# THOUGHT EXPERIMENTS IN THE PHILOSOPHY OF PHYSICAL SCIENCE

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IT is sometimes said that the aims and methods of philosophy of science resemble those of science itself. Bunge, for instance, believes that the scientific method should be applied to the philosophical study of science (Bunge 1973, p. 19). Such a claim is not particularly interesting or controversial until it is spelled out in more detail: we need to know what the scientific method is and why it should be applied to the philosophical study of science. (Bunge does in fact tell us his view, in typical forthright style). I am not, however, convinced that there is such a thing as the scientific method; it is, I think, more likely that science uses an array of methods. If this is true, then it may be asked which, if any, of these methods should be applied to science as well as in science. So, if thought experiments are regarded as representing a method of science, it may be asked whether this method has application in philosophy of science[1].

I shall attempt to provide an answer to this question by considering a topic in the philosophy of physical science, namely the analysis of the idea of a *quantity*. This topic is, in my view, an important one. Physical science is characterized by certain sorts of laws, styles of explanation, measurement practices, and so forth. The task of the philosophy of physical science is thus to determine what these characteristics are, to identify the kinds of laws, explanations, measurements, etc., found in physical science. To accomplish this task, it is necessary at some stage to focus on the idea of a quantity, for it is quantities that are the objects of measurement and explanation and it is quantities that are related to one another in laws. We would not, in my view, then be too far wide of the mark if we were to distinguish physical science from other fields of science by stating that the aim of physical science is to investigate the relations between quantities that are found in the world. But there has been relatively little attention paid to the idea of quantity, as compared to, say, explanation and law. This is one reason why it is worthwhile to consider whether thought experiments might play a role in the analysis of the idea of a quantity. Another is that recent discussions about the nature of quantities have typically made mention of certain imaginary situations. Ellis, for example, invites us to consider a universe that contains just one object and then asks whether that object could have any quantities. These imaginary situations are candidates for thought experiments in philosophy of science. To decide whether these situations do indeed constitute thought experiments, we need some independent account of the nature of thought experiments. For this purpose I shall make use of an account of thought experiments in science which is, essentially, due to John Norton[2]. It would, however, be helpful if this account could be used not only to decide whether the situations in question constitute thought experiments, but also whether they are *good* thought experiments. If they are "good," then presumably we will be inclined to accept the conclusions that can be drawn from them.

## I. Thought Experiments in Science

In his contribution to this volume, John Norton characterises thought experiments as follows:

*Thought experiments are arguments which:*

i) posit hypothetical or counterfactual states of affairs, and

ii) invoke particulars irrelevant to the generality of the conclusion.

(Norton, 1991, p. 85)

He goes on to show, convincingly, that these characteristics are exemplified by Einstein's use of thought experiments. He does not, however, claim to give a definition of thought experiments, only necessary conditions. Norton points out that one could add premises that posit counterfactual states of affairs to any argument with a general conclusion, and provided that any particulars mentioned in these premises were irrelevant to the conclusion, i) and ii) would be satisfied. He also mentioned that not every particular that could be invoked will have the "appropriate experimental character." Hence, to come up with sufficient conditions, more must be said about the particulars that can legitimately be invoked in the arguments that constitute thought experiments. It is not John Norton's intention to identify sufficient conditions for thought experiments, and what he has to tell us about Einstein's use of thought experiments does not turn on anything as precise as a definition of thought experiments. Nevertheless, for present purposes it will be helpful if we can say a little more about them.

To this end, notice that we can deal with the first of Norton's strictures simply by requiring that the arguments have no redundant premises. The second, however, is less easy to deal with. The counterfactual or hypothetical state of affairs should be "experimental," if it is to be posited in a thought experiment, but what, exactly, does this amount to? I shall leave this point to one side for the moment, and focus on another aspect of Norton's characterisation, namely that thought experiments are arguments. Arguments can be used for a variety of purposes: to prove a theorem, support a proposition, convince an opponent, to give an explanation, and so on. It may, then, be possible to become a little clearer about thought experiments by asking about the purpose or *function* of the arguments which constitute them. Norton states that thought experiments in physics provide, or purport to provide, us with information about the physical world (Norton 1987). So this, I take it, is his view about the function of thought experiment arguments. But we may wonder how this function can be fulfilled by positing *counterfactual* or *hypothetical* states of affairs, because these are not part of the physical world.

