Einstein and the nature of thought experiments

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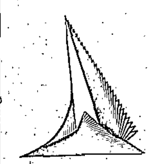

Reflections on thought experiments and Einstein's use of them

Students new to the work of Einstein are invariably introduced to his *annus mirabilis* and his use of *Gedankenexperiment* or thought experiments. Whilst four of the five *annus mirabilis* papers are explored in other articles in this or the March issue of *School Science Review* (see Box 1) and have perhaps become rather well known, how many stop to question the nature of thought experiments? Here I discuss the issue of the nature of thought experiments, which strikes at the very heart of contemporary research in the philosophy of science, and reflect on Einstein's use of them.

What is a thought experiment?

As with many things in science, especially physics, 'what if' questions are far easier to ask than to answer:

> *There are more things in heaven and earth,*
> *Horatio,*
> *Than are dreamt of in your philosophy.*
> (Hamlet 1.5 166–167)

and

> *A fool can ask more questions than a wise man can answer.* (Anon)

Both of the above statements come to mind here. However, by considering physics as 'natural philosophy' and taking a philosophical approach to the question we can always arrive at a view if not an answer. Philosophy involves the analysis of arguments, '*often aided by the formal methods and conceptual resources of symbolic logic (and other areas, such as probability theory)*' (Hitchcock, 2004). What follows can be considered an argument as to what constitutes a thought experiment.

Firstly, however, let us consider an example of a thought experiment that not only illustrates their nature but also the fact that this was not something new to Einstein.

ABSTRACT
This article addresses the nature of thought experiments, from ancient times to their use by Einstein for work on relativity. By taking this route, via the work of Galileo, it is hoped that the article will be both more readable and usable by teachers across a wide range of science disciplines.

Box 1 Discussions of Einstein's *annus mirabilis* papers in *SSR*

In the March issue (*SSR* **86**(316):

A great equation: *E = mc*² by Robert P. Crease (pp. 45–48)

Original Einstein paper: Does the inertia of a body depend on its energy content? *Annalen der Physik*, November 1905.

Teaching relativity to 10-year-olds by Christina Astin (pp. 34–35)

Original Einstein paper: On the electrodynamics of moving bodies. *Annalen der Physik*, September 1905.

Teaching the photoelectric effect by Christina Astin (pp. 36–38)

Original Einstein paper: On a heuristic viewpoint concerning the production and transformation of light. *Annalen der Physik*, June 1905.

In this issue:

Molecular reality: the contributions of Brown, Einstein and Perrin by Mick Nott (pp. 39–46)

Original Einstein paper: On the movement of small particles suspended in a stationary liquid demanded by the molecular-kinetic theory of heat. *Annalen der Physik*, July 1905.

The Roman philosopher–poet Lucretius (99–55 BC) wrote a six-book epic, *De rerum natura* (*The nature of the universe*) in which he addresses, amongst many other issues, the question of the finite nature of the universe. The following extract from Lucretius serves, in my view, as an exemplar for a thought experiment:

> *Let us suppose for a moment that space is finite;*
> *Then let someone proceed to the furthest boundaries*
> *You then have to choose whether you think it will travel*
> *in the direction he sends it, as far as you like,*
> *or whether you think that something will get in the way.*
>
> *With neither answer can you avoid the conclusion*
> *that the universe stretches out on all sides forever,*
> *for whether the spear finds something in the way*
> *and cannot proceed, or whether the way is open,*
> *the point it started from is not the end of the universe.*
>
> *In this manner one can go on, and wherever you put the limit*
> *I shall ask: Now, where is the spear?*
>
> *There is no point at which you can set a boundary;*
> *The more space you give the spear, the further it goes.*

So a thought experiment, I contest, has three requirements:

- It is carried out in the mind (however one cares to define 'mind' – see Squires, 1990, for a discussion).
- It draws on experience.
- It allows the *experimenter* to *see* what is happening (perhaps a better term to use than 'see' is 'imagine' or 'form a mental image').

