The Use and Misuse of Critical Gedankenexperimente

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Summary

Three uses of critical thought experiments outlined in the paper are related to general questions of evaluation. A proposal offered by Karl Popper concerning the so-called "apologetic" use of *Gedankenexperimente* is critically assessed. Specifically, his methodological principle that one should not use a second theory in order to defend a first theory against a critical thought experiment is discussed with reference to the photon-box *Gedankenexperiment* (Einstein-Bohr debates) and the Maxwell-demon paradox. It is argued that the rescuing of one theory from conceptual anomaly by appealing to another need not constitute a misuse of a critical thought experiment.

1. The term *Gedankenexperiment* was first introduced into the vocabulary by the German physicist-philosopher Ernst Mach[1]. Despite his strong tradition of positivism and empiricism, Mach wrote "On Thought Experiments" where he explored some uses of these highly rationalistic tools of science.

In the most general sense of the term a thought experiment is the conceptual counterpart to a real experiment, or if no real experiment is possible, it is an experiment in pure imagination[2]. There are several questions associated with *Gedankenexperimente* which are of some methodological interest.

(a) What types of thought experiments are there and how do they function in science?

(b) Are there any a priori rules for setting up such an experiment or for evaluating its consequences? Since many of the significant mental

[1] Mach's earliest reference to the term *Gedankenexperiment* is given in his essay "Über Gedankenexperimente", *Zeitschrift für den physikalischen und chemischen Unterricht*, Vol. X (January, 1897), pp. 1—5. The article was rewritten by Mach and adapted to his later work *Erkenntnis und Irrtum*, Leipzig: Johann Ambrosius Barth, 1905.

[2] Thought experiments, according to Mach, are the necessary preconditions for physical experiments and as such they are guides to the performance of the real experiment. Pierre Duhem, in *The Aim and Structure of Physical Theory*, carried Mach's analysis further by making some distinctions about the varieties of thought experiments. "The unperformed experiment, the experiment which would not be performed with precision, and the absolutely unperformable experiment do not exhaust the diverse forms assumed by the fictitious experiment in the writings of physicists who claim to be following the experimental method; there remains to be pointed out a form more illogical than all the others, namely, the absurd experiment." According to Duhem, the absurd experiment is logically impossible to perform if construed as an empirical procedure. (Translated by P. Wiener. New York: Atheneum, 1962, p. 202.)

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experiments are unactualizable they must be evaluated solely on rational grounds.

Among the various roles that thought experiments play in the development of physical theory, for example, as illustrations of a physical principle, or as a means of defining concepts, there is one class of experiments which stands out in significance. These I shall call critical thought experiments. They represent the most controversial use and are sometimes the cause of a crisis period either in the life of a well-established theory or in a newly established theory. The focus of this paper shall be on the use and misuse of critical thought experiments.

2. A critical thought experiment can best be defined by its function rather than by its structure. These experiments are used primarily to expose paradoxes or inconsistencies in a theory. Thomas Kuhn, in *The Structure of Scientific Revolution*, emphasizes half the story, namely, thought experiments as exposing the old paradigm.

> ...the analytical thought experimentation that bulks so large in the writings of Galileo, Einstein, Bohr and others is perfectly calculated to expose the old paradigm to existing knowledge in ways that isolate the root of the crisis with clarity unattainable in the laboratory[3].

We can distinguish three types of critical thought experiments each one a response to a different question.

(a) The pure critical thought experiment satisfies the following five conditions.

(1) The experiment is formulated within the context of an explicit set of theoretical principles and a physical model.

(2) The experiment is constructed and executed in thought by bringing together elements from three spheres: the theory proper: formalism and interpretation; known empirical data; and a priori principles. These latter principles while not derived from experience nor falsified by experience are useful in making our experiences appear more intelligible. They also serve as analytical tools of discovery. A priori principles are not relevant to any one theory *in particular*, but are relevant to physical theories *in general*. They are not stated in the theory proper but are called into practice from our general background knowledge when the situation warrants it. Some examples are: the principle of continuous variation; the principle of symmetry; the principle which states that with a change in the effect there must be a change in the cause.