An alternative view about the function of thought experiments is entertained by Kuhn. Kuhn considers the possibility that thought experiments produce, not new understanding about nature, but new understanding about the scientist's conceptual apparatus (Kuhn 1977, p. 242). Thus, by considering how concepts and theories might be applied to certain imaginary situations, it may be possible to discover hitherto unknown incoherences and inconsistencies in them. For this purpose, information about the physical world is not necessary. And it would seem that at least some of the thought experiments of Einstein mentioned by Norton are primarily concerned with such matters. The verifiability heuristic mentioned in Norton's Section 3, for example, is a heuristic for theory construction. The first version states that a theory should not use terms that have no import for observation. Thus, in the famous magnet and conductor experiment mentioned at the beginning of "On the Electrodynamics of Moving Bodies," Einstein shows that the presence of the electric field which, according to classical electrodynamics, is induced by the movement of the magnet, produces no additional effort over and above that observed when the conductor is set in motion, where there is no induced electric field. But does this tell us anything about the world? Surely we *already* knew that if a conductor and magnet are in relative motion, a current is set up in the conductor. In fact the thought experiment, if it is to be effective, must presuppose this fact. One might then conclude that what is counterfactual or hypothetical in this example is the existence of the electric field. And the lesson to be learnt is that we require a theory that does not have the consequence that such a field exists under the conditions of the experiment.

I may have given the impression that Norton's view about the function of thought experiments is altogether different from that entertained by Kuhn. This would be the case if the activities of theory construction and conceptual clarification provided no information about the world. But this is not true, as Kuhn himself acknowledges. Kuhn maintains that such theoretical activity provides new *understanding* about the world (Kuhn 1977, p. 261). This can happen when we attempt to apply our existing conceptual framework to new situations, situations that we may experience or which we may posit. For instance, in the first Galilean dialogue, Salviati considered a thought experiment involving balls rolling down the sides of a triangle. If ABC is a right angle triangle with hypotenuse CA, then Salviati asked how the Aristotelian concept of speed could be applied to the motions of balls sliding down CA and the perpendicular CB to determine which is faster. The well-known result of this experiment is that the application of the Aristotelian idea leads to three equally good yet mutually incompatible answers to the question as to which moves faster[3]. Hence the ground is prepared by Galileo for the introduction of a new concept of speed. Kuhn states that there is nothing self-contradictory about the Aristotelian idea of speed. It is only when this is applied to certain particular situations that confusions, such as those made apparent to Sagredo and Simplicio, ensue. Had we not been aware of these situations, then we would have felt no need to introduce new concepts. But if there is no possibility that the sorts of states of affairs posited in thought experiments which suggest revisions of our framework of concepts may be encountered in the world, then there would be no point in implementing such revision. For the aim of science, ultimately, is to understand the world. Hence a "good" thought experiment will lead to conceptual change which in turn results in new experience and new observations.

Thus, the views Norton and Kuhn about the function of thought experiments resemble one another more closely than we might have expected. If Norton had expressed the function of thought experiments in terms of understanding about the world, rather than mere information, then his position would be virtually identical to that of Kuhn. This judgement is in fact borne out by Norton's examples. As we have seen, Einstein's magnet and conductor experiment shows that the application of classical electrodynamics leads to an asymmetry, namely the presence of an induced electric field when the magnet moves but not when the conductor moves. This is not an inconsistency, but, as Norton shows, it violates Einstein's verifiability heuristic. If the special theory was a consequence of Einstein's use of this heuristic in theory construction, then the magnet and conductor experiment may be seen to play some part in the discovering of the new understanding of the world provided by special relativity. It plays a part insofar as it demonstrates that classical electrodynamics is not constructed in conformity with the verifiability heuristic and hence that some new theory is needed.

