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"Experimental thoughts on thought experiments in medieval Islam"

Abstract
The study begins with the language employed in and the psychological basis of thought experiments as understood by certain medieval Arabic philosophers. It then provides a taxonomy of different kinds of thoughts experiments used in the medieval Islamic world. These include purely fictional thought experiments, idealizations and finally thought experiments using ingenious machines. The study concludes by suggesting that thought experiments provided a halfway house during this period between a staunch rationalism and an emerging empiricism.

1. Introduction

There is no (medieval) Arabic term or phrase for "thought experiment". Be that as it may, medieval philosophers and scientists working in Arabic both concretely employed thought experiments in their philosophies and discussed their merits and demerits abstractly. Indeed, it would seem that thought experiments truly captured the imagination of medieval thinkers in the Muslim world, who left behind a significant body of examples and analyses of such experiments. What follows makes no pretense to being a complete history of that body of work. Instead, this study focuses primarily, although by no means exclusively, on thought experiments as they are used and discussed in Ibn Sīnā (980–1037), the Avicenna of Latin fame. Along the way, however, this study also touches on other notable figures and their uses and thoughts about thought experiments. These figures include the famed medieval Arabic optician Ibn al-Haytham (965–1040, Lt. Alhazen) and the renowned Muslim Theologian Abū Ḥamid al-Ghazālī (1058–1111).

As a first pass, one can divide thought experiments in the medieval Arabic world into two classes: those that are in principle impossible to carry out and those that at least appear to be possible to carry out even if in practice they cannot. Examples from contemporary philosophy of the first class include zombie worlds and persons splitting and recombining, etc. In the medieval period just as now such thought experiments functioned primarily as intuition pumps intended to give someone a senses of what is at least possible. I refer to this class of thought experiments as "fictional thought experiments". Contemporary examples of the second class of thought experiments abound in the works of Einstein, as, for instance, riding a light beam or his use of moving trains and lightening flashes in relation to simultaneity or one's expected experience in a free falling elevator to explain gravity. Since within the medieval period thought experiments of this sort frequently describe idealized accounts of otherwise realizable situations, I refer to this class as "idealized thought experiments." The class of idealized thought experiments further divides into those that appeal to some form of mechanical apparatus, to which the name "mechanical thought experiments" is appropriate, and those that do not.

Continuing this first pass, medieval thinkers in the Muslim world also had different aims for thought experiments. In some cases, the aim was simply to help one envision or vividly to grasp some abstract conclusion of a demonstration. As such, the thought experiments are not integral to the actual proof(s) for the desired conclusion. In other cases, a thought experiment is integral to the proof in that it either constitutes the whole of the argument or is intended to establish a necessary premise for the argument. Additionally, in those cases where the thought experiment intends to prove a premise, it might show that some state of affairs is at least possible or more significantly that some scenario is factive.

Towards developing these sketchy remarks, I begin with a brief discussion about the language and psychology of imagination, particularly as it occurs in the works of Avicenna. That Avicenna in fact embedded thought experiments within an overall psychology seems to set him apart from the thinkers that preceded him. Following the comments on psychology, the remainder of the study is a taxonomy of various sorts of thought experiments used among thinkers in the medieval Islamic world: first, instances of fictional ones and second idealized ones. When possible, I also discuss the philosophical attitudes and responses to the various thought experiments. What I hope emerges is a sketch of the place of thought experiments among medieval Arabic-speaking philosophers and scientists that others may use to fill in the whole picture.

2. The Language and Psychology of Thought Experiments in the Medieval Muslim World[1]

While there is little doubt that ancient Greek philosophers crafted and employed what we now call "thought experiments," (see Ierodiakonou and Becker in the present volume), Katerina Ierodiakonou has also noted, "there is no evidence that [the ancients] classified examples based on imaginary or invented assumptions in a special category" (see Ierodiakonou in the present volume, **p. xxx**). By the time

[1] The most detailed discussion to date about the relation of thought experiments to theories of psychology developed in the medieval Arabic world is Tanelli Kukkonen's landmark 2014 article, to which this section is heavily indebted.

of Avicenna, however, the premises driving thought experiments were seen to form a special category or at the very least to present a special problem. To appreciate the problem one must begin with the language that Aristotle and his commentators used for thought experiments, for it is that terminology that medieval Arabic-speaking philosophers primarily inherited and used when constructing or discussing thought experiments.

Perhaps most frequently Aristotle introduces thought experiments with a conditional statement (See Kukkonen 2002 and 2014, esp. §I; and Ierodiakonou 2005, esp. §IV). The conditional's antecedent then functions as an initial supposition that governs the thought experiment. In some places—like *Physics*, 7.1, 242a9–10, where Aristotle agues against the possibility of self-motion—he explicitly introduces a thought experiment as a hypothesis or supposition (*hupekeito*). In medieval Arabic, or at least in Avicenna's philosophical vocabulary, the notion of an hypothesis or supposition, particularly as used in thought experiments, is usually rendered by *farḍ*.

