Chapter 2
Thought Experiments in Ancient Greece

It is not so much the particular form that scientific theories have now taken – the conclusions which we believe we have proved – as the movement of thought behind them that concerns the philosopher.

Eddington, *The Nature of the Physical World* (1932: 353)

Image an ancient Greek who is exercised by questions of cosmic import: Is the universe finite or infinite? Is the Earth spherical or flat? Is the Earth the centre of the universe or does it rotate around a different hub, say the sun?

To some of these questions the answers are known today, thanks to the theoretical and observational work of our predecessors. But even in the absence of observational evidence the ancient Greeks, driven as we are today by theoretical curiosity, sought solutions. How do you satisfy this theoretical curiosity when observation fails as a guide and theory is uncertain? One possibility is to investigate the logical and conceptual consequences of an adopted view with the aim of establishing whether it provides an answer. If one proposition claims that the universe is finite, another that the Earth is flat, and yet another that the Earth moves, in each case an investigation must be launched in order to ascertain the consequences, which follow from each hypothesis. In the absence of real experimentation or actual observation, an investigation of conceptual and logical consequences amounts to experimentation in thought. Just as in real experiments, thought experiments introduce a number of parameters, which depict the imaginary scenario in a mental laboratory, in order to investigate their consequences. This is precisely the procedure, which some of the ancient Greeks adopted.

To illustrate, consider the conundrum of whether the universe is finite or infinite, a question to which even today no definitive answer is known. The Greek mathematician and philosopher Archytas of Tarentum introduced a thought experiment, with the help of which he hoped to obtain an answer to the question (see Huggett 2010: 33–34; LePoidevin 2003: Chap. 6; Genz 2005: 205–206). As Archytas's life coincided with the lifetimes of Plato and Aristotle, he must have been aware of the Greek geocentric worldview. The geocentric worldview was the dominant paradigm until it was displaced by the heliocentric worldview of Nicolaus Copernicus in

F. Weinert, *The Demons of Science*,
DOI 10.1007/978-3-319-31708-3_2

1543 (Weinert 2009: Part I). According to the geocentric worldview the Earth sits motionless—bereft of both a daily and an annual rotation—at the centre of a closed universe. In the Aristotelian version of this model concentric shells carry the planets in perfect circles around the central Earth. The sun itself is regarded as a planet, which occupies the sphere which, in the later heliocentric worldview, will be occupied by the Earth. The geocentric model harbours a closed universe, because the 'fixed' stars mark its boundary, beyond which resides a Deity, described by Aristotle as the 'Unmoved' Mover. The Unmoved Mover remains outside the bounded sphere, which constitutes the universe. But this Deity is ultimately responsible for all the motions below the outer sphere because it provides the energy, which keeps the spheres spinning around the centre. The Greek geocentric worldview therefore assumed a finite cosmos because the universe of planets and spheres reaches its limit at the boundary of the 'fixed' stars.

Humans cannot physically travel to the 'edge' of space but the flight of fantasy is less fettered. Archytas's imagination saw a space traveller flying to the boundary of the cosmic sphere: he might as well have imagined a demon. He asked whether the space traveller could penetrate the outer layer.

> If I am at the extremity of the heaven of the fixed stars, can I stretch outwards my hand or staff? It is absurd to suppose that I could not; and if I can, what is outside must be either body or space. We may then in the same way get to the outside of that again, and so on; and if there is always a new place to which the staff may be held out, this clearly involves extension without limit. (Quoted in Grant 1981: 106; see Fig. 2.1)

Archytas concludes that the universe has no edge and must therefore be infinite. How reliable is this conclusion, given that it was reached without access to empirical data? Can thought experiments teach us something about the external world?

Fig. 2.1 Archytas's traveller reaches the end of the universe and extends his spear through the canopy of the fixed stars. *Source*: Wikimedia Commons

A preliminary answer to these questions emerges from a consideration of two thought experiments, both due to Aristotle, which address two further issues regarding the shape of the world.