I further contest that thought experiments, based on the three points above, are arguments following the 'premise–inference' approach common to all deductive arguments. That is, take the premise if p then q; take the condition there is p; the inference is then that there is q. However, this approach does rely on the premise being true and as such is not infallible. The classic example here is to demonstrate that $1 = 2$ (see Box 2); it is left to the reader to spot the flaw in the premise.

Box 2 Demonstrating that $1 = 2$

Spot the flaw.

When $1 = 2$

Let $x = y$

Then $x^2 = xy$

$x^2 + x^2 = x^2 + xy$

$2x^2 = x^2 + xy$

$2x^2 - 2xy = x^2 + xy - 2xy$

$2x^2 - 2xy = x^2 - xy$

$2(x^2 - xy) = 1(x^2 - xy)$

Therefore $2 = 1$

Often thought experiments are either not capable of being performed, as in the Lucretius example, or would give the wrong result if they were. Consider the famous Galileo experiment of dropping balls from the tower at Pisa. The result holds for objects dropped in a vacuum but Italy was not in a vacuum when this experiment was supposed to have taken place. In fact it is more likely that Galileo never carried out a real experiment; rather he carried out a very simple thought experiment commenting:

> *Without experiment, I am sure that the effect will happen ... because it must happen that way.* (Galileo, 1632)

Referring to the earlier quote by Hitchcock, and taking an approach based on Brown (2004), we can see how this works in 'symbolic logic':

> The rate of falling of a 'heavy' ball is H.
>
> The rate of falling of a 'light' ball is L.
>
> If a heavy ball falls faster then $H > L$.
>
> Therefore the two together must fall faster than the heavy ball alone since $(H + L) > H$.
>
> But the two together must also fall slower than the heavy ball alone since the light ball will drag the heavy ball (see endnote 2) and this can be notated as: $(H + L) < H$.
>
> The only way this can be true is if $H = L = (H + L)$.

Striving for contradiction?

Given that I accept thought experiments to be arguments, then, just as any two opposing arguments strive to contradict each other, opposing thought experiments must fail either on the grounds of a false premise or a fault in the logic of the inference. Indeed one could argue that in this way thought experiments do not differ from real experiments: if one contradicts the other then one or other must be at fault. In the context of Einstein this is true of the Michelson–Morley (1887) experiment (see endnote 3). When carried out in 1887 the results suggested that there was no ether through which everything moved, but repeated versions from 1921 to 1933 by Dayton Miller (see http://www.alternativescience.com/ether.htm) reported evidence for ether drift. In this case the inference from his results was taken, by him, to be the existence of the ether rather than others' ideas that there may be other possible explanations, such as incorrect experimental procedure.

Einstein and thought experiments

As a young man Einstein imagined himself running alongside a beam of light. What would it look like? The wave would appear to him to be stationary:

> *I should observe such a beam as a spatially oscillatory electromagnetic field at rest. However, there appears to be no such thing, whether on the basis of experience or according to Maxwell's equations.* (Einstein, 1949)

Taking the three requirements outlined above we can see that this qualifies as a thought experiment:

- ☐ It was carried out in the mind.
- ☐ It drew on previous experience, Maxwell's equations.
- ☐ It allowed Einstein to *imagine* what would happen.

Indeed, Kuhn (1977) suggests that any thought experiment must have two characteristics, which are in keeping with the above (for further discussion, see Helm and Gilbert, 1985):

- ☐ The use of concepts in a way they have been used before.
- ☐ The conflict confronting the 'experimenter' must have confronted them before.

However, it could be argued that in a strict Kuhnian sense Einstein's work on synchronised clocks would not meet the second condition since Einstein had not been confronted with the issue before the thought experiment.

And so to trains ...

It would not be the done thing to fail to explore the path of light in a moving train as an example of a thought experiment. Imagine, as we can with thought experiments, a clock consisting of a light pulse reflecting between two perfect mirrors, such that the time taken for the pulse to return to the lower mirror is one second, encased in a transparent box. The path of the light viewed by an observer on the train, that is at rest relative to the clock, would be as shown in Figure 1.