(3) The experiment does not introduce any untested idealizations.

(4) No hypothetical data are introduced.

(5) The actual performance of the experiment is superfluous.

(b) The second type of critical thought experiment obeys all the conditions of the previous paradigm except (3), the introduction of an untested idealization. In this use of a critical mental experiment the

[3] Chicago: University of Chicago Press, 1967, p. 88.

author introduces an idealization simply on the grounds that the theory does not prohibit it. By introducing such an idealization, the critic shifts the justification to the proponent of the theory. The proponent is then put into a position of either offering an explanation for why the idealization is not valid or accepting the criticism.

(c) A third variety of critical *Gedankenexperiment* is used to investigate claims of the form "no set of physical circumstances can be conceived which will..." Experiments of this type not only permit untested idealizations, but they permit hypothetical data and even hypothetical laws.

3. Here are some examples. In Galileo's work entitled *Dialogues Concerning Two New Sciences* he offers a critical thought experiment directed at Aristotelian mechanics[4]. Aristotle, we recall, maintained that heavier bodies fall with a velocity greater than lighter bodies in the same medium. Galileo asks us to consider two homogeneous bodies of different weight connected by a rigid weightless bar. Taken separately, the heavier body has a greater natural velocity than the lighter body. On one view, since the heavier body will increase the velocity of the lighter body while the lighter body will retard the natural velocity of the heavier body, the velocity of the combination will be somewhere in between the natural velocity of the two weights. However, looked at from another point of view, the new body consisting of two homogeneous weights and the weightless rigid rod has its own unique natural velocity greater than that of any of its component parts. Consequently, Galileo derives a contradiction. But what about the idealization Galileo used, namely, "a thin rigid weightless bar"? Why was such an idealization acceptable in the experiment? The answer is given by Mach. A successful idealization is grounded in the principle of continuous variation. By changing the relative weights of the rod and the attached masses, we recognize that the weight of the rod plays a more and more negligible role in the weight of the system and thus, according to Aristotle, in the natural velocity of the system. The idealization is empirically grounded if it represents the limit of a series of successive states, where the components of the series are obtainable in nature. Another condition stipulated by this first type of critical thought experiment requires that as we approach the idealization, the effects it has on our results are either negligible or in our favor.

For the second example, we turn to the Maxwell-demon *Gedankenexperiment*[5]. Maxwell purported to demonstrate that the second law of thermodynamics could not be applied to every conceivable thermodynamic system. Lord Kelvin named the mental experiment "Maxwell's demon" because it consisted of a super-intelligent or super-sensitive

[4] For the translation by Henry Crew and Alfonso De Salvio see the Dover edition, 1914, p. 62.

[5] For the original statement of the paradox see J. Clerk Maxwell, *Theory of Heat.* New York: D. Appleton, 1872, pp. 308–309.

being who could make instantaneous velocity selections of the molecules in a gas. (Maxwell referred to a being with highly sharpened faculties.) The demon, while positioned at a trap door between two chambers containing gas, allowed molecules of high velocity through the door to one chamber while retaining all low velocity molecules in the other chamber. If the experimental preparation is acceptable, the conclusion which follows is that the total entropy of the system is decreased, a violation of the second law of thermodynamics.

By chosing such a perfect and incredible creature, Maxwell was reaching out to the pure limits of possibility, far beyond what any mechanical device could ever hope to accomplish. The idealized demon-trap-door combination far from being an extrapolation of a series of obtainable states in nature, was rather a pure leap in the imagination and thus does not measure up to being an empirically grounded idealization.

A third class of critical thought experiments not only permits idealizations but counter-factual conditions. It therefore provides philosophers as well as scientists with their most important conceptual tool for arguing that a certain proposition is synthetic a priori, analytically true or unfalsifiable. Let us recall the positivist's dictum: Try to imagine, if you can, a state of affairs which can be realized in theory or in practice that provides empirical evidence for or against some hypothesis. Henri Poincaré offers an argument against the a priorist view that non-Euclidean space is unvisualizable, a claim held by neo-Kantians in the 19th century.