As mentioned before, the Greeks also faced the question of whether the Earth was spherical or flat. There is no doubt that throughout the ages a number of scholars were led to the conclusion that the Earth is flat (see Hannam 2009: 35–38). But the great authorities of the ancient geocentric worldview—cosmologists like Aristotle and astronomers like Claudius Ptolemy were convinced that the Earth was spherical. There was, first, empirical evidence for the sphericity of the Earth. As Aristotle says, the 'evidence of the senses' corroborates the assumption of the spherical shape of the Earth. He refers to the eclipses of the moon, which show a 'curved outline' of the Earth on the surface of our satellite,

> (…) and, since it is the interposition of the earth that makes the eclipses, the form of this line will be caused by the form of the earth's surface, which is therefore spherical. (Aristotle 1952b: Book II, Chapter 14, 297[a])

The Greeks were also aware that the view of the night sky changes, as an observer on Earth moves from north to south.

> There is much change (…) in the stars overhead, and the stars seen are different, as one moves northward or southward. Indeed there are some stars seen in Egypt and in the neighbourhood of Cyprus which are not seen in the northerly regions and stars, which in the north are never beyond the range of observation, in those regions rise and set. All of which goes to show not only that the earth is circular in shape, but also that it is a sphere of no great size: for otherwise the effect of so slight a change of place would not be so quickly apparent. (Aristotle 1952b: Book II, Chapter 14, 298[a])

Centuries later Ptolemy would point out that an observer, moving in an eastern direction from Greece, would notice that the sun rises earlier in eastern than in western parts of the globe. If the Earth were a flat disc, all observers would experience a simultaneous rising of the sun in the east and a simultaneous setting in the west. As this is not the case the Earth must be a sphere or at least, it cannot be a disc.

It is interesting to note that Aristotle is not content with the observational evidence of the spherical shape of the Earth. He feels the need to prove that 'its shape must necessarily be spherical' (Aristotle 1952b: 297[a]9). In his attempt to provide a proof he employs a thought experiment: he considers how the Earth could have acquired its spherical shape (Aristotle 1952b: 297[a]13–30). He assumes that every portion of the Earth has weight, endowed with a downward movement towards the centre of the universe. Aristotle here appeals to his theory of motion. According to it material objects 'strive' to where they naturally belong, i.e. the geometric centre of the universe (Weinert 2009: 7–9). Hence the reason for the downward motion of 'every portion of the earth' is that an object, which possesses weight—as pieces of earth do—'is naturally endowed with a centripetal movement' (Aristotle 1952b: 297[a]15–20). And if an equal amount of such material chunks 'strive' towards the centre, they will form a mass with a spherical shape.

Whilst the empirical observations show that the Earth must be spherical, it is the task of the thought experiment, relying on Aristotle's theory of motion, to 'prove' that the Earth is spherical by necessity.

Aristotle's theory of motion, with its central doctrine—that there is no motion without a mover (Aristotle 1952a: BKVII, VIII)—played a central part both in his cosmology and his 'proof' that the Earth occupies the 'centre' of the universe, where it was neither endowed with a daily nor with an annual rotation. Did the Greeks have any 'observational evidence' that the Earth does not move? They believed themselves to be in possession of such evidence: for if it moved, buildings would crumble under the impact of the motion, and such strong easterly winds would blow that birds would never be seen flying from west to east (Ptolemy 1984: §1.7). Aristotle even produced a thought experiment—the so-called tower thought experiment (Fig. 2.2)—to this effect. A consideration of the fall of an object from the height of a tower seemed to show that the Earth cannot possibly perform a daily rotation on its own axis from west to east.

Imagine an object is released, like a stone, from a tower, which sits on a rotating Earth. Would the object fall in a straight line down to the bottom of the tower? A modern physicist would answer in the affirmative but Aristotle came to a different conclusion. According to Aristotle's theory of motion, when the object is dropped from the height of the tower, it 'strives' back to its natural place near the centre of the universe, which is occupied by the Earth. But whilst the body is in free fall, the Earth moves in an eastward direction beneath it. An orbiting Earth would leave the falling object behind. However, no such observations are ever made, from which Aristotle concludes that the Earth must sit motionless at the centre of the universe.

