# Newton's Bucket Experiment: Fictional or Real?[1]

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Abstract:
Newton's example of a revolving bucket filled with water is one of the most well-known experiments in the philosophy of physics. It is usually interpreted as an argument for the existence of absolute space. In this paper I challenge this interpretation. In line with recent literature, I explain that a target of the example is the inadequacy of Descartes's definition of motion. But I also a raise a serious problem for the current reading which comes from the attribution of "absolute and true circular motion" to the water revolving inside the bucket. The solution resides in an examination of Newton's meticulous experimental setup as a self-contained, realistic description of how the quantity of true motion of a body of water changes (under which conditions and with what kind of effects). I argue that the example should be read as real experiment and that it exemplifies a double methodological aspect. The example presents an analysis of true motion which connects (i) the concrete causes of changes in motion with (ii) their quantitative representation.

## 1. Introduction

Newton's example of a rotating water bucket is by now a famous argument in the history of physics. It is often considered an argument for the existence of absolute space and one against a relational conception of motion. To simplify, absolute space is taken to be a rigid, three-dimensional entity void of matter which does not change and with parts which do not change their order. It is supposed to contain all the matter of the universe and it has been easily assimilated with the space of Euclidean geometry. This space has its own manner of existing, independent of any kind of matter or body.[2]

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[2] In the scholium to the definitions, Newton himself only said this much: "Absolute space, of its nature without reference to anything external, always remains homogenous and immovable." (Newton 1999, 408)

Early twentieth-century philosophers of physics retold the example as an idealized spinning bucket filled with water. The effects following from the water moving have been attributed to absolute motion and these effects proved the existence of (unobservable) absolute space. As I will present in Section 2, recent literature, by paying due attention to the Cartesian intellectual context, argues that the role of the example is to show the inherent tension in Descartes's definition of motion and his own system of physical principles. While the Cartesian relative motion is inadequate for a quantitative project in physics, Newton's conceptual alternative comprising of absolute motions is assumed to work as a solution in a straightforward manner.

Here I reveal a serious tension generated by the latter position—with which I otherwise agree—as an interpretation of the bucket example based on a thought experiment. Simply put, the example of the bucket *cannot* be a direct instance of a trajectory in absolute space (Section 3). Rather than taking the example to be a thought experiment, I argue that Newton's original text describes an actual, real experiment as proved by the concrete methodological steps which it follows(Section 4). (i) It illustrates quantitative relations in terms of Newton's definitions and laws, and (ii) these quantities pertain to a quasi-isolated system. The qualification of absolute and true circular motion applies therefore to a system constructed in very specific ways, and not imagined moving in absolute space simpliciter.

## 2. The classical and revisionist readings

The familiar summary of the bucket experiment goes as follows. Consider a bucket filled with water which starts to rotate faster and faster. The water inside will slowly pick up the motion and it will rise on the walls of the bucket. The fact that the water changed its shape and tends to move away from the center of the bucket is a sign that the water *really is* in motion. When the water and the bucket revolve at the same rate, the water still recedes from the center.

The argument in the classical reading[3] is structured along the lines of an inference to the best explanation from an observable state of affairs to the existence of an unobservable entity. The best explanation of the shape of the water is motion, and the best available frame of reference for that motion is assumed to be absolute space. Therefore, the reader is led to accept absolute space as a kind of entity required for the explanation of an observable empirical circumstance. So,

[3] See, for instance, Nagel (1961, 209) and Maudlin (2012, 20-24).

the "proof" is as convincing as the indispensability of absolute space is for the water's shape.

Current literature shows how the classical reading has stretched its credibility as a charitable interpretation of Netwon's own arguments. The classical reading makes the structure of the Scholium irrelevant and the larger intellectual context of the *Principia* invisible for the most part. For instance, a copy-paste method of interpretation lumps together the bucket with the two globes example treating them both as thought experiments. They are both subsumed to one argumentative goal: to show that the motion of the water is independent of the relative positions with respect to *any* bodies.

