. We notice once again how science was dependent on patronage to an extent that is hard for us to accept today.

Galileo's written version, entitled *Discourse on Bodies in Water* and published in 1612, was based on Archimedes's classic work *On Floating Bodies*, which had emphasized hydrostatics. Archimedes had offered an account of buoyancy that had been intended to explain the situation once equilibrium is reached. In other words, he had described the state of affairs when a body is stationary and floating, or when it has sunk and lies at the bottom. He had said nothing about the *process* of rising to the surface or of sinking; his view had been limited to *statics* as opposed to *dynamics*. Galileo therefore saw a way of breaking new ground by delving into hydrodynamics. This was a risky business, because in claiming the right to give an account of motion, he was encroaching into the philosophers' domain – yet again. Resorting to the model of the lever, he wanted to explain the downward motion of a sinking body and the corresponding upward rise of the water surface, two motions with different speeds. And he did this by resorting to the model of a lever with different arm-lengths, a lever that makes a short swing on the short side and a quick swing on the long side. He adopts therefore a mechanical view of the world – and this was seriously at odds with the Aristotelian worldview, at least in two senses.

First of all, Aristotelians had always believed that each of the four elements had its own specific motion: for instance earthly bodies move down because they have heaviness, while fiery ones move up, because they have lightness. Heaviness and lightness were for them real attributes belonging to things according to their nature. Each object or material will therefore have its share of overall heaviness or lightness in proportion to its constitution from the elements. From these fundamental, elemental motions, therefore Aristotelians offered the explanation of all motion. As regards the specific case we are dealing with here, the case of sinking or floating, the shape of the body, they used to say, was not the determining factor but only a *causa per accidens*, an explanation of secondary importance. The floating object needs to be understood in terms of its own inherent constitution in terms of the elements, the proportion of which determines the object's intrinsic quantity of heaviness and of lightness. Galileo was dissociating himself entirely from this kind of explanation. He was proposing a worldview in which buoyancy was the result neither of an innate upward trend (lightness as an attribute) nor of an effect of shape. For him, it was the result of the body's downward motion being counterbalanced by a counterforce. The implication here was that bodies, be they predominantly earthy or predominantly fiery, have only one type of motion: downwards. The Aristotelians were not amused.

Secondly, the fact that water shows a kind of skin at its surface was perfectly in line with the Aristotelians' broad view of liquids in general. For them, water, being a continuum, has a tendency to preserve its cohesion and integrity, as their master had expressed quite clearly in his work *De Caelo*: "Since there are two factors, the force responsible for the downward motion of the heavy body and the disruption-resisting force of the continuous surface, there must be some ratio between the two. For in proportion as the force applied by the heavy thing towards disruption and division exceeds that which resides in the continuum, the quicker will it force its way down; only if the force of the heavy thing is the weaker, will it ride upon the surface."[10] On this issue, Galileo had a problem. For him, water was made up of corpuscles with no intrinsic difference between them. It did not matter whether these corpuscles were at the surface or within the interior of the liquid. This view therefore, as mentioned above, ruled out any idea of surface-tension. How could Galileo then account for the impressive demonstration of his opponent Delle Colombe? To account for the intriguing floating chip of ebony, he had no choice but to resort to an explanation that was considerably extravagant. He proposed that, as the chip is lowered onto the surface, the observable slight depression of the water surface as it floats makes the chip associate itself with a layer of air above it. In this way, the composite object, layer of air and layer of ebony, will have a specific weight less than that of water. Was he introducing, through the back door, some occult forces here, some "magnetic virtue of air" as his opponents were quick to remark? These are his words:

> *But if it [the ebony chip as it presses down onto the water surface] has already penetrated and is, by its nature, denser than water, then why does it not proceed to sink but stops and remains suspended within that small cavity that had been produced by its weight? I would say: because, as it moves down until its [upper] surface arrives at the water level, it loses a part of its own weight, and it then proceeds to lose the rest of its weight as well by descending deeper even below the water surface, which produces a ridge and a bank around it. It loses weight as it descends in such a way that it drags down to itself the air above it, by adherent contact. This air proceeds to fill up the cavity produced by the little water ridges, in such a way that, in this case, what really descends and is located in water is not just the ebony chip, or the iron chip, but the composite of ebony and air, from which there results a solid [solido]which does not exceed water in density as does ebony on its own, or gold on its own.*[11,12]

This is the best Galileo could come up with as he tried to reason things out from within his system. I think it is fair to say that, as an explanation, it looks farfetched and *ad hoc*. What it shows is a strong determination on his part to save his overall worldview at all costs. He was ready to go even that far.