By focusing on the function of the arguments that constitute thought experiments, we have, I think, become a little clearer about the nature of thought experiments. For example, we are now able to say something about the particulars mentioned in Norton's condition ii). The experimental character of these particulars would thus seem to pertain to their relation to the framework of scientific concepts. It may be that this framework cannot be applied to them in a consistent or unambiguous way, as was the case in Galileo's thought experiment, or it may be that ingredients within the framework, i.e., theories, endow the particulars with properties that have no import for observation, as was true of Einstein's thought experiment. There are, doubtless, many other ways in which our concepts and theories can be affected by particulars mentioned in thought experiments. We could, therefore, formulate a third condition for thought experiments in terms of their function to append to Norton's two necessary conditions and then claim to have jointly necessary and sufficient conditions. I am, however, a little hesitant to do this, since the conditions may only capture what are considered to be "good" thought experiments, and rule out those that are not effective. Nevertheless, when we turn to thought experiments in the philosophy of science—if there are such things—particular attention should be paid to the functions which these fulfill.

## II. Quantities and Measurement

We learn about quantities through measurement, and by reflecting on measurement practices and results thereby obtained it is possible to reach some general conclusions about quantities. For example, if two things $x$ and $y$ have a quantity $q$, then $x$ and $y$ will be comparable with respect to $q$. They will either be equal in $q$ with respect to one another, or one will be greater in $q$ than the other. In symbols

$x =_q y$ 1a

$x >_q y$ 1b

$y >_q x$ 1c

This is a conclusion which is suggested by reflection on measurement practices. Measurement carried out in the laboratory, measurement of weight, temperature, resistance, etc., is normally conducted by means of instruments calibrated with reference to standards on some scale, such as the gram scale, Celsius scale, ohm scale, and so on. Hence what is obtained is a reading on that scale. But this presupposes that the scale in question has already been set up. And this in turn involves devising a system of standards that can be compared to objects that have the quantity in question by means of measurement operations.

The process by which a value for a quantity is obtained involves, essentially, comparison with a standard. In some cases this is explicit in that the standard is actually used in the measurement, as it is with the equal arm balance; more often it is implicit in that the standard has been used to calibrate an instrument, as is the case with the spring balance. Consider the equal arm balance. If an object $a$ is placed on the left hand pan and the standard $s$ on the right hand pan, then either the pans will remain in a balanced or underflected state, or there will be a deflection. If we represent these states by $B(a,s)$, $D(a,s)$ and $D(s,a)$, and if the value assigned to $s$ (by convention) is one unit, then

If $B(a,s)$, then $w(a) = 1$ 2a
If $D(s,a)$, then $w(a) < 1$ 2b
If $D(a,s)$, then $w(a) > 1$ 2c

where $D(s,a)$, $D(a,s)$ signify respectively, that the right hand pan moves down and left moves up and that the left moves down and the right moves up, and where $w(a)$ is the value assigned to $a$ as the measure of its weight on the s-scale. We assigned, for instance, $w(a) < 1$ to $a$ if $D(s,a)$, because we know, in virtue of the principle of moments, that if $s$'s pan moves down and $a$'s moves up, then $s$ is heavier than $a$. In other words

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|---|---|
| $B(a,s)$ only if $a =_w s$ | 3a |
| $D(s,a)$ only if $s >_w a$ | 3b |
| $D(a,s)$ only if $a >_w s$ | 3c |

> where $a =_w s$ means that $a$ is equal in weight to $s$, $s >_w a$ means $s$ is greater with respect to the quantity weight than $a$, etc. Here the relationships 3 underpin 2: they justify the assignments of values expressed in 2 in that, for instance, it is only correct to assign $w(a) = 1$ given $B(a,s)$ on condition that 3a holds. 3 are prior to 2 in the sense that 2 presuppose that a scale, the s-scale, has already been set up, whereas 3 do not.