In order to make Aristotle's demonstration move convincing, it can be retold with the insight of modern physics in mind. An object, which is dropped from a height of, say, 50 cm, will descend to the ground in 0.3 s (Fig. 2.2). During this time the Earth will travel 140 m eastward, at a speed of 464 m/s, with respect to a point on the equator. Hence if an object were released even from such a moderate height, it should land 140 m to the west of the bottom of the tower, on the assumption of a

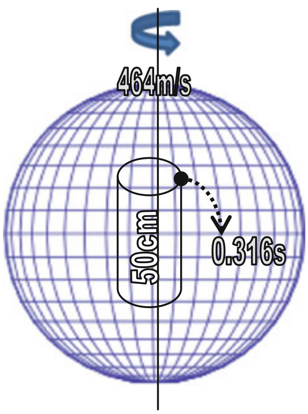

Fig. 2.2 Aristotle's Tower Argument. Although the argument was meant to show that the Earth is stationary, the argument is not valid, because it is based on mistaken premises. *Source* (of sphere): Wikimedia Commons

rotating Earth. A falling object would trail the small tower, which rotates with the Earth—like a person on a spinning wheel—by an impressive gap of 140 m. As such occurrences are not observed, even a 'modernized' Aristotle would conclude that the Earth must be motionless.

The Aristotelian theory of motion, which leads to the stipulation of a motionless Earth, looks as if it were able to explain the appearances: the Earth *seems* to be at rest with respect to the sun, which glides across the horizon from east to west; the released object *seems* to fall straight down towards the centre of the Earth; it *seems* to be eager to return to its natural place. What can be inferred from such examples?

2.1 Some Preliminary Lessons

From the consideration of these thought experiments some preliminary conclusions can be drawn.

1. Thought experiments can be inconclusive.
2. Thought experiments can be misleading.
3. Thought experiments can lead to alternative conclusions.

Ad (1) *Thought experiments are inconclusive*. However appealing Archytas's thought experiment about the infinity of the universe appears to be, it is hardly conclusive. It is an attempt to highlight the logical inconsistency of the Aristotelian assumption that the universe has a boundary. But it has no empirical force, which could disprove the assumption. Archytas does not take into account that an unbounded surface is not the same as an infinite surface. If the universe were like the surface of a sphere it would be finite but without a boundary. The British cosmologist Stephen Hawking indeed made the suggestion that space-time could be finite and yet unbounded if it were described in imaginary time. In imaginary time the universe would have zero size at both the beginning (Big Bang) and the end of time (Big Crunch). The Big Bang starts in a smooth condition, an ordered state, but the Big Crunch corresponds to a collapse into a black hole (Fig. 2.3).

The French physicist and mathematician Henri Poincaré proposed a different response, by way of a thought experiment, which also assumes that the universe is a sphere, but subject to some unusual laws (Poincaré 1952a: 85–86; cf. LePoidevin 2003: 98–99; Huggett 2010: 34–35). In the sphere temperature is not uniform but diminishes towards the edge. It reaches absolute zero at the edge, which constitutes the boundary of the imaginary universe. The temperature, T, varies in such a way that absolute temperature is proportional to $R^2 - r^2$ (where R is the radius of the sphere and r is the distance of a point on the sphere to the centre) (Fig. 2.4). Furthermore, in this world all objects shrink in proportion to their change in temperature as they move away from the centre. 'A moving object will become smaller and smaller as it approaches the circumference of the sphere' (Poincaré 1952a: 65). This world will appear infinite to its inhabitants, since their bodies and measuring