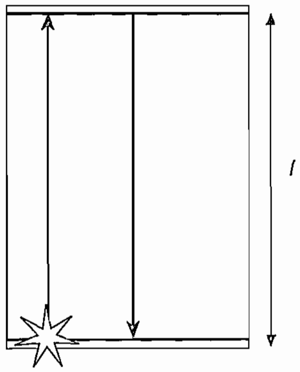

Figure 1 Light clock as viewed by observer on the train.

However, if the same clock is viewed by an observer on the platform as the train travels by at half the speed of light – remember this is a thought experiment – then the path of the light pulse would resemble that shown in Figure 2.

The two observers then see the pulse of light travelling different distances in one second. For the observer on the platform this is:

$$h^2 = s^2 + l^2$$

where $s = l = 1.5 \times 10^8$ m.

Hence the total distance is 4.24×10^8 m.

However, the first postulate of special relativity does not allow for anything, even light itself, to travel faster than 3×10^8 m s^{-1} and therefore the two results cannot agree.

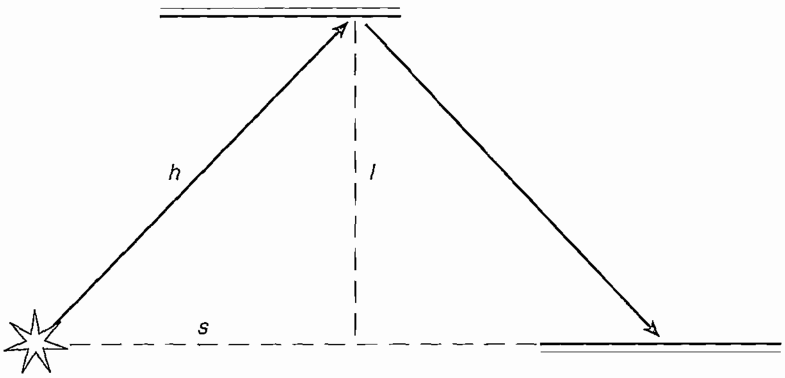

Figure 2 Path of light viewed from the platform.

Thought experiments and paradox

Thought experiments, if pushed too far, often appear to give rise to a paradox. This is very often true for relativity when one reads the many claims to have 'shown that' relativity is flawed; see, for example, http://www.btinternet.com/~time.lord/Relativity.html. One of the most often misquoted paradoxes is the 'two twins experiment'.

Imagine two twins of near identical age (each with an identical clock). Bob stays on Earth and Alice travels, in a spacecraft, at near the speed of light to a distant place before returning at a similar speed. From Bob's perspective, Alice's clock appears to run slow, thus putting Bob's ahead. However, from Alice's perspective the Earth is moving and hence she sees Bob's clock running slow, thus putting her clock ahead of Bob's.

The paradox appears to arise from the argument above which suggests that when Alice returns to Earth her clock will be both in front and behind Bob's and she will be both younger and older than him. In reality there is no paradox and Alice will have aged more slowly than Bob. The argument above relies on a symmetry that does not exist; the rocket accelerates from Earth and must undergo three more accelerations in turning round and returning and landing on Earth. A very neat approach to explaining the twin paradox can be found in Linton (1997).

The so-called twin paradox has been demonstrated experimentally in many ways and at many times. In my view the classic demonstration remains that of Hafele and Keating (1972), when caesium atomic clocks were flown around the Earth on scheduled commercial flights. The flight path of the eastward flying clock predicted a time loss of 40 ± 23 ns when compared to a reference caesium atomic clock at the US naval observatory. The results show a loss of 59 ± 10 ns, showing an '*unambiguous empirical resolution of the famous clock "paradox" with macroscopic clocks*'.

Endnotes

1 The fifth of the 1905 papers is 'A new determination of molecular dimensions', which was Einstein's doctoral thesis and, whilst being submitted to *Annalen der Physik* in August 1905, some amendments were required and it was not published until February 1906.

2 It is a moot point as to whether the view that a light ball would drag the heavier one back would be accepted by all – a strong case exists for this not being so in the Aristotelian view.

3 It is one of the many myths surrounding Einstein that he developed the constancy of the speed of light and hence special relativity from the premise of the Michelson–Morley result. Einstein developed special relativity from the premise of constancy of the speed of light embedded in Maxwell's equations.

Acknowledgement

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