Poincaré's proposal of an imaginary world is an illustration of what one possible world would be like on the model of Lobachevskian space. I quote Poincaré.

> If geometric space were a framework imposed on each of our representations considered individually, it would be impossible to represent to ourselves an image without this framework, and we should be quite unable to change our geometry. But this is not the case;...
>
> Suppose, for example, a world enclosed in a large sphere and subject to the following laws: The temperature is not uniform; it is the greatest at the centre, and gradually decreases as we move towards the circumference of the sphere, where it is absolute zero. The law of its temperature is as follows: If R be the radius of the sphere and r the distance of the point considered from the centre, the absolute temperature will be proportionate to $R^2 - r^2$. Further, I shall propose that in this world all bodies have the same coefficient of dilatation, so that the linear dilatation of any body is proportional to its absolute temperature. Finally, I shall assume that a body transported from one point to another of different temperature is instantaneously in thermal equilibrium with its new environment[6].

[6] Henri Poincaré, *Science and Hypothesis.* New York: Dover, 1952, pp. 64–65.

In Poincaré's imaginary world, measurements of the circumference of a circle would be greater than 2π times the radius, thus illustrating the conceivability of a Lobachevskian universe.

4. The question of the appropriate and inappropriate use of idealizations in the construction of thought experiments is discussed by Karl Popper in his classic work *The Logic of Scientific Discovery*. Popper contends that, in their critical use, thought experiments help elicit certain possibilities which were overlocked by a theory. He introduces the term "apologetic" as a way of emphasizing certain misuses of *Gedankenexperimente*.

In Popper's words:

> My point is not to refute certain arguments, some for which, for all I know, may have long been discarded by their originators. I try, rather, to show that certain methods of argument are inadmissible — methods which have been used, without being challenged, for many years in the discussions about the interpretation of quantum theory. It is, in the main, the apologetic use of imaginary experiments which I am criticizing here, rather than any particular theory in whose defence these experiments were propounded[7].

In defending a theory against a critical thought experiment scientists have used all sorts of methodologically questionable defenses. Some observers argue that the fervor in which scientists hold to their theory in light of criticism is not unlike the religious dogmatist. In Max Planck's *Scientific Autobiography* he described the intransigent attitudes of older scientists.

> ...a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it[8].

What constitutes a thought experiment in *apologia*? Popper offers two conditions, any violation of which is considered to be a misuse of these rational tools of discovery.

(a) In defense of a theory, one should not introduce any idealizations or other special assumptions unless they are favorable to an opponent, or unless any opponent who uses the imaginary experiment in question would have to accept them.

> ...the argumentative use of imaginary experiments is legitimate only if... the rule is adhered to that the idealizations made must be concessions to the opponent, or at least acceptable to the opponent[9].

(b) One should not use a second theory in order to defend a first theory against a critical thought experiment[10].

[7] Karl Popper, *Logic of Scientific Discovery*. New York: Harper, 1959, p. 442.

[8] Max Planck, *Scientific Autobiography and Other Papers*. Trans. by F. Gaynor, London: Williams and Norgate, 1941, pp. 33—34.

[9] Popper, *Op. Cit.*, p. 444.

[10] Popper, *Op. cit.*, p. 447.

Two things are immediately striking about the previous two methodological rules. First, there is something smelling of subjectivism in basing the validity of an idealized experiment on the whim of what an opponent will or will not accept. In emphasizing the attitude and behavior of scientists over and above the nature and status of the idealization itself, Popper likens himself to those sociologists of science who see social factors, especially consensus, as a primary justification for a scientific debate[11]. The second striking point is that these rules are weighted heavily in favor of the critics.