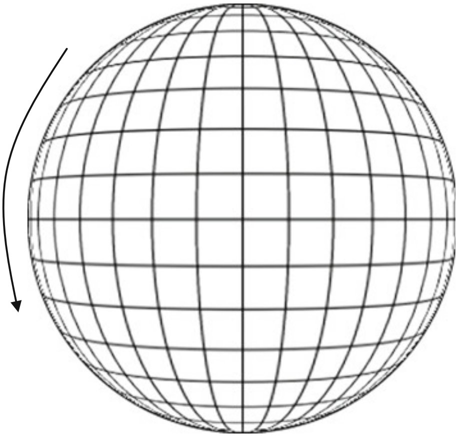

Fig. 2.3 *Hawking's no-boundary proposal* on the analogy of a globe with lines of latitude. The size of the universe increases with increase in imaginary time, as indicated by the *downward arrow*. Note that this cosmological model is asymmetric with respect to time, since the beginning is characterized by smooth conditions, whilst at the end the universe collapses into black holes (Hawking 1988: 138; see Penrose 2005: §25.8)

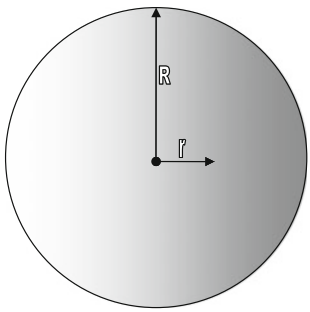

Fig. 2.4 Poincaré's Imaginary World, in which temperature varies with distance to the edge and objects shrink accordingly

tapes will become colder and smaller as they approach the boundary of the sphere. Even their steps will shrink in such a manner that they will never reach the edge.

Yet another response can be drawn from Leibniz's relational view of space. According to the German mathematician, physicist and philosopher G.W. Leibniz, space is the order of coexisting things, i.e. material objects are constitutive of space. A Leibnizian could argue that as long as there is matter—any kind of matter, even radiation—there is space. On such a view space may be unbounded but still finite since one could always add further material to expand the existing space, as it were. It would be an expanding space, although Archytas may well ask the question: Does the material not expand into a pre-existing space?

Such thought experiments are inconclusive because they are empirically underdetermined. They do not muster enough empirical evidence to secure the conclusion. Aristotle, for instance, could have defended his view of a closed cosmos by pointing out that the fixed stars form indeed the boundary of the material universe, and accept that Archytas's spear-wielding space-travelling demon could have penetrated it. His spear would have travelled through the layer of the fixed stars but not entered the vacuum beyond. This ether-like vacuum constitutes the habitat of the Deity—the Unmoved Mover—but it was no longer to be regarded as physical space. The postulation of an ether, beyond the boundary of fixed stars, would have allowed Aristotle to escape Archytas's conclusion.

Ad (2) *Thought experiments can be misleading*. Aristotle employed his tower argument to 'prove' that the Earth must be stationary. Instead it is the celestial objects —the sun, the planets and the 'fixed' stars—, which circle around the central Earth. The sun occupies the place of the Earth in the heliocentric view. The Greeks generally underestimated the distances of the planets from the 'centre'. Such miscalculations can lead to certain inconsistencies: the 'fixed' stars were said to reside at a distance of 20,000 Earth radii, which is less than today's Earth-sun distance of 150,000,000 km (Zeilik 1988: 29–31). Nevertheless the whole canopy of the fixed stars was supposed to rotate, from east to west, in a 24-h rhythm whilst a planet, like Saturn, which orbits below the sphere of the fixed stars, completes its journey in 30 years.