Additionally, Aristotle and his commentators sometimes refer to thought experiments using terms derived from *noein*, "to think". One example in Aristotle is at *Physics*, 3.8, 208a14–16, where he criticizes certain thought experiments involving infinity. Aristotle's late Neoplatonic commentator, John Philoponus (490–570), in his commentary on the *Physics* (Philoponus, *In Physicorum*, 574.14; 575.8; 10; 18) has a more approving appraisal of experiments "in thought" (*kat' epinoian*) when defending the idea of an immaterial extension. The Greek term *noein* and its cognates were frequently rendered into Arabic with some form of ʿ*aql*, "to intellect".

The objects of intellect (*maʿqūlāt*) indicate the universal essences of things abstracted from their material conditions. As such the objects of intellect hardly seem suitable in cases where particulars are being imagined or where counterfactual premises are needed.

What is needed in these cases are more fantastical imaginations, in Greek *phantasia*. The transliteration *fanṭāsīyā* or the native term *khayāl* was frequently used in Arabic to capture the notion of *phantasia*. Among medieval Arabic Peripatetics both *fanṭāsīyā* and *khayāl* were used to indicate either a particular psychological faculty, namely, imagination, or the product of some internal psychological faculty. The recognized difficulty with using mere imaginations or fantasies in thoughts experiments is that there seems to be no check on the imaginative faculty to ensure that its objects tell us something informative about the world. It is just such a concern that prompted the late Hellenistic Neoplatonist, Simplicius (c. 490–c. 560), to complain about putting one's faith in such fantasies (Simplicius, *In De caelo*, 418.30).

One is now in a position to see the special problem that Avicenna seems to recognize about the premises used in thought experiments. If these premises are products of the faculty of intellect, then, as Taneli Kukkonen acutely observes, they "only idealize material circumstances in the framework of a well-defined set of assumed natural laws and invariance" (Kukkonen 2014, 446). In other words, premises produced by the intellect do not lend themselves to the counterfactual scenarios that frequently are at the core of a thought experiments. Alternatively, if the premises of thought experiments are nothing more than unbridled compositions of the imagination, then there is no assurance that their content connects up with anything in the world so as to give one a deeper insight into the world. For Avicenna the question at stake is a psychological one: what faculty of the soul produces the premises employed in (legitimate) thought experiments as opposed to wild ravings? Intellect seems too restricted and imagination seems too unrestrained.

Avicenna's solution to this dilemma was to introduce a new internal sensory faculty, *wahm*, which for lack of any exact English translation is usually termed the estimative faculty. (For discussions of Avicenna's theory of *wahm* see Black 1993, Hasse 2000, esp. II.2, Hall 2006, Kukkonen 2014, esp. §3.) Avicenna identifies the estimative faculty among the five internal perceptive faculties, which are common to humans and (higher) non-human animals alike (Avicenna *De anima*, 4.3). These faculties include common sense, memory, the retentive and compositive imaginations and finally the estimative faculty. According to Avicenna, the estimative faculty perceives non-sensible features or intentions (sing. *maʿná*) within sensible particular things. The classic example is the sheep's recognition of the particular ferocity in a given wolf, for while ferocity is not itself something sensible it is manifested in the sensible features of the wolf, like its sharp fangs and claws and the carnivorous odor that it exudes. In non-human animals the estimative faculty is the highest functioning psychological power, less than intellect but also more than mere imagination. It allows these animals to interact with the world around them in a fairly accurate way. Even in humans, according to Avicenna, it is the estimative faculty that allows us to navigate many of our day-to-day interactions.

Additionally, Avicenna appeals to the estimative faculty to explain the objects and premises of the mathematical sciences. The objects of mathematics, Avicenna tells us, are certain formal features of material objects but which can be considered in the estimative faculty as abstracted from their material conditions, like, for example, squareness (Avicenna, *Madkhal*, 1.2, 12–13). In this respect, the estimative faculty is what allows the mathematician to consider perfect geometrical figures or numbers in the abstract even though these are never instantiated physically; it is the power that allows the physicists to imagine perfectly frictionless planes or a sphere's touching a two-dimensional surface at a single point, even though again in the nitty-gritty world around us none of these exists. These mathematical abstracta, Avicenna says, exist by supposition (*bi-l-farḍ*), usually a supposition imagined by the estimative faculty. That is to say, while mathematical abstracta exist in a mental act of conceptualization (*taṣawwur*), they do not exists, at least not in the exact way that the mathematician investigates them, in the concrete material particulars that populate the world. It is the estimative faculty, then, that provides mathematicians and (theoretical) physicists with an idealized picture of the world. In this respect, the estimative faculty offers up a rough and ready guide to real physical possibilities. Still one must be careful to distinguish between what exists as such in the estimative faculty and what actually exist as separate in the world. For Avicenna, if one is to move from the possibilities imagined in the estimative faculty to what actually exists, one must also have a demonstration or provide some actual instance in the world of what the estimative faculty posits.