So, all in all, we can say that debate on water and buoyancy that had started *viva voce* in 1611 and then dragged on in writing for more than four years had no clear winner.[13] As historians now recognize, one important thing we see in this debate is the emergence of a growing gap between two very different professional identities: on the one side, we have professional philosophers, the Aristotelians, whose principles are derived from acknowledged philosophers; on the other side, we have a specimen of a new species of intellectual, a mathematician-philosopher, who seemed to violate the disciplinary boundaries that had been well established and respected for hundreds of years.

2. COMPARING WITH THE ASTRONOMY DEBATE

Let us draw a quick comparison now between this debate and the one on the solar system. As is well known, the main story of the solar-system debate, in short, was this. With the use of the telescope, Galileo discovered new evidence in favour of the heliocentric view that had been promoted mathematically by Nicholas Copernicus about fifty years beforehand. Galileo therefore started to defend the idea that Copernicus's view was not a mere mathematical shortcut to obtain quick predictions of planetary positions, but was a true description of how things are. In the ensuing debate, which involved Aristotelians yet again, Galileo was challenged to explain some pretty glaring instances of counterevidence to his proposals. And this is the crucial point where this solar-system debate shows some remarkable similarity with the buoyancy debate. In both cases, Galileo had to deal with counterevidence that seemed obvious and convincing. In both cases, he made proposals that were unconventional and therefore somewhat suspicious.

Instead of going into all the intricate detail of the solar-system debate, let us consider the crucial points only. One obvious element of counterevidence for the proposal that the Earth is in motion is direct experience. We simply have no sensation of movement. In line with this, as common sense suggests, if the Earth were in motion, there should be some detectable displacement during the falling of an object, because, by the time the object hits the ground, the Earth would have moved a little. But nothing of the kind is observed. Here we have, therefore, a serious challenge to anyone who wants to argue that the Earth moves. For Galileo, however, this kind of argument was not the most worrying. He rose to this challenge in a spectacular way by establishing the basic principles of relativity. He proved that, for two reference frames in uniform motion, no such displacement should be expected.[14]

The real worrying element of counterevidence was the lack of stellar parallax. If the Earth were really in motion through space, then the nearby stars should show some displacement with respect to the distant stars. Our view of the night sky would be somewhat like what we see from a moving train: nearby trees shifting across the distant background. But no such effect is evident in the night sky. So again, Galileo had a problem. He tried to use his telescope, but it was all in vain.[15] The only way he could respond to this problem was to adopt what had already been suggested by some commentators before him, namely that the absence of stellar parallax was due to the fact that all stars were infinitely far out in space.[16,17] This suggestion, of course, did solve the problem. It was however *ad hoc* and embarrassing – embarrassing because it went against Galileo's own idea that Aristotle had made a mistake in assuming that there is an essential difference between the sub-lunar universe and the rest. For Galileo, the entire universe should be homogenous with a uniform distribution of stars throughout.

So here we see a clear common feature with the previous debate, a common stylistic feature involving the way science was engaged in. In both cases, Galileo faces an insurmountable problem but sticks to his guns; he does not shy away from defending himself by walking on stilts, as it were: by producing auxiliary hypotheses that, because of their *ad hoc* nature, apparently drain his position of its convincing power.

3. CONCLUSION

What conclusion can be drawn? There is of course much more that can be said about all the major points highlighted above. The little that has been mentioned however is enough to justify the following three points. First, we need to accept that the practice of science rarely involves clear-cut crucial experiments that decide an issue at one go. What has been highlighted in both debates confirms the idea, proposed by philosopher Imre Lakatos, that science does not develop according to naïve falsificationism but according to a more complex process involving auxiliary hypotheses.[18] These auxiliary hypotheses can have various degrees of plausibility or acceptability, depending on how they fit in with background beliefs that are shared by both the proponent and the opponent of the theory. The early stages of the new scientific paradigm inaugurated by Galileo were vulnerable. There was no knock-down argument on either side. It is true that, in both debates, Galileo's view did eventually turn out to be correct. At that time, however, his case had some obvious weaknesses, even on his own terms. Secondly, a few words about the Church. Although the way the Church handled Galileo during the solar-system debate remains an embarrassment, especially because of its official declaration that heliocentrism was heretical, which it certainly is not since it is not even theological, the arguments mentioned above can nevertheless help us understand why the case was so intriguing, and why some Aristotelians and theologians were not immediately won over by Galileo's arguments.[19,20] And finally, a word about Galileo's genius: as we know, time proved Galileo right in both debates. This shows that he was a man of genius: he had a way of seeing ahead, a way of seeing beyond what can be expressed by reasoned argument and experiment. We see him sometimes groping in the dark, especially in formulating auxiliary hypotheses, but in fact he was groping in the right direction.

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