According to Popper, the critic of a theory must be given free reins to explore all possible means by which to falsify a theory. This is consistent with his philosophy of science which places a high premium on criticism and revolutions in science. When the emphasis in science is seen to be falsification rather than verification, it is quite reasonable that the rules for defending a theory be more rigid than those for criticizing it. To say that the adversaries, in their evaluation of a thought experiment, must agree on the assumptions and idealizations is to place equal emphasis on defense and criticism. However, by saying that the assumptions and idealizations used in response to a critical thought experiment must be acceptable to the critic, without imposing the same demand on the proponent of a theory, it is clear what is being emphasized—refutation and revolution.

5. In discussing Popper's second methodological principle we shall focus on two thought experiments: Einstein's Photon Box and Maxwell's Demon. Referring to the Bohr-Einstein debates on the completeness and consistency of quantum theory, Popper admonishes Bohr for the apologetic use of thought experiments.

> If, therefore, as Bohr suggests, we must assume certain characteristic formulae of Einstein's gravitational theory in order to rescue the consistency of quantum theory. . . this amounts to the strange assertion that quantum theory contradicts Newton's gravitational theory, and further to the still stranger assertion that the validity of Einstein's gravitational theory (or at least the characteristic formulae used, which are part of the theory of the gravitational field) can be derived from quantum theory[12].

Popper is referring to "Einstein's Photon Box" which can be summarized as follows[13];

(a) A box containing an accurate time mechanism allows us to release a single photon through a small hole.

(b) The time at which the photon is released can be given to any degree of accuracy by a clock which is connected to the shutter.

[11] For example, see John Ziman, *Public Knowledge: The Social Dimension of Science*. Cambridge: Cambridge University Press, 1968. [12] Popper, *Op. Cit.*, p. 447.

[13] The detailed argument is found in *Albert Einstein: Philosopher-Scientist*. Ed. by P. A. Schilpp. New York: Harper, 1959, pp. 224–230.

(c) If we weigh the box before and after the photon is released we can determine the difference in the mass of the box. From this mass difference the energy of the photon can be calculated.

(d) Since the energy of the photon can be calculated to any degree of accuracy (because the mass difference can be measured as accurately as we wish) and since the time measurement, which is independent of the energy calculation, can also be made to any degree of precision, the uncertainty relation connecting time and energy ($\Delta E \, \Delta T \geq \hbar$) can in principle be violated.

In responding to Einstein's critical thought experiment Bohr utilized some equations from the general theory of relativity[14]. The specific nature of his response is not at issue for us. What is at issue is the justification for Popper's second methodological rule, namely Bohr's bringing in one theory to defend another against refutation by a critical thought experiment. The steps of Popper's argument can be outlined as follows: (Let Q. T. = quantum theory; G_e = Einstein's gravitational theory; G_n = Newton's gravitational theory.)

(1) From Q. T. we can derive an inconsistency. The inconsistency consists of an experimental arrangement which violates the time-energy uncertainty relation.

(2) In responding to Einstein's thought experiment Bohr uses Q. T. and G_e. The inconsistency in Q. T. disappears.

(3) When G_n is added to Q. T. the inconsistency is not resolved.

(4) G_n and G_e are inconsistent.

(5) Therefore Q. T. and G_n are inconsistent. (A result that Popper finds at least to be a strange assertion).

Surely, Popper is not speaking exclusively about logical consistency. If Q. T., viewed as a system of propositions, is logically inconsistent, whatever we add to it will not reduce that inconsistency. There is another form of inconsistency implied which can be described as follows: A subclass of theoretical statements is applied to an experimental arrangement whereupon a statement is implied which is logically inconsistent with one or more statements in the theory. The procedure for eliciting the inconsistency is not strictly logical. The application of theoretical principles to an experimental arrangement (a process of adaptation) requires that we apply certain rules of interpretation. It must be assumed that we have correctly incorporated all relevant features of the thought experiment. These are theoretical rather than strictly logical procedures.

The notion of an inconsistent physical theory is used in two senses. (i) When the propositions of Q. T. are combined with the propositions of G_n, a contradiction can be derived (internal inconsistency). (ii) When Q. T. and G_n are used to interpret an experimental arrangement, a result is obtained which is inconsistent with at least one principle of or consequence of Q. T. or G_n (external inconsistency).