Now all assignments of values to objects by measurement are inferences from conditions such as 2. These inferences are not normally made explicitly, since, as I have mentioned, most measurements are made using calibrated instruments. Nevertheless, as I have suggested, calibration ensures that an implicit or "inbuilt" comparison with a standard is made when the instrument is used. For example, a spring balance is calibrated by marking divisions on a fixed scale that record the extensions produced by standards. So if object $a$ produces an extension which designates the numeral 1 on the fixed scale, the value $w(a) = 1$ is assigned on the assumption that $a$ produces the same extension as the standard $s$. Furthermore, all assignments are underpinned by conditions like 3, conditions which establish a relationship between states of affairs manifest on the application of measurement operations and the actual relation between test object and standard object in the quantity[4]. Standards are selected from the domain of objects that have the quantity in question on grounds of convenience. Any object *could* serve as a standard. Hence, the relations that hold between a standard and a test object do not do so in virtue of some special attribute of standards. Rather, such relations will hold throughout the domain of the quantity. So, by reflecting on measurement practices we can conclude that objects that exhibit a quantity are necessarily comparable with respect to that quantity in accordance with expressions 1. Such relations are the basis of all measurement.

## III. Quantities and Thought Experiments

Let us now ask what, exactly, a quantity is. There are two answers that have been given to this question, namely that quantities are classes and that quantities are properties. If a quantity is taken to be a property, then the property must be a *quantitative* property—one that admits of degrees or has associated *magnitudes*—as opposed to a qualitative property. If $q$ is taken to be a class, then the class must be *ordered* in accordance with 1. Those who advocate what I shall call the quantities-as-properties view will accept that quantities have associated with them ordered classes but will maintain that the orders are consequent on the order of the magnitudes of the quantity. So if $x >_q y$, then the quantities-as-properties theorist will claim that this is the case because the magnitude of $q$ possessed by $x$ is greater than that of $y$. However, those who incline to the nominalist or extensionalist view that quantities are classes maintain that the order of a quantity is *sui generis* and hence not capable of further explanation. If we can get by without introducing magnitudes, then we may well prefer the nominalist view on the grounds of simplicity. But other considerations besides simplicity must first be taken into account and it is here that the imaginary situations mentioned above are relevant.

As I have said, Ellis invites us to consider a universe which contains just one object. Suppose we refer to this as object *e*. If properties are *inherent* in objects, then *e* may possess qualitative properties such as being yellow, being shiny, being made of aluminum, and so forth. And it will also, on this view, have quantitative properties, such as having a mass of 10 grams, a resistance of 5 ohms, a temperature of $20^0$ Celsius, etc. Ellis takes it to be part and parcel of the quantities-as-properties view that

> All this exists, so to speak, before measurement begins. The process of measurement is then conceived to be that of assigning numbers to represent the magnitudes of these pre-existing quantities; and ideally it is thought that the numbers thus assigned should be proportional to these magnitudes. (Ellis 1966, p. 24).

Ellis dismisses this view of quantities on the ground that it overlooks the essentially relational character of quantities. He believes that when we say that an object has a quantity, we are talking about its relationships to other objects, and not about the object in isolation (Ellis 1966, p. 25). The quantities-as-properties theorist is, apparently, willing to talk about an object having quantities in total isolation from any other object. *e* is the sole occupant in its universe and hence (provided we reject trans-world relations among individuals) has no relationship with any other objects.

The proponent of the other view of quantities, namely that these are ordered classes, will claim that *e* does not possess any quantities. If *e* is all there is, then *e* will be a member of a class, the class of things which has *e* as a member, but there will be nothing else in the class. Since it is necessary for there to be two or more things before there can be an order, it follows that no ordered classes can be constructed out of the contents of *e*'s universe. The extensionalist account of quantities does not take quantities to be inherent in objects but as constituted by the relations of objects to one another. The extensionalist will therefore understand a statement like "*b* is 5 grams in weight" to describe *b*'s relations to other objects in the order of weight. These relations will have the form of expressions 1. By assigning *b* the value of 5 on the gram scale, we mark the place of *b* in the order of weight in accordance with 2 and 3. To say that the weight of *b* is 5 grams is, as it were, a shorthand description of *b*'s relations to other objects that have weight.