Considering the intellectual context of the text has made scholars aware that Newton's original arguments target Cartesian notions of motions and rest (and since they revisit the text, I will use the name of 'revisionist readings' for them.) To name but a few, Stein (1967), Laymon (1978)[4], Rynasiewicz (1995, 2014, 2018) and Brading (ms.): all set clear that "Newton's main philosophical target in the scholium is Descartes" and not relationists[5] about motion in general. Specifically, the example of the bucket is an argument from the effects of absolute motion and follows a similar structure of argumentation to previous parts of the Scholium (which are arguments of distinguishing absolute from relative motions by their properties and causes).[6]

For instance, Stein (1967, 273) shows that much of Newton's criticism in the Scholium targets inconsistencies arising from Descartes' definition of motion. The bucket experiment in particular shows that Descartes's definition of proper motion (motion in the philosophical sense) is inconsistent with Descartes' own needs for dynamics. And that this is the aim of the argument, not the existence of the absolute frame of reference.

Here's the argument in a nutshell.[7] Both Descartes and Newton share some commitments, but they diverge on the definition or analysis of fundamental terms. Both start with the assumption that a body has a unique, proper motion. However, they choose to define that motion in radically different ways. Descartes selects one relative motion to be the privileged definition of proper motion, while Newton introduced absolute motion. Moreover, both Descartes and Newton take the endeavor to recede to be correlated with the proper circular motion of a body. The faster the circular motion, the larger the endeavor to recede, and also the larger

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[4] Laymon's paper is mentioned in Earman (1989, 62-64).

[5] According to a fully relationist view, *all* motion is relative motion to other bodies. Given his definition of proper motion in the *Principles*, Descartes could also be seen as a relationist about motion.

[6] Ryansiewicz 1995, 2014.

[7] Brading, *Philosophy and the Physics Within*, Ch 3 (ms) has the clearest presentation. See also Laymon (1978) and Rynasiewicz (2018).

the quantity of motion in the water. But in the case of the rotating water, Descartes' definition of proper motion which appeals to the surrounding bodies, will not support these correlations.

To see why, we start with Descartes's definition of proper motion in *Principles* II.25 (Descartes 1982, 51). It is "*the transference [translationem] of one part of matter or of one body, from the vicinity of those bodies immediately contiguous to it and considered at rest, into the vicinity of some others.*" Secondly, it will be part of a law of nature for Descartes that the endeavor to recede varies accordingly to the circular motion. If one has a stone whirled in a sling, for instance, the faster the stone is whirled, the greater the tension in the string. This means that the stone is trying to move away from the center with an ever-greater force. (*Principles* II. 39)

Now we apply Descartes' definition to the various stages of the motion of bucket, before and after the water starts to revolve. We see then that the presence of proper motion and the endeavor to recede do not correlate in the way his own law of nature states they should. In fact they are anti-correlated. In the beginning, the Cartesian relative motion was the greatest, but there was no endeavor to recede. Later, as the Cartesian relative motion decreases, the water starts to reveal an ever-greater endeavor to recede by raising up on the walls. Finally, when the bucket is at relative rest, the endeavor was the greatest.

To conclude, the revisionist interpretation sets clear that Newton establishes "that centrifugal endeavor is neither a necessary nor a sufficient condition for the existence of relative circular motion of the water with respect to its surroundings (the bucket)." (Rynasiewicz 2014), which is the direct negation of what Descartes relied upon.

## 3. The complexity of motions problem

Now, however, a bigger question looms large on the horizon. It arises when we try to square Newton's other claims about absolute motions with the case of the bucket. Both classical and revisionist interpretations assumed that Newton's description is along the lines of an idealized thought experiment: the bucket and water revolved somewhere (in absolute space, in the rest frame of the observer) but not on a particular patch of land on Earth. Because of this setup, it appeared that Newton's definition of absolute motion as change of place in absolute space can be applied directly. It was Descartes's definition of proper true motion that caused inconsistencies. We will see however that applying Newton's idea of absolute motion is not quite as straightforward as we hoped.

Let us pause for a moment and ask ourselves this very question: *what does it mean to say that there is an absolute true circular motion of the water in this example?* Note that I am not asking what absolute circular motion is in general or, as one might be tempted, what the water is spinning with respect to in an otherwise empty universe. We are taking the example at its face value. We do not follow a thought experiment of a bucket rotating in an empty universe, from which all matter was annihilated after the bucket started to move. The passage carefully describes actions performed in the world as we know it. Newton himself says that the description is something following his own observations and actions ("as experience has shown me"). Here, in this material world: *what would it mean to adopt Newton's definition of true motion as absolute motion when we witness the changes invoked in the rotation of the bucket?*

One answer readily suggests itself: the water moves in a circular trajectory in absolute space. Or, alternatively, the water revolves around a single axis at rest in absolute space. For instance, one could think that "true motion yields true orbits and that these orbits are described in absolute space."[8] This would be a straightforward interpretation of the true motion of the particles of water as a trajectory in absolute space and time.