To sum up, Avicenna developed the notion of an estimative faculty in order to explain a number of disparate, albeit related, phenomena. Among these phenomena are the semi-rational thoughts and cognitive processes of those higher animals that lack an intellect. Another was to show how idealizations used in mathematics, which do not actually exist separately in the world, can be informative about the world. Finally, the estimative faculty provides Avicenna with a psychological underpinning for thought experiments, which does justice to their frequently counterfactual nature while also explaining how they can have import about the world as it actually is.

3. Fictional Thought Experiments in the Medieval Islamic World

In this section I consider two sorts of fictional thought experiments with very different aims. In one case, the thought experiment functions as a subsidiary aid to help one better grasp the conclusion of some argument that is independent of the thought experiment. In the other case, the thought experiment is integral to the overall argument. Again fictional thought experiments proceed from an initial supposition that is physically impossible in principle to carry out, although presumably an all-powerful agent, like God, could realize the scenario. Arguably, the best known fictional thought experiment coming from the medieval Islamic world is Avicenna's famous "flying man" (see Marmura 1986, Druart 1988, Hasse 2000, esp. II.1). Here is that thought experiment in Avicenna's own words:

> One should imagine through an act of the estimative faculty (*yatawahhama*) as if one of us were created complete and perfect all at once but his sight is veiled from directly observing the things of the external world. He is created as though floating in air or in a void but without the air supporting him such that he would feel it, and the limbs of his body are stretched out and away from one another, so they do not come into contact or touch. Then he considers whether he can assert the existence of his self. He has no doubts about asserting his self as something that exists without also [having to] assert the existence of any of his exterior or interior parts, his heart, his brain, or anything external. (Avicenna, *De anima*, 1.1, 16)

Avicenna presents this thought experiment no fewer than five times throughout his oeuvre.[2] The purpose of the thought experiment is to get one to think of one's self (*dhāt*) as perhaps distinct from one's body or sensible apprehensions. For it certainly seems possible, even if only by an act of God, that an individual could come into existence all at once devoid of any sensory input, sensations or sensible memories. Yet even in this deprived state the individual, one imagines, would be aware or conscious of his or her self (*shuʿūr bi-dhāt*), or so Avicenna imagines. (For a detailed study of self-awareness (or consciousness) in the thought of Avicenna see Jari Kaukua 2015.)

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[2]These are in *De anima* 1.1 (translated here) and 5.7, the *Mashriqīyūn*, *Ishārāt wa-l-tanbīhāt* and *al-Risāla al-Aḍḥawīya fī l-maʿād*. See Hasse 2000, 80–7 for a discussion of the differences among the various presentations.

What is important to note is that Avicenna does not claim here that this thought experiment demonstrates that the human soul or self is immaterial. What is needed truly to establish that conclusion is a proper demonstration, which Avicenna provides in addition to the thought experiment (see Avicenna, *De anima*, 5.2). Instead, the thought experiment, Avicenna tells us, is only a way of arousing (*tanbīh*) in us some consideration of what an immaterial existence might be like (Avicenna, *De anima*, 1.1, 15).

Interestingly, Avicenna also uses a close etymological cousin of *tanbīh*, namely, *tanabbuh*, again "arousing," in association with the aim of induction (*istiqrāʾ*) (Avicenna, *Burhān*, 3.5, 158). Induction, Avicenna informs us, cannot establish some universally true claim, but at best can only show that something is probable (Avicenna, *Burhān*, 1.9, 48). While the link is admittedly tenuous it does suggest that Avicenna may have viewed thought experiments as at least on par with induction in scientific practice.

Avicenna, however, does not use fictional thought experiments solely as incitements, which play no substantive role in demonstrations. In some cases, they form an integral part of a demonstration as in indirect proofs. In fact, Avicenna relies on thought experiments and the use of the estimative faculty in just this way scores of times throughout his *Physics*. Examples include *Physics*, 2.1 when discussing self-motion (discussed in depth in Kukkonen 2014); numerously throughout *Physics*, 2.7–9 and 4.11, when discussing place, void and space (McGinnis 2007a and Lammer 2016); thought experiments also frequently appear in his criticism of the infinitely small, i.e., atomism at *Physics*, 3.4–5 (Lettinck 1999 and McGinnis 2015) and the infinitely large at *Physics*, 3.7–9 (McGinnis 2010). These are just to mention some of the more prominent appearances of thought experiments within the works of Avicenna. Let me consider briefly some of Avicenna's comments concerning the void and how one thought experiment features prominently in his refutation of it.