Can we classify Ellis' reasoning as a thought experiment, and if so is it a good thought experiment? Ellis formulates an argument in which he posits a counterfactual state of affairs, *e*'s being the only object in the universe, in which a particular, *e*, is mentioned which is irrelevant to the generality of the conclusion. The conclusion is that the quantities-as-properties theorist fails to express the essentially relational character of quantities. The particular *e* is clearly irrelevant to the generality of this conclusion because Ellis could just as well have introduced another particular as the sole occupant of the universe. It is evident, then, that Norton's conditions for thought experiments are satisfied. With regard to the function of the argument, Ellis' intention is to confront the quantities-as-properties position with a certain state of affairs and so demonstrate that this view attributes quantities where none should be attributed. In so doing he believes, I take it, that he is giving some clarification of the concept of quantity and hence is making some progress towards gaining greater understanding of physical science. This, presumably, is the point of thought experiments in the philosophy of physical science. If thought experiments in science are ultimately supposed to increase our understanding of the world by contributing to the process of changing the framework of concepts in terms of which we think about the world, then thought experiments in philosophy of science should be directed towards changing and clarifying the concepts that pertain to science itself. This is precisely what Ellis is trying to do.

I do not, however, believe that he is completely successful. If thought experiments in science are to lead to new understanding about the world, then the counterfactual states of affairs should not be *too* different from actual states of affairs. Outlandish situations in which energy is not conserved, entropy decreases, infinitely fast signals exist, time "flows" backwards and forwards at random are not likely to prompt any new knowledge about our world. Since these states violate many of our laws and theories, they have little relevance. Kuhn makes a similar point with regard to concepts. He believes they should not be such as to be applicable in an appropriate manner to any possible situation, rather, it is sufficient to demand that they can be applied correctly to any situation we are likely to meet (Kuhn 1977, p. 254). There may, however, be certain hypothetical situations that we will never meet, such as balls rolling down frictionless planes, so perhaps Kuhn is being overly restrictive. But if we were to say that the situation and states of affairs posited in thought experiments *sufficiently resembled* those that do actually exist and are such that the former enable us to better understand the latter, then I think this would be a substantially correct position with regard to good thought experiments.

Now it would seem that a universe containing just one object is fairly remote from anything we are likely to encounter. The quantities-as-properties theorist could then respond to Ellis as follows: The idea that a quantity is an inherent property may apply to *e* even though *e* is the sole occupant of its universe, but this does not matter since this notion applies to situations closer to those that we are likely to encounter in such a way that the relational character of quantities is captured. Thus, if more than one object exhibits q, then they stand in an order in virtue of the inherent magnitudes they possess. So if $a >_w b$, then this is because the magnitude of *a*'s weight is greater than that of *b*. Since any confusion or incoherence engendered by the application of this concept of quantity will only result when it is applied in single object universe, such confusion will not result when the concept is applied in our universe. This response is, I think, quite congent.