But the main inconsistency in Aristotle's 'proof' of a motionless Earth derives from his theory of motion. According to Aristotle's theory, every motion needs a mover and objects possess 'natural' places. A stone dropped from the height of the tower 'strives' back to Earth where it naturally belongs. By contrast, smoke rises to the sky, that is, to its natural place. In the thought experiment the tower is attached to the surface of the Earth. It moves with the spinning Earth. But what would be the source of the falling stone's motion? The air, it must be assumed, is not strong enough to give it a push in the horizontal direction of its motion. As it only has a vertical component, the source of its motion is its 'desire' to return to its natural place on Earth. It follows from Aristotle's reasoning that the tower, on the assumption of a spinning Earth, would have a centrifugal motion but not the falling stone. If the Earth turned on its axis the stone should land to the west of the tower because it does not partake of the centrifugal motion of the Earth. But as this displacement is not observed, it must be concluded that the Earth does not spin. So Aristotle reasoned. However, already Nicolaus Copernicus—the first modern proponent of heliocentrism—was able to parry the force of the Aristotelian argument by adopting the medieval impetus theory of motion. According to the impetus theory of motion a projector impresses a certain impetus—a motive force—onto the moving body, which equips it with motion. Applied to the Earth, this means that the motion of the Earth is not a violent but a natural motion. As Copernicus explained, 'the clouds and the other things floating in the air or rising up' take part in this natural motion of the Earth (Copernicus 1543: Bk. I, §8). Equally for the tower argument. The tower, the stone and the experimenter are part of the rotating reference frame and hence take part in the motion of the Earth. The stone falls straight down to the bottom of the tower, not because the Earth stands still, but because it is part of the reference frame, in which the experiment takes place. This phenomenon is well known to every traveller. A train moves at a constant speed in a straight line so that writing, reading, coffee drinking and dropping objects happens in the same way in a moving train as on a stationary platform. Physicists no longer accept the impetus theory but explain the phenomenon by reference to the principle of inertia. An object, if undisturbed by an external force, will either remain at rest or in rectilinear motion. Any object, which is part of the reference frame, will partake of this motion. Therefore an insect in a moving car will buzz around in the same way as in a room of a house. Just by following the erratic flight of the insect an observer will not be able to tell whether the insect is in a reference frame, which is at rest or in uniform motion. Hence the Aristotelian theory of motion is misleading because it is based on a mistaken premise: his theory of motion. As his theory of motion is mistaken, his thought experiment remains inconclusive.

Ad (3) *Thought experiments can lead to alternative conclusions*. Thought experiments can be retold from a different perspective, which may lead to an alternative interpretation of the phenomenon. They are not logically compelling (cf. Gendler 1998; Bishop 1999). Aristotle, Ptolemy and the Greek tradition provide what looks like compelling arguments against the motion of the Earth. But even during Greek antiquity there were some dissenting voices. Hiketas of Syracuse, and Heraclides Ponticus both taught the diurnal (daily) motion of the Earth. Aristarchus of Samos is reported to have taught both the daily and annual rotation of the Earth. But to the Greeks the evidence seemed to weigh so heavily in favour of a stationary Earth that it took some 1400 years before Copernicus was able to resurrect the ancient ideas and put them in a coherent framework. In his heliocentric model, Nicolaus Copernicus displaced the Earth from the centre of the universe. He bestowed on the Earth a dual motion: a daily rotation on its own axis and an annual rotation, from west to east, like the other planets, around the 'central' sun (Weinert 2009: Chap. I). Although Copernicus's work was largely based on the astronomical observations provided by his Greek predecessors, he arrived at a different conclusion, based on the impetus theory of motion. The impetus theory of motion was itself the result of a medieval thought experiment (see Fig. 3.1), whose purpose was to disprove the Aristotelian theory of motion. Such alternative conclusions are possible because thought experiments are inconclusive and empirically underdetermined. They do not replace real experiments. Yet, as the subsequent Chapters on the demons of science will show they are of considerable importance in the history of ideas. Many leading scientists grant them a leading role in scientific thinking.

Given the somewhat uncertain nature of thought experiments, it is not surprising that views differ on how to characterize such mental activities.

http://www.springer.com/978-3-319-31707-6

The Demons of Science
What They Can and Cannot Tell Us About Our World
Weinert, F.
2016, IX, 251 p. 40 illus., 8 illus. in color., Hardcover
ISBN: 978-3-319-31707-6