[14] In particular, Bohr used a relationship from general relativity which describes the change in the rate of a clock as a consequence of its deplacement in a gravitational field.

The two types of inconsistencies are quite distinct. In the first instance we have a purely formal or logical inconsistency derived exclusively from the axiomatics of the theories. A system of propositions cannot be rescued from internal inconsistency by simply adding more propositions; it is inconsistent in-and-of itself.

The second type of inconsistency is a consequence of applying theoretical propositions to an experimental arrangement. This procedure requires the use of auxiliary hypotheses. A system of theoretical principles inconsistent with a given interpretation of a specific experimental arrangement can be termed externally or relatively inconsistent.

There are many more possibilities for resolving an external inconsistency as compared with an internal inconsistency. For example, by adding certain principles to those already provided, we can reduce what was an externally inconsistent result to a consistent one. This is the case with the photon-box thought experiment, where, according to Bohr, unless certain characteristic formulae of G_e are added to Q. T., the latter theory is inconsistent. But were he speaking of an internal inconsistency, clearly Q. T. could not be rescued by appealing to G_e. Once these two types of inconsistencies are distinguished there is no longer any peculiarity in Popper's conclusion. While one might admit to some peculiarity in saying Q. T. and G_n are internally inconsistent, it is not at all strange that Q. T. and G_n be externally inconsistent with respect to some experimental arrangement. After all, it is one thing to say that G_n does not rescue Q. T. from external inconsistency and quite another thing to say that G_n and Q. T. are mutually inconsistent as axiomatic systems.

Since the photon box experiment shows that quantum mechanics is rescued from external inconsistency by G_e we may wish to define a new quantum mechanics which includes Einstein's general theory of gravitation, (Q. T.)′ = (Q. T. and G_e). Now we can argue, quite reasonably, that (Q. T.)′ is internally inconsistent with G_n (since G_n and G_e are internally inconsistent).

6. Let us return to the discussion of Popper's second methodological rule. Are theories to be treated as self-contained and self-consistent systems which are not to be rescued from anomaly by other theories? The history of physics suggests that this has not been the case. In its present state physics contains numerous paradigms, each applied to a certain class of phenomena. This may falsely suggest that a paradigm or theory is an entity unto itself. Nothing could be further from the truth. The process by which a physicist answers a paradoxical thought experiment is more an art than it is like calculating some result. He makes use of all theories which are relevant and even constructs theories for the sole purpose of answering the criticism. In this sense, Bohr was in an established tradition when he proposed an answer to Einstein's photon-box experiment.

The history of suggested solutions to the Maxwell-demon *Gedankenexperiment* is evidence of the wide variety of imaginative attempts to answer the paradox. The hypothetical demon is capable of following individual particles in a gas container and directing the faster particles to one side of the chamber while directing the slower particles to the other side. He acts like a master switchman.

Maxwell's experiment allegedly showed that without any expenditure of work, the temperature of one side of the container is raised, while the temperature of the other side is lowered, contradicting the second law of thermodynamics.

The various solutions proposed to answer the paradox yield some fruitful information concerning the approaches that scientists have taken in response to a critical thought experiment. One such solution attacked the idea that such a being could in fact make the proper selections. The criticism leveled by P. W. Bridgman is based upon an argument from the inconceivability of such a mechanism.

> Even if it be nothing more than the ability to make automatically a selective response to the velocity and direction of the approaching molecules, such an ability involves some sort of mechanism, and this mechanism must have a minimum size and a number of molecules and might well be so course as to make dealing with individual molecules impossible. I think we would not now be willing to assume such a mechanism unless we could give some suggestion as to how to construct it[15].

An imaginary experiment should be judged on its specific purpose. We can always criticize an argument for what it purports to accomplish but doesn't. The three types of critical thought experiments outlined in the introductory section of the paper each serve a specific function: to derive inconsistencies from within a theory; to draw a theory to its physical limits; to discuss the hypothetical possibilities of falsifying a theory with a certain class of empirical data.