Ellis' thought experiment does, however, have another dimension. The conclusion which he draws from his experiment is that quantities are not inherent properties. But in the passage quoted above, he draws attention to a tendency of the quantities-as-properties theorist to believe that values assigned in measurement are proportional to inherent magnitudes. Yet those values are *conventional* in several respects. For instance, the selection of a particular lump of platinum as the kilogram standard is a matter of convention, as is the assignment of the value 1000 grams to it. Hence assignments on the gram scale embody both of these conventions. So if object *a* weights 7 grams, 7 is *not* proportional to anything like its inherent weight magnitude. Although quantities-as-properties theorists do, I think, sometimes tend to reify conventional aspects of measurement, it is by no means necessary to do so in order to adopt the view that quantities consist of magnitudes[5]. A quantities-as-properties theorist can maintain that these magnitudes do not have any specific values associated with them prior to the setting up of scales of measurement. Ellis' argument is therefore telling only against certain versions of the quantities-as-properties viewpoint. It could be said here that Ellis does not really need to introduce a single member universe to make this point; he could equally well have pointed out the conventional aspects of measurement as it is normally practised. The fact that there are other avenues to a conclusion reached by a thought experiment does not, however, mean that the experiment in question is not a good one. Furthermore, if Ellis had developed his case in a slightly different way and had asked what must be presupposed in order to assign 10 grams, 5 ohms, 200 celsius, etc., to *e*, he would have effectively demonstrated the conventional aspects of such assignments. He would have shown that the preconditions necessary for such assignments were not satisfied in *e*'s universe, and hence any version of the quantities-as-properties position that entails that such assignments can be made is seen to be untenable.

I shall now consider some lines of arguments that have been urged against the extensionalist account that objects are ordered classes. I think it is true to say that many people would tend to dismiss this account in view of the well-known problems associated with the extensionalist position with respect to properties in general. Although it is not my intention here to defend this account, I believe that it is a viable position for quantities. This is because the counter-examples and thought experiments direct against extensionalism about quantities are not as effective as those directed against extensionalism about properties in general. With regard to the example just discussed, I suggested that this was not a good or effective thought experiment if it was intended to demonstrate that all versions of the quantities-as-properties account is untenable, but that is effective against certain versions of this account. In what follows I will give examples of both good and bad thought experiments directed against extensionalism.

To begin, it is worth mentioning an argument given by David Armstrong—which he himself calls a thought experiment (Armstrong 1978, p. 7)—which is very similar to the Ellis thought experiment, but which, so to speak, points in the other direction. Armstrong asks us to consider a white thing. It is a member of the class of white things. Now imagine the rest of the class no longer exists. The class of white things now only has one member. But the thing is still white, and hence the rest of the members of the class which previously existed had nothing to do with its whiteness, and hence being white is not a matter of belonging to the class of white things. If we suppose *e*'s universe to have evolved from a universe that contained many things besides *e*, things that had mass, temperature, resistance, etc., then it could be argued that *e* retained these quantities after its fellows no longer existed (cf. Forge 1987). These are both thought experiments, for essentially the same reasons as for Ellis' experiment, but they are not good ones. Armstrong *assumes* that the white thing is still white after the rest of the members of the class of white objects have ceased to exist. But surely this presupposes the point at issue, namely that being white is an inherent property and not a matter of class membership. The same can be said about the other experiment.

Turning to another thought experiment directed against extensionalism about quantities, we can also mention Armstrong. Armstrong points out that the "really notorious weakness" of extensionalism in general is that there could be two distinct properties *F* and *G* that have exactly the same extensions. This is not itself a thought experiment, as *F* and *G* are not particular properties, it is more like a scheme for constructing thought experiments. It is not, however, necessary to develop *thought* experiments in order to uncover the inadequacies of extensionalism about properties in general. As everyone knows, everything which has a heart also has kidneys, hence the class of things that have hearts is identical to the class of things that have kidneys. But it would seem that the properties in question are not identical. No hypothetical or counterfactual states are needed in order to attack extensionalism about properties as a whole. However, I do not think that there are in fact any examples of co-extensive *quantities*. For two quantities to be co-extensive, not only would the quantities have to be exemplified by the same objects, the *order* of these objects would have to be identical. Quantities are not merely classes, they are *ordered* classes. The criterion for the identity of quantities is thus sameness of order (Ellis 1966, p. 32). If it is true that there are in fact no co-extensive quantity, then the "really notorious weakness" of extensionalism as it applies to quantities must be exemplified by some counterfactual or hypothetical state of affairs.