Avicenna introduces the notion of a void (*khalāʾ*), by claiming that its proponents appealed to a certain thought experiment to motivate their position (Avicenna, *Physics*, 2.6 [5]). In the thought experiment, the proponents of the void consider some contained body, whether the water in a jug or what lies between the moon's orbit around the earth. Here the contained body exists within certain limits of the containing body. They, then, through an act of the estimative faculty, Avicenna continues, imagine that the contained body is eliminated; however, the elimination of the contained body does not eliminate the interval or dimension (*buʿd*) between the limits of the containing body. What is eliminated and what is not eliminated, however, are distinct things. Thus, the thought experiment concludes, the interval or dimension is distinct from the body existing in it, albeit, that interval is something existing together with the body when the body exists in it.

Avicenna's criticism of this argument is precisely to appeal to the limits of the estimative faculty's abilities (Avicenna, *Physics*, 2.9 [11]). To begin, Avicenna happily endorses the general method of analysis (*taḥlīl*) that the thought experiment employs: one uses the estimative faculty to isolate some formal feature within a body for closer scrutiny. In fact, Avicenna maintains that it is just this method that allows one conceptually to distinguish the form of a body from its matter. The problem in the present case comes from thinking that what is separable in thought must also be separable in reality. He clarifies by appealing to the form-matter case: Were one able to remove all forms from some matter, the matter, Avicenna observes, would simply cease to exist, for the form is the principle of actualization. As for the case of the imagined void interval, he writes:

> Let us grant that this interval is assumed in the estimative faculty, when a certain body or bodies are eliminated. How does one know that this act of the estimative faculty is not false [when applied to something existing separate from the estimative faculty], such that what follows upon it is absurd, and whether this assumption is, in fact, even possible, such that what follows upon it is necessary? (Avicenna, *Physics*, 2.9 [11])

Avicenna's complaint is twofold. First, if the thought experiment is to show the extra-mental existence of a void interval, one must show that a separate void interval can exist separate from an act of the estimative faculty. In other words, one must demonstrate that the separate existence of a void does not lead to some absurdity, as in the form-matter case, where the actual elimination of form would entail the actualization of matter without its having any principle of actualization, i.e., any form. Second, even assuming that one can show that the separate existence of a void is *possible*, the thought experiment has not shown that a void's existence is *necessary*. A hallmark of scientific knowledge, however, which goes back at least as far as Plato and Aristotle (cf. Plato, *Theatetus*, 152C[3] and Aristotle, *Posterior Analytics*, A.2, 71b9–12), is that scientific knowledge (Gk., *epistēmē*, Ar. *ʿilm*) is necessary and explanatory of what is. Avicenna accepts these criteria for knowledge. Thus he complains that the thought experiment alone has failed to meet one of the conditions for knowledge; what is additionally needed to show that a void's existence is necessary is a demonstration.

None of this is to say that a thought experiment for Avicenna cannot be an integral part of a demonstration. His own refutation of the void provides one with just such an example. At *Physics*, 2.8, Avicenna aims to show that the existence of a void would make motion impossible. He identifies three general sorts of motion: natural circular motion (such as that of the heavens), natural rectilinear motion (such as that of the elements, earth, water, air and fire) and finally forced motion (such as a projectile like an arrow or a thrown ball). Thought experiments in the form of indirect proofs for the impossibility of a void appear in Avicenna's treatment of all three classes of motion. I shall consider just one: his refutation of the possibility of forced motion in a void (Avicenna, *Physics*, 2.8 [18]).

The argument begins by imagining along with the proponents of the void that an infinite void exists in which objects move. Now in the case of forced motion, for example my shooting an arrow, I, by means of the bow, impart a certain motive power to the arrow. Given this scenario, either the arrow will continue in its motion unabated infinitely or it will come to a stop. The arrow cannot continue on infinitely,

[3] Admittedly Plato is speaking about perception here, but the suggestion is that perception just is knowledge because it has the hallmarks of knowledge: it is about what is and is infallible (*apseudēs*).

Avicenna believes, for a finite agent, and I am finite, can only ever produce a finite effect, but should the arrow continue moving without ever stopping, I would have produced an infinite effect. If the arrow ceases to move, then the privation or absence (*ʿadam*) of motion must belong to the arrow either essentially or owing to some external cause. If not moving, that is, the absence of motion, belonged to the arrow essentially, then its motion would be impossible from the start, for its essence would preclude its moving. As for an external thing's bringing the arrow to rest, we have been asked to imagine a void, and so something literally devoid of any causes that might arrest the arrow's motion. Of course, Avicenna develops each of these moments in the argument in greater detail, but almost every moment has one imagining how the projectile would move or come to rest in a void.