The purpose of the demon experiment is to drive the theory to its limit and to indicate that by itself it is insufficient to give an adequate account of the law of entropy. There is no *obvious* logical or physical reason to invalidate the operation of the demon. If the thought experiment were constructed to suggest that an actual experiment be performed then there is some ground for Bridgman's criticism. But no such purpose is advanced. The demon represents "physical possibility" given the formulation of thermodynamics during Maxwell's time.

> Thus Maxwell's sorting demon could effect in a very short time what would probably take a very long time to come about if left to the play of chance. There would, however, be nothing contrary to natural laws in the one any more than in the other[16].

[15] P. W. Bridgman, *The Nature of Thermodynamics*. Cambridge, Mass.: Harvard University Press, 1941, p. 156.

[16] Sir James Jeans, *The Dynamical Theory of Gases*. Cambridge, Eng.: Cambridge University Press, 1925, p. 183.

There are several things to be learned about the growth of physics from the Maxwell-demon *Gedankenexperiment* which have particular relevance to Popper's notion of the apologetic use of thought experiments. Theories can grow even while sustaining paradoxical results. Generations of physicists can deal with the paradox in different ways without unanimity amongst themselves. Maxwell first proposed his criticism in 1872 and it wasn't until 1929 that L. Szilard wrote a paper which laid the groundwork for the general solutions to the paradox which were to follow[17]. The important advancement made by the modern solutions is that they calculate the entropy change of the entire system, the demon and the gas. Let us consider, for example, L. Brillouin's simplified discussion[18].

In order for the demon to make the proper selection of molecules he must be capable of detecting and measuring their velocities.

(a) Let us assume we have an isolated system, at a constant temperature equilibrium.

(b) In such a system the demon could not detect the molecules by any radiation techniques since the radiation in the system would be entirely that of a black body and nothing can be seen in the interior of a black body.

(c) Let us suppose, then, that the demon has a source of visible light in order to detect the molecules.

(d) By radiating his light he contributes to a total entropy increase in the system. The demon receives some information about the molecules but his payment is the added entropy to the system.

(e) The demon with his newly acquired information about the molecules can operate the trap door and decrease the entropy of the system of gas.

(f) When we add the total contributions, (i) of decreasing entropy resulting from the separation of the molecules and (ii) of increasing the entropy resulting from the information retrieved by the demon, the total balance is greater than zero.

Previously, the demon's activity was seen to play no role in the change of entropy. But when it was shown that there is an important connection between entropy and information theory, a more penetrating analysis of the demon revealed that the law of entropy was actually preserved.

There was no single approach to solving the paradoxical *Gedankenexperiment* and it is often not clear beforehand what is to count as a refutation. Free access was made of other theories whether classical or quantum and such methods were not considered apologetic. When a principle like that of entropy has been so useful to science, the scientific

[17] "Über die Entropieverminderung in einem thermodynamischen System bei Eingriffen intelligenter Wesen", *Zeitschrift für Physik*, Vol. 53, Nos. 11—12 (February—March, 1929), pp. 840—856.

[18] The argument is a summary of the detailed analysis which appears in Leon Brillouin's work *Science and Information Theory*. New York: Academic Press, 1956.

community does not give it up so easily. They would rather establish or make use of another theory which when added to thermodynamics explains away the paradox.

In the particular example of the Maxwell demon we see a movement which ultimately led to the study of the mechanism of the demon.

For example, in order to save thermodynamics from the paradox of the demon, one critic of the thought experiment held that the demon could not see the molecules if the system were at a constant temperature, and thereby could not obtain the required information. His adversary must then devise another technique for detecting the molecules[19].

This brings us to a higher level in the argument because it stimulates our thinking about the mechanism. How does the demon do it? Perhaps there are some inherent limitations. We must get inside the demon who up until now was treated as a "black box". The development of the solution to the Maxwell-demon paradox can be represented by the following stages.