This answer is tempting only if we consider the system moving fictionally in our imagination. However, it *cannot* work for a system moving in reality. Because many other elements factor into the trajectory of the true motion of water such as the bucket movements on earth, the Earth's movements around the sun and so on and so forth. This complexity of composing many motions creates a serious a problem for taking Newton's true and absolute circular motion of the water as a straightforward trajectory in absolute space.

Newton is aware of this problem: previously in the Scholium he gives the example of the ship sailing on the Earth. After introducing the distinction between absolute motion (as "the change of position of a body from one absolute place to another") and relative motion ("change of position from one relative place to another"), Newton mentions that if the Earth would be truly at rest ("continue to exist in the same part of the unmoving space") then a body at rest on the ship

> [...] will move truly and absolutely with the velocity with which the ship is moving on the earth. But if the earth is also moving, *the true and absolute motion of the body will arise partly from the true motion of the earth in unmoving space and partly from the relative motion of the ship on the earth.* (Newton 1999, 409, my emphasis)

[8] Rynasiewicz (2018, 5) traces this idea back to Kepler and the trajectory of Mars.

Similarly, in the case of the bucket experiment, the water is described as circular from the point of view of the experimenter. Both find themselves on the surface of the Earth and both are presumably also placed in absolute space. If the Earth were at true rest, then the trajectory would be truly a circular one in absolute space. But it is not, and therefore we face the issue of composing the motions. The motion of the water is composed of the motion of the bucket on earth, of the revolution of the Earth around its axis, of the Earth around the common center of gravity of the Earth and Moon, etc. The resulting trajectory would not resemble a circle and the axis of revolution is not at rest in absolute space.[9]

All in all, the complexity of true motions creates a serious a problem for taking Newton's "true and absolute circular motion of the water" simpliciter. In other words, how are we to reconcile the relativity of motion and the variety of choices for a point of reference with Newton's straightforward use of the qualifications of "absolute" and "true" as they pertain to the water in the revolving bucket?[10]

## 4. The experiment reconsidered: the devil is in the details

I argue that in order to solve this problem we should take Newton's bucket as a real experiment and not a thought experiment. It does not describe the water in a bucket placed in an empty universe. Instead, it is a meticulous construction of a system of interacting bodies. It provides a realistic description of how motion is being transferred and one which allows for gauging the quantitative change in the endeavor to recede and its connection with the change in the quantity of motion. The system is so constrained in its description that the endeavor to recede is uniquely determined by the interventions of impressed forces on the water. Therefore, the changes in relevant quantities could be expressed in a double conditional (one changes iff the other one changes).

Evidence for my reading comes from Newton's explicit inclusion of several specific choices he made in the setup. Though often overlooked, these choices describe the items he worked with, the order of the operations, the succession of observations; all of which are essential for moving from a particular case to general considerations concerning circular motion.  When taken together, they show that Newton's setup is a purposeful description of an actual experiment: by

[9] As Berkeley, one of the first to carefully pore over Newton's Scholium, also concludes. (*De Motu* 1721, §62, p. 58)

[10] It would be rather disappointing if the example turned out to work only as a critique of Descartes, but not be successful in explaining how absolute motions are distinguished from relative ones by their effects in a concrete instance. The answer I provide here is briefly: absolute motions are distinguished from relative ones by their effects because the former constitute the necessary and sufficient elements of a dynamical analysis of relevant quantities in an isolated system.

its very construction it achieves the description of a *quasi-isolated system of interacting bodies in which the causes and effects of motion are carefully monitored.* In his curated description, Newton explicitly states the forces which are the causes of motion and the way in which motion is transmitted from one body to another. Because all the relevant sources of impressed forces are given, we can analyze afterwards the relations among various quantities of motions using only the conceptual tools provided by Newton in the beginning of the *Principia* (the definitions and the laws of motion).