In this case and the others where thoughts experiments are integral to the demonstration Avicenna is not restricted to limiting his conclusion to a mere possibility existing in the estimative faculty. That is because these arguments are intended precisely to show that the separate existence of the subject of the thought experiment is impossible. Thus, if the initial supposition plus a set of auxiliary premises, all of which are taken to be true or even necessary, lead to an absurdity or impossibility, the initial supposition must be jettison. None of this is new to Avicenna. Still, it does suggest that Avicenna was principled with respect to his use of fictional thought experiments: either they must be accompanied by an independent demonstration or they are conceded because one's opponent actually accepts them as true depictions of reality.

4. Idealized Thought Experiments in the Medieval Islamic World

What distinguishes idealized thoughts experiments from fictional thought experiments is that the former at least give the appearance that they are physically possible and so could actually be realized without necessarily appealing to the action of an all-powerful agent. I consider two broad classes of idealized thought experiments used in the medieval Islamic world: mechanical thought experiments and non-mechanical ones. Mechanical thought experiments appeal to some ingenuous machine or apparatus and at the very least give the impression that one could actually carry out the experiment or build the apparatus. Before turning to these mechanical thought experiments, let me begin with a classic example of a non-mechanical idealized thought experiment.

In his *Incoherence of the Philosophers*, al-Ghazālī (1058–1111) challenges the philosophers' insistence that a principle of sufficient reason must govern all actions. He denies that the principle necessarily applies when it comes to the choices of volitional agents. More specifically al-Ghazālī wants to show that even if presented with two completely indiscernible options, God and even humans can, unlike Buridan's ass, choose one over the other. His argument for this conclusion relies solely on the following idealized thought experiment:

> Let us suppose (*nafriḍu*) two indiscernible dates immediately before someone who looks on them hungrily, but is incapable of taking both. He will take one of them necessarily through an attribute whose character is to

> specify one thing from its like. Everything you mentioned concerning specifications of superiority, proximity or facility of access, we determine, by supposition (ʿ*alá farḍ*), to be absent, but the possibility of taking remains. You have two options: either (1) to say that the indiscernibility in relation to his desires is wholly inconceivable, which is fatuous given that the supposition [of the date's indiscernibility] is possible, or (2) to say that when the indiscernibility is supposed, the hungrily longing man would always remain undecided, staring at the two [dates], but not taking either of them simply by willing, but choosing to stand aloof from the desire, which is also absurd, whose falsity is known necessarily. (al-Ghazālī, *Incoherence*, Disc. 1 [46])

The argument is straightforward. We are asked to imagine an idealized situation where every conceivable factor for preferring one desired option over another has been eliminated. Al-Ghazālī takes it as patently possible that the imagined scenario could exist in the world and not merely in the estimative faculty. If the situation is possible, then it is certainly possible that the hungry man will choose one piece of fruit over another without any reason weighing in for his preference for that particular piece. Indeed, al-Ghazālī thinks that choosing in this situation is not merely possible but necessary. He thus concludes that even in humans there must be some psychological faculty that chooses between indiscernible things, called "will" or "volition" (*irāda*).

I know of no philosopher working within an Avicennan psychological framework who addresses this thought experiment. Presumably, if confronted with it, Avicenna would have required some proof that the imagined scenario could exist in the world and not merely in the estimative faculty.

Perhaps a more interesting response comes from the Andalusian Peripatetic, Ibn Rushd (1126–1198), that is, Averroes. Although Averroes' comments say little about the nature of idealized thought experiments as a class of arguments, they are informative about the present example (Averroes, *The Incoherence of the* Incoherence, Disc. 1, [39–41]). Averroes complains that al-Ghazālī's thought experiment does not set out one unique set of preferences, for example, to prefer to eat $date_1$ or $date_2$. Instead, observes Averroes, there are two distinct sets of preferences: (1) to eat or not to eat and (2) to eat $date_1$ or $date_2$. Of course with respect to set (1), the hungry man has every reason to prefer to eat over not eating, and so indeed wills to eat on the basis of that reason. That action is achieved regardless of whether he eats $date_1$ or $date_2$. As for case (2), if the man were subsequently asked why he preferred, for example, $date_1$ over $date_2$, he would say that he did *not* prefer the one date over the other; he simply preferred to eat rather than not to eat. Thus, while there is no reason for preferring one date over another, neither is there any preference for one date over another that needs a reason. Again, however, there seems little to glean from Averroes' discussion here about the nature of thought experiments or idealization (although see Knuuttila and Kukkonen 2011, esp. §2).