(1) The original thought experiment posits a being who somehow takes measurements and divides the slower from the faster molecules.

(2) In early stages of the criticism qualitative arguments are provided as to why the measurement fails[20]. Proponents of the thought experiment offer alternative measurement processes.

(3) Finally, in the later stages of the criticism, detailed quantitative arguments emerge. A study of the interaction between the demon and the molecules is given in terms of the exchange of quanta and the retrieval of information.

The argument moves from a more general and less systematic analysis to a more detailed and quantitative analysis of the mechanism of the demon. The following passage from Bridgman is characteristic of the qualitative arguments in stage two.

> ...when the mechanism gets small, the mechanism itself and its controls (including in the controls the brain of the demon) becomes subject to temperature fluctuations which are proportionately larger the smaller the mechanism. How do you know that this will not vitiate the entire program? Another doubtful feature is the method by which the demon would learn of the approach of the individual molecules. The only method would appear by light signals; these must come in quanta and must react with the molecule. The reaction is uncontrollable, and may be sufficiently large to divert the molecule by so much as to vitiate the manipulations of the trap door[21].

[19] Leon Brillouin, "Life, Thermodynamics, and Cybernetics", *American Scientist*, Vol. 37, No. 4 (October, 1949), pp. 554–568.

[20] Wolfgang Yourgrau emphasizes the importance of thought experiments in their early stages as pre-analytical arguments "before the proof has assumed its rational form of a concatenation of coherent steps." ("On Models and Thought Experiments in Quantum Theory", *Monatsberichte der Deutschen Academie der Wissenschaften zu Berlin*, Vol. 9, No. 11 (1967), p. 872.)

[21] Bridgman, *Op. Cit.*, p. 157.

Once the right questions were asked about the interaction of the demon and molecules, the quantitative results began to appear. Calculations were made of the entropy change of the system which included the change in entropy of the demon when he obtains information from the molecules.

7. In conclusion, when confronted by a critical thought experiment proponents of a theory have responded in several ways. Some would reject the critical experiment because the author does not expose each stage of the argument in complete detail. The critic outlines a possibility. In the case of Maxwell's demon, let us recall Bridgman's suggestion, "I think we would not be willing to assume such a mechanism unless we could give some suggestion as to how to construct it." This type of response represents a misunderstanding of the nature and purpose of the mental experiment. For many critical thought experiments it is not necessary that a detailed analysis of each stage be provided. The experiment serves science as a half-baked argument which impels us to pursue a problem in greater depth.

Critical thought experiments have also been rejected on the basis that certain idealizations are implausible. But merely declaring that an idealization is implausible is dogmatic. The opponent of the thought experiment is obliged to offer reasons against using an idealization and his reasons must go beyond the fact that the idealization does not obtain in reality[22].

Finally, a proponent of a theory, in rescuing it from anomaly, is justified in appealing to another theory and appropriating from it principles which are relevant for a complete description of the phenomena. This does not constitute a misuse of thought experiments. In the process, science is driven to greater unity. The fragmentation of scientific theories represents a primordial stage in the development of our knowledge.

[22] In response to the Einstein-Podolsky-Rosen thought experiment, constructed to exhibit the incompleteness of quantum theory, D. H. Sharp leveled this kind of argument. ("The Einstein-Podolsky-Rosen Paradox Re-examined", *Philosophy of Science*, Vol. 28, No. 3 (July, 1961), pp. 225—237.) The assumption by Einstein et al of the separability of the wave function was attacked by Sharp because of the impossibility of the attainment of zero interaction potential of two initially interacting and later spatially separated systems. Why is the idealization of zero interaction potential any different methodologically from that of an isolated or closed system which physicists are quite at home with? For a rejoinder to Sharp see C. A. Hooker, "Sharp and the Refutation of the Einstein, Podolsky, Rosen Paradox", *Philosophy of Science*, Vol. 38, No. 2 (June, 1971), pp. 224—233.

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