Here is Newton's own description of his performed experiment:

> If a bucket is hanging from a very long cord and is continually turned around until the cord becomes twisted tight, and if the bucket is thereupon filled with water and is at rest along with the water and then, by some sudden force, is made to turn around in the opposite direction and, as the cord unwinds, perseveres for a while in this motion; then the surface of the water will at first be level, just as it was before the vessel began to move. But after the vessel, by the forces gradually impressed on the water, has caused the water also to begin revolving perceptibly, the water will gradually recede from the middle and rise up the sides of the vessel, assuming a concave shape (as experience has shown me), and, with an ever faster motion, will rise further and further until, when it completes its revolutions in the same times as the vessel, it is relatively at rest in the vessel. The rise of the water reveals its endeavor to recede from the axis of motion, and from such an endeavor one can find out and measure the true and absolute circular motion of water, which here is the direct opposite of its relation motion. [...] (Newton 1999, 413)

I consider the above to be a successful, thoughtfully described experiment because it embodies two crucial methodological factors:

a. The quantitative factor. The dynamics is specified quantitatively: it includes all the sources of motion, it specifies the relevant quantities, how they are correlated, how they change, and what the source of their change is.
b. The quasi-isolation factor. The description gives explicit reasons to consider the system relatively isolated from other bodies which are not referred to.

On my view, then, it is precisely because these two methodological constraints are carefully followed, that we are allowed to consider the resulting motion as generated by absolute and true quantities.

a. The quantitative factor

Newton focuses on variations of quantities and not in the *states* of motion or rest of the water and the bucket. Variations are between the level of the water, the quantity of motion of the water, the endeavor to recede. The level of water and the concave shape are in a quantitative relation with the endeavor to recede. And the same level and shape vary directly with the quantity of motion in the water.

The quantitative factor also reveals that the temporal order of changes is what allows Newton to claim the endeavor to recede as an *effect* of changes in quantity of motion (and not a cause, as Descartes assumes in his *Principles*). Newton notes how the water gradually starts to revolve "by the forces gradually impressed on the water." The changes are all happening gradually and in time because they are based on how motion is communicated *from the bucket to the water*. Some of it will be lost, but the unwinding of the "very long" cord supplies enough motion to make the revolution perceptible. The (temporally) *prior gradual* change in the motion of the water is the cause of the endeavor to recede to increase noticeably *afterwards*.

So, the quantitative dynamics of motion is crucial for the experiment: it explains from where and how the motion is communicated concretely, within the system composed of the bucket, water, and the cord. The sources of motion are the tension resulting from the cord being "twisted tight" and from "the sudden force" by which we can turn the bucket in the beginning. Once that initial "push" is given to the bucket, the system is free from our/external interference.

Consider how different choices described by Newton would make a *real* difference in the expected effects. The length of the cord, putting water first and then rotating the bucket, having enough time to notice the water moving up, filling the bucket up to a certain level, whether we give the bucket a push or we let the cord unwind by itself, how strong of a 'sudden force' – all these involve choices of calibration. And it is the careful calibration of these variables that allows for the detection of the endeavor to recede to be observed. But other variables, such as whether the experiment is performed in dry air or humid air, on a top of a mountain or in a valley, etc. –do not prima facie intervene.

If one tries to replicate the experiment, it will become obvious that, for instance, a cord that is not long or twisted enough will not provide enough motion to the bucket to get the water revolving. If the water sits in the bucket while the winding is done, it will gather some motion before the initial push. So, filling the bucket *after* winding the cord eliminates this error. Similarly, if the bucket does not get the initial push or if the push is not sudden enough, the motion transferred by the cord to the bucket is oftentimes insufficient to separate the walls of the bucket from the water and together they will behave more or less like a single body. The water will not gain enough motion to rise on the walls. To sum up: once this experiment is performed it becomes painfully clear that the key element of motion being communicated (and lost, by friction) is essential to causing an endeavor to recede in the water.

b. The quasi-isolation factor.

More importantly, we can capture the changes in quantities featured in the system without using other bodies as points of reference for their magnitude. For example, in using the rate of revolution, the only point of reference explicitly mentioned by Newton is *the axis of the rotation*, which is a mathematical place determined only with respect to the bucket's features. The spatial separation between the walls of the bucket to the axis (the radius of rotation) is an absolute quantity, even if the place of the axis might not be absolute. The inherent force (*vis insita)* of the particles of water will come into play, and so would the walls of the bucket as a centripetal force (impressed force) keeping them from flying off on a tangent. These quantities can be, again, considered absolute. Here, in fact, we describe operations taking place in a geometrical space.