Turning now to the mechanical variety of idealized thought experiments, for obvious reasons they were almost exclusively applied to issues and problems in the natural sciences. That is because this class involves describing a machine or apparatus that can, at least in principle, be constructed and as such must be constrained by the laws of physics and principles of mechanics. One such physical issue, in which there was a proliferation of mechanical thought experiments, was the problem of the *quies media*, that is, medial rest.

The issue at stake is whether a body that undergoes contrary changes must come to some rest between one change and then the contrary change. For example, must a ball thrown upward come to a slight rest, be it ever so short, before it moves downward or can the ball change from moving upward to moving downward Instantaneously? Aristotle in his *Physics*, 8.8, had argued for a medial rest. His generally argument assumed something like the following form. Let a body move from A to C. At every moment in its motion from A to C, the body is in a process of arriving at C, whereas at every moment in its motion from C back to A the body is in a process of arriving at A. A is not C, and so during the body's motion back to A, it is *not* in a process of arriving at C. Now to-be-in-a-process-of-arriving-at-C and *not*-to-be-in-a-process-of-arriving-at-C are contradictory predicates, and nothing can simultaneously have contradictory predicates. Hence, reasons Aristotle, there must be some instant at which the body arrives at C and some other instant at which it departs C. Finally, since time is continuous and between any two points (or in this case instants, i.e., temporal points) on a continuum there is some magnitude, there must be some temporal magnitude, and so some time, between the instant of the body's arriving at C and of its departing from C when it is at rest at C.

Aristotle's word on this subject was far from the last. Indeed, the issue was still very much alive in Avicenna's time (see Rashed 1999, esp. §2, Morrison 2005, 58–9 & 91–2 and Langermann 2008). In fact, the issue had generated so much unrest that Avicenna dedicated an entire chapter of his *Physics*, 4.8, to the problem. Avicenna himself even confesses that he did not find the arguments on either side particularly impressive (Avicenna, *Physics*, 4.8 [9]). The issue is particularly pressing for Avicenna since he provided an analysis of motion that allowed for motion at an instant in such a way to avoid Aristotle's conclusion (see Hasnawi 2001, McGinnis 2006 and Ahmed 2016). As for the arguments pro and con, Avicenna notes that the main premise in arguments for there being a rest between contrary motions involves identifying some purported impossibility in the situation, like the contradiction that Aristotle mentioned in the above case. He further notes that the counter arguments simply need to show that the instantaneous change from one type of motion to its contrary is not impossible. Those who opposed Aristotle's conclusion appealed to this last point, and an easy enough way to show that possibility is simply to describe a machine that produces just such a motion.

Avicenna himself mentions one such contraption proposed by the detractors of a medial rest (Avicenna, *Physics*, 4.8 [4]). We are to imagine a sphere mounted upon a wheel and the wheel makes a continuous rotation. Next imagine a two-dimensional plane above the apparatus that is situated such that, when the sphere is at its apex during the wheel's rotation, the sphere encounters that plane at some single point, C. Since the wheel that is carrying the sphere is moving continuously, the sphere will touch C for only an instant. Thus, during the sphere's ascent it will have been in a process of arriving at C, while during its descent it will be in process of departing from, i.e., not arriving at, C, just as Aristotle describes, and yet contrary to Aristotle, the sphere will be at C for only an instant. While the example takes advantage of circular motion, it does suggest that a body can *actually* be at a point for an instant and at that instant change from one sort of motion to its contrary.

As already noted, Avicenna was not impressed with any of the available arguments concerning this issue, pro or con.[4] His objection to the present one involves a digression about the nature of mechanical thought experiments more generally (Avicenna, *Physics*, 4.8 [12]). His concerns are much like those registered about fictional thought experiments. The difference is that, while in the case of fictional thought experiments one must provide a demonstration that what the thought experiment describes can exist separate from the estimative faculty, in a mechanical thought experiments one must first ask if the proposed machine can in fact actually work. Can it be constructed in principle? If it cannot, then the thought experiment must be treated as if it is a fictional one.

Today we might think that the proposed thought experiment immediately fails the can-it-work test since it appeals to perfects spheres and planes, i.e., mathematically idealized ones, rather than to physical ones. In fact, Avicenna mentioned that some complained about this thought experiments in just this way.

[4] While Avicenna ultimately will agree with Aristotle that there must be a rest between contrary motions, his own unique argument for this thesis appeals to the forces producing the motions rather than the sorts of motion involved.