Suppose $F$ and $G$ are mass and resistance and consider a universe that contains only lengths of copper pipe of uniform diameter. The order of mass will, in this universe, be identical to the order of resistance. For if $x >_m y$, then $x >_r y$, where $>_r$ is the order of resistance. This is clearly a thought experiment. It introduces a counterfactual state of affairs, a universe consisting of copper pipes, and it mentions particulars irrelevant to the generality of the conclusion—we could have considered lumps of platinum and the quantities density and heat capacity. It is an argument intended to show the untenability of extensionalism about quantities. But it is not, I think, a good thought experiment for it is too far removed from our actual practices of measurement.

Many quantities are, in actual fact, extensive. What this amounts to is that the class of objects in an extensive quantity is closed under a concatenation operation $\sigma$. The operation can be interpreted in various ways depending on the quantity in question. For small objects, the concatenation operation for weight can be interpreted as the placing of pairs of objects on the same balance pan. Thus for any "small" objects $x$ and $y$, the concatenated or composite $x\sigma y$ can be understood simply as the result of placing $x$ and $y$ together on a balance pan. If $w(x)$ and $w(y)$ are the values assigned to $x$ and $y$ measures of their weights, then we find that $w(x) + w(y) = w(x\sigma y)$. Now mass and resistance are both extensive quantities, but the way in which the contenation operation is interpreted for objects that have both quantities is not the same for each quantity. Suppose that two identical pieces of copper pipe are connected in parallel by welding them together. The mass of this concatenated object will be twice the mass of its two parts but its resistance will be the same as that of its parts. If this object was then introduced into the copper pipe universe, then the order of mass would no longer be identical to the order of resistance.

In actual practice we will be able to discern differences in the orders of objects with respect to extensive quantities by performing certain measurement operations on them. Our concept of quantity should accord with our measurement practices in that it should designate the sort of entity that we discover by means of measurement. The thought experiment described above only seems to be effective when we do not take into consideration an important aspect of measurement, namely the investigation of composite objects. So even if it is allowed that the application of the concept of quantity to a universe consisting of copper pipes is at all relevant, the thought experiment can still be said to be ineffective because it fails to support its conclusion when we come to consider composite objects. To be effective in demonstrating that extensionalism about quantities suffers from the same fatal defect as extensionalism about properties in general, a thought experiment should posit a situation in which our normal practices of measurement can be carried out[6].

The experiment just considered is supposed to show that the identity conditions for classes, same membership and same order, leads us to conflate quantities. The case I shall consider now is intended to demonstrate that the notion that quantities are ordered classes is too wide: there are some ordered classes that are not quantities. It has been mooted in parliament that each Australian resident is to be issued with an identity card bearing photograph, a number and other details. If such cards were issued, then all Australians would be members of a class, namely the class of Australian residents, that can be ordered, namely by identity card number. However, suppose that the government office in charge of the cards made a dreadful mistake and issued everyone in Australia with cards bearing the number 0, except for two individuals who were issued cards bearing 1 and –1 respectively. But this still leaves us with a (partially) ordered class and furthermore a class closed under concatenation. The concatenation is simply the addition of the numbers on any identity cards. It would seem, then, that the class of Australians now constitutes an extensive quantity.

The state of affairs that I have just described is a hypothetical state of affairs in that Australians do not have identity cards (yet); and if they did I think it very unlikely the numbering mistake would go undetected. Furthermore, it is used in an argument, an argument that it is intended to establish that the extensionalist view of quantities is too wide. The only one of Norton's conditions for thought experiments that may not appear to be satisfied is that concerning particulars irrelevant to the generality of the conclusion. The particular cited is the class of Australians ordered with respect to identity card number. If this was the only possible counter-example, then it would not be irrelevant to the conclusion that extensionalism about quantities is too wide. However, it is evident that we can construct as many other counter-examples as we wish. Consider any class of n people, issue n–2 of them with cards bearing 0, one of the remainder with a card bearing the number x and the other a card bearing –x. The class will then count as an extensive structure. Hence our particular is irrelevant to the generality of the conclusion.