Using this space as a frame of reference allows us to treat the path of the water in a simplified manner and thus it addresses directly the complexity of motions. This space can be considered as a frame of reference *only when we are justified in treating the system of interacting bodies in isolation and after the relevant quantities (but not their values) have been chosen*. Clearly, not everything in the scenario is up for explanation: the shape of the body of water is roughly described as 'concave' and it is presumed to arise from a tendency to move away from the center of rotation. This tells us that, for instance, a fuller description/prediction of the shape of the water was not the intended goal of the scenario.

More importantly, the bucket system as an experimental setup is only *quasi*-isolated: it is isolated for the purposes of noticing the effects of the motion communicated to the water, and not fully causally isolated. The experimenter (or the natural philosopher, in general) must decide whether the gravitational field of the Earth, for instance, makes a difference. To be sure, the bucket and the water find themselves in Earth's pull (and react to it), but this attraction is unlikely to make any difference on the interactions between the cord, the bucket, and the water. We have, therefore, prior experience of other facts giving us good reasons to bracket other bodies in the universe (such as the Earth) *not* because they have *no* causal effect whatsoever on our system or because we imagine the absolute space being void of matter. Instead, we can abstract the existence of other bodies precisely because we have good prior reasons to believe that they do not have a *significant causal* effect for the variations in the quantities we ascribed to the water.

The choices involved in abstracting the existence of other bodies can also be supported by Newton's other considerations about the application of the laws of motion in the *Principia*. We made the prior decision that locally, for the bucket system, the revolving motion of the earth can be considered a uniform straight-line motion (and not circular) for the duration of the experiment. Similarly, the gravitational field is uniform for the system of the bucket. Accordingly, Corollaries 5 and 6 to the laws of motion are in place. And we know this to be a good choice because all the sources of motion are explicitly incorporated. Thus, the two methodological factors of the bucket experiment reveal that there are choices involved in describing the motion of bodies, choices which are prior to and more important than choosing a point of reference to describe trajectories.

The two factors work together, and they make Newton's description in accordance with his own rules for the study of natural philosophy. Rule 1 states that "no more causes of natural things should be admitted than are both true and sufficient to explain their phenomena," and Rule 2: "Therefore, the causes assigned to natural effects of the same kind must be, so far as possible, the same." (Newton 1999, 794-5) Newton made explicit the causes of the variations in the shape of water and thus allowed for a quasi-isolated system. We have no reason to hypothesize that the water changes shape because, say, the air pushes the water from the center to the sides. Such hypotheses should not be feigned because we already have a good grasp of the sources of motion in this experiment.[11] Similarly, the quantities are tracking causes and effects: if the rise of the water in the bucket is a natural effect in this case, the cause will be an increase in the quantity of motion of the water. And we know *why* and *that* the quantity increased because it was provided in the description.

We can now sum up how exactly this experiment allows us to refer to the rotating water to be in true and absolute circular motion. We can do so *not* because its trajectory is around a single axis at rest in absolute space, but because we can successfully incorporate it in a system of interacting bodies which captures all the relevant causes of variations in quantities by using Newton's definitions and laws of motion. It is 'true' motion because the variations in the centrifugal endeavor are due to given impressed forces (and not relative positions). And it is 'absolute' because the axis of motion and the quantities could be thought of only in terms of the quantities of Newton's *Principia* (mass, motion, inherent and impressed forces,

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[11] Air could be a cause of motion in other cases. A house carried away by revolving air in the vortex of a tornado is altogether a different story/experiment.

and geometrical relations thereof), while bracketing the presence of other external bodies or their relative places.

## 4. Conclusions

In this paper I argued that we should abandon the classical interpretation of Newton's bucket example as an idealized thought experiment concerning the existence of absolute space. The revisionist reading is right to argue that Newton's concern is to show the inadequacy of Descartes' definition of motion and the inherent tensions within the Cartesian dynamics. However, I argued that this could only work if we pay attention to the methodological factors. Newton's setup allows for an experiment comprising of a quasi-isolated system of bodies (the bucket, water, the cord) undergoing changes in quantities of motion. The water in the bucket can be said to have a true absolute circular motion only insofar as we included the relevant causes of change in motion and modelled them using Newton's definitions and laws of motion. The shape of the water's trajectory in absolute space (conceived as an all-encompassing rigid frame) is neither the starting point, nor the endpoint of Newton's experiment.

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