Avicenna dismisses the objection as inadequate, since in his cosmology there actually were perfectly instantiated spheres, namely, the celestial spheres that carry the planets along their orbits. Consequently, at least part of the imagined apparatus can, by Avicenna's lights, be physically instantiated.

Avicenna's complaint comes when considering whether these rotating spheres can come in contact with a flat surface at a single point. The perfect spheres that Avicenna permits are embedded within one another. Thus, while a sphere may be in contact with the surface of another sphere, on Avicenna's view, it would not contact it at a single point but in its entirety, either containing or being contained. He in fact argues that one can demonstrate the physical impossibility of a sphere's actually touching a flat plane at a single point, even if one grants the physical existence of both a perfect sphere and a two-dimensional surface. He reasons thusly: between the flat surface and the sphere there must be a void or not. At *Physics*, 2.8, Avicenna spilt much ink to show that a void is not only physically impossible but also conceptually impossible (McGinnis 2007b, esp. §IV and Lammer 2016, §5.3). Thus, if the proposed apparatus entails a void, then it entails an impossibility, and so must itself be a vacuous product of the imagination.

If there is no void, Avicenna's argument continues, then there must be a plenum whose surface contacts the flat two-dimensional plane and the convex surface of the sphere. Now, according to the continuous theory of physical bodies, which Avicenna adopts, points have no determinate existence in a continuous surface, save as endpoints of lines. Consequently, Avicenna goes on, points exist in the continuum only if there is a physical separation of the continuous surface, in which case the point exists as an endpoint, otherwise it exists merely as a product of the estimative faculty's positing the point. Thus, Avicenna continues, it is impossible that the single point of the sphere should have some separate, determinate position in the surface of the plenum that touches the flat two-dimensional plane given the very nature of continua.

He concludes his critique of this thought experiment thus:

> This [argument] makes the laws of nature dependent upon certain mathematical abstractions of the estimative faculty, which is not right. In fact, beyond going outside the discipline [of physics], that [argument] doesn't even entail what [they] wanted it to prove, but only requires that the continuity of the two designated motions be in the estimative faculty. We, however, don't deny that that continuity is in the estimative faculty. We deny [the continuity] only of the natural things that deviate from the abstractions of the estimative faculty. (Avicenna, *Physics*, 4.8 [12])

As a curious historical addendum, the post-Avicennan polymath, Quṭb al-Dīn Shīrāzī (1236–1311), showed how a model used in astronomy could produce a continuous motion between a body that ascends and then descend, which is perhaps immune to Avicenna's criticism (Morrison 2005, 58–9 & 91). Shīrāzī took advantage of a mathematical devise—the eponymous Ṭūsī couple—that Naṣīr al-Dīn al-Ṭūsī (1201–74) had constructed to bring about a better match between astronomical observations and the predictions of the geocentric model of the universe adopted by ancient and medieval astronomers. The Ṭūsī couple assumes two continuous and uniformly rotating circles (but the device could also be constructed using spheres). One circle is inside the other with the contained circle having half of the diameter of the containing circle and rotating twice as fast as and in the opposite direction as the containing circle. The overall effect, Ṭūsī observed, is that a certain point on the circumference of the smaller circle oscillates up and down the diameter of the larger circle. This oscillating "point" was subsequently identified with some planet.[5] Shīrāzī's contribution to the debate about medial rest was to note that since solely continuous rotations produce the oscillation, the point/planet will come to one endpoint of the diameter and then without rest (for the rotations do not stop) instantaneously move back toward the other endpoint. Consequently, to the extent that one believed that the astronomical model used in Ptolemaic systems described the actual workings of the heavens, the Ṭūsī couple would pass Avicenna's can-it-work test.

Let me conclude with one final set of possible mechanical idealized thought experiments, now drawn from the great medieval Muslim optician, Ibn al-Haytham.[6] (I say, "possible" because for some the examples that I give are seen as instances of *actual* experiments rather than *thought* experiments; I let the reader decide.) Throughout his *Book of Optics* (*Kitāb al-Munāẓir*, Lt. *De aspectibus*) Ibn al-Haytham takes what by all appearances is a staunch empirical approach to the study of optics, suggesting numerous experiments and apparatus to verify empirically various

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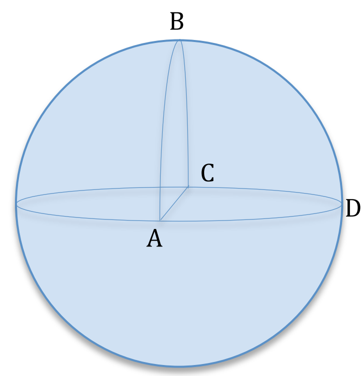
[5] A graphic representation can be found on Wikipedia under "Tusi Couple": https://en.wikipedia.org/wiki/Tusi_couple.
[6] The position I present here draws heavily upon A. Mark Smith 2015: ch. 5.

principles used in optics. In numerous cases, he suggests a set of experiments that require the construction of highly precise apparatuses, which he describes with meticulous care, indeed such care that they appear to be more idealizations than devices actually used by him. Unfortunately, the exacting details of his descriptions and the length it would take to describe them preclude presenting even one of them here in full detail, although one example might help make my point.



