historical findings about where Einstein got his ideas! "Millikan relied upon a lot of physical theory, treated as unproblematic, when he 'observed' the charge on the electron" is a correct statement of the case. But such a statement is not, most emphatically *not*, on all fours with "Blauberman[15] is a qualified psychoanalyst, therefore we can rely upon his use of psychoanalytic theory when he classifies a patient's discourse as phallic-intrusive." What one *observes* in the psychoanalytic session is words, postures, gestures, intonation; everything else is inferred. I think the "lowest level" inferences should be the main object of study for the time being—we should be objectifying and quantifying "low-level theoretical" statements like "Patient is currently anxious, and the thematic content is hostile toward his therapist," rather than highly theoretical statements like "He has superego lacunae" or "His dammed-up libido is flowing back to anal channels." In the process of such objectifying-and-quantifying research, I can think of no better methodological prescription than the one with which Aristotle sets the standards of conceptual rigor as he begins his consideration of ethics, "It is the mark of an educated man to look for precision in each class of things just so far as the nature of the subject admits." No more—but no less, either.

[15] Lillian Ross, "The Ordeal of Doctor Blauberman," *New Yorker*, 37 (May 13, 1961), 39–48; reprinted in Lillian Ross, *Vertical and Horizontal* (New York: Simon and Schuster, 1963).

MICHAEL RADNER

Popper and Laplace

This paper is designed as a consideration of one pattern of escape from the classic Laplacian determinism. The most convenient representation of the anti-Laplacianism that I am concerned with is Sir Karl Popper's 1965 lecture "Of Clouds and Clocks: An Approach to the Problem of Rationality and the Freedom of Man."[1] However, before embarking on an examination of Popper, I shall briefly review Laplace's standpoint.

Let us go back for a moment to the text of Laplace's *A Philosophical Essay on Probabilities*.[2] At the start of chapter II, Laplace asserts that all events, including the actions of the will, follow the laws of nature, and that it is only in ignorance of true causes that we deny this fact. The connection between events is guaranteed by the principle of sufficient reason. "We ought then," he says, "to regard the present state of the universe as the effect of its anterior state and as the cause of the one which is to follow."[3] Then follows the famous passage which I will paraphrase here. An intelligence which could satisfy the following three conditions would be able to correctly envisage both past and future: (1) To know all forces in nature. (2) To know the states of all things in nature. (3) To be able to analyze and calculate from these data. "The human mind offers, in the perfection which it has been able to give to astronomy, a feeble idea of this intelligence."[4] This last quotation reveals the source of Laplace's confidence in determinism. Laplace was responsible for major developments in celestial mechanics, where it seemed to him that planetary motion needed no cause external to the framework of the Newtonian program. The formation of the solar system was accounted for by Laplace's nebular hypothesis. Laplace's work toward a solution of the stability problem for the solar system

[1] The Arthur Holly Compton Memorial Lecture presented at Washington University, April 21, 1965 (St. Louis: Washington University, 1966).
[2] Trans. F. W. Truscott and F. L. Emory (New York: Dover, 1951).
[3] *Ibid.*, p. 4.
[4] *Ibid.*, p. 4.

convinced him that God is not required to keep things running as Newton had believed. Thus it was natural for a scientist deeply immersed in the most mathematically perfect of the sciences to say, "The curve described by a simple molecule of air or vapor is regulated in a manner just as certain as the planetary orbits; the only difference between them is that which comes from our ignorance."[5]

Let us now turn to Popper's account.

1. Clouds and Clocks

As the title of Popper's lecture indicates, he is primarily concerned with the implications of determinism-indeterminism for free will, the mind-body problem, and rationality. To characterize determinism and indeterminism succinctly, Popper utilizes the picture of a continuum of systems with clouds on the left representing systems of very random behavior, and clocks on the right representing systems of very orderly and predictable behavior. In this scheme, the solar system is a very good clock. The opposing views may now be formulated in terms of the cloud-clock picture. The "physical determinist" says that all clouds are really clocks, and that we are just more ignorant about the behavior of systems on the cloud side than we are about those on the clock side. This is the Laplacian view, which we will have occasion to examine later. The indeterminist, on the other hand, claims that all clocks are clouds to some extent. A better way of putting it is this. All physical systems are imperfect, and some are more imperfect than others. On the right, we have fine, precise systems like clocks, and on the left messy systems like clouds of gas molecules. Thus, according to the indeterminist, there is random behavior present to some degree in all systems. Chance is an objective feature of the universe, not merely a product of our ignorance. This position may be ascribed to Democritus and Charles Sanders Peirce, as well as to quantum physicists.

Popper declares that he is an indeterminist and that Peirce was correct in claiming that indeterminism is consistent with Newton's physics. Thus Popper is not just asserting that indeterminism is true because quantum physics now reigns. Hence, before we can proceed to the next stage of the analysis of the clouds and clocks lecture, we must take a detour through a reference he cites in the lecture, namely, "Indeterminism in Quantum Physics and in Classical Physics," published in the *British Journal for the Philosophy of Science* in 1950.

[5] *Ibid.*, p. 6.

2. Indeterminism in Classical Physics

Popper's indeterminism article is long and involved, and I will not analyze it in toto. However, we shall see whether it adequately backs up his claim that indeterminism holds, in the sense that all clocks are clouds "to some considerable degree."

In this paper, Popper takes indeterminism to be the view that not all events are determined in every detail; determinism is the view that they all are determined. 'Determined' is interpreted by Popper as 'predictable in accordance with the methods of science.' This