The extensionalist would do well in the light of this thought experiment to retreat from the position that the existence of an ordered class is sufficient for the existence of a quantity. He or she may, however, now propose that an ordered class is a quantity only if the members of the class stand in some definite relation with those of some other ordered class. For example, consider the class of resistors, the class ordered with respect to resistance. If an identical constant voltage is applied to every member of this class, then the order of current flow will be the inverse of the order of resistance. There is, then, a definite *correspondence* between the orders of the two classes. The extensionalist may therefore claim that ordered classes embedded in networks of correspondence of the kind just indicated are quantities, but that isolated ordered classes are not. It would seem that the class of Australians ordered with respect to identity card number is an isolated class in this sense.

The thought experiment just considered is a good one because it directs our attention to the framework of concepts used to describe physical science in such a way that it becomes evident that quantities must be regarded as standing in certain correspondences with one another. We may have had other reasons to believe this. But, as I said previously, a good thought experiment is not necessarily the only way to reach a particular conclusion. The thought experiment is thus effective because it fulfills the sort of function that Kuhn proposes for thought experiments in science. It increases our understanding of science by focusing attention on the concepts we apply to science in such a way as to such certain changes in these concepts, changes that involve regarding quantities as ordered class embedded in networks of correspondences rather than as isolated and unconnected. Perhaps I should add that the experiment is a good one only if one inclines toward extensionalism. It is not quite so good from the point of view as the quantities-as-properties theorist since it not only fails to eliminate the rival view, it leads to a strengthening thereof.

## Conclusion

I have suggested that there are thought experiments in the philosophy of physical science, and hence that this particular method is found both in science and in philosophy. In conclusion I would mention what seems to be a point of difference between the way this method is used in the two disciplines. It would seem that the hypothetical or counterfactual states of affairs posited in thought experiments should "sufficiently resemble" those we are likely to encounter. In philosophy of science I think it is much less easy to tell when this condition is satisfied and hence that there is room for debate and disagreement. In science, on the other hand, our theories are sufficiently well developed that the resemblance between the counterfactual or hypothetical situation posited and any situation we are likely to encounter in the world is much easier to identify. Hence judgements about the effectiveness of thought experiments in science will be easier to make.

## NOTES

1. Blackwell, for instance, in his bibliography of the philosophy of science

classifies thought experiments under the heading "Aspects of Scientific Method." I do not, however, believe that the substance of what follows depends in any way on thought experiments being classified as a "method," rather than a tool, technique, etc. My use of "method" here does not carry any special connotations.

2. I am grateful to John Norton for letting me see an advance copy of his contribution to this volume.

3. Aristotle maintained that the quicker of two things traverses a greater magnitude in equal time, an equal magnitude in less time and a lesser magnitude in less time (Kuhn 1977, p. 246). Having got his listeners to accept that the two bodies attain the same terminal velocity at A and B, Salviati gets them to say that the body falling down the perpendicular moves faster as it reaches its goal first. But this contradicts the hypothesis that both begin and end their motions with the same velocity.

4. Conditions analogues to 2 and 3 can be formulated for the spring balance. Let SE($a$,$s$) mean "$a$ and $s$ produce the same extension" and let GE($a$,$s$) mean "$a$ produces a greater extension than $s$," then we have

If SE($a$,$s$), then w($a$) = 1
If GE($a$,$s$), then w($a$) > 1
If GE($s$,$a$), then w($a$) < 1

and

SE($a$,$s$) only if $a =_w s$

GE($a$,$s$) only if $a >_w s$

GE($s$,$a$) only if $s >_w a$

5. I think that David Armstrong succumbs to this tendency in his account of laws of nature, see Forge 1986.

6. Why not express the thought experiment in terms of *intensive* quantities? The answer to this question is that all intensive quantities are indirectly measurable in that their measurement presupposes the existence of a directly measurable extensive quantity.

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