When considering refraction, Ibn al-Haytham describes an apparatus for testing the refractive properties of different media, which requires as one of its parts, a relatively large quarter sphere of glass (like, for example, ABCD in the diagram). Rays of light are allowed to pass through the quarter sphere before passing through a different medium like air or water. The technological state of glass working, particularly at a time before machine-produced glassware, makes it difficult to assume that any quarter sphere produced in Ibn al-Haytham's time would have been free of the various flaws that typify handmade glass items, such as the tiny bubbles or various stretch, mold, shear or pontil marks. These imperfections, however, would have distorted the observed results of the experiments. Similarly, for the device to give the mathematically exact results, which Ibn al-Haytham claims, the two flat surfaces of the quarter sphere would need to be exactly perpendicular and the curved surface perfectly convex, again features that seem all but impossible given the technology of the time.

Ibn al-Haytham makes similar exacting demands on the specifications for another apparatus, now used in validating the equal-angles law found in discussions of reflection. Noted historian of science, A. Mark Smith, has this to say about the level of precision required of that apparatus in order to get the purported results:

> Indeed, given [the apparatus'] obvious unfeasibility as actually described—with all planes perfectly aligned and all measurements perfectly reproduced—the test appears to have been an elaborate thought experiments designed to confirm what [Ibn al-Haytham] already took for granted, that is, that light reflects at equal angles. (Smith 2015, 199)

It is not my intention to diminish the significance of Ibn al-Haytham's contribution to optics—it is impressive indeed—rather, I merely want to suggest that some of his experiments might best be classified as instances of what I have been calling idealized thought experiments.

4. Conclusion

There can be little doubt that thinkers in the medieval Islamic world appreciated the role and significance of thoughts experiments for philosophy and the sciences. Indeed the prevalence of thoughts experiments in these areas seems to have lead Avicenna to explore the psychology behind them and present rules for determining acceptable and unacceptable use of premises relying on them.

He lauded and even employed thought experiments himself when used as intuition pumps primarily to arouse in us a better understanding of some independently proven point. When thought experiments were integral parts of a proof, however, he was more hesitant. If thought experiments were used in indirect proofs, they needed to be part of a conditional premise, ideally functioning as the consequence of some hypothesis whose very possibility was being questioned. In any other use, Avicenna stresses that one must prove that the situation imagined in the thought experiments can actually occur in the real world, and so does not have its existence merely as a product of the mind, or particularly, of the estimative faculty. In other words, when thought experiments were to play some integral role in a proof, Avicenna requires that the assumed scenario be executable at least in principle.

A scenario could be shown to be executable in principle, at least in some cases, if it relies on a mechanical apparatus that did not violate any physical principles. Indeed there appears to have been a proliferation of idealized mechanical thoughts experiments within natural philosophy, whether physics proper, optics, astronomy or the like. Such a proliferation at least suggests that physics within the medieval Islamic world was beginning to show the first tendencies of an experimental approach to the sciences, although this tendency is better described in terms of "methodological experience" (see McGinnis 2003 and Janssens 2004). Whatever the case, the use of thought experiments would have been part of an empiricism that went hand in hand with a marked rationalist leaning.

As for evidence of this last point, we have seen Avicenna's demand that thought experiments really need to be accompanied by a demonstration (*burhān*). A demonstration in this context would have meant a logically valid syllogism proceeding from necessary first principles, where first principles are products of the intellect (*ʿaql*) not the estimative faculty. This same tendency also seems present in the experiments of Ibn al-Haytham. The punctilious precision with which he described the apparatus that his experiments employed all but necessitates that the demands of an idealized mathematical demonstrations directed his detailed instructions. Finally, the medieval Jewish philosopher, Abū l-Barakāt (1080–1165), after cataloging various arguments against a *quies media*, notes that those who favor there being a medial rest would only be satisfied by a demonstration proceeding from the intellect (Abū l-Barakāt, *al-Muʿtabar*, 2.14, 97). By implication mechanical arguments, whether of the thought experiment variety or otherwise, would have taken a back seat to a proper intellectual demonstration.

To conclude, thought experiments in the medieval Islamic milieu seemed to function as a halfway house between empiricism and rationalism, allowing the idealization that rationalism demands while also appealing to sensible intuitions favored by an empiricist approach to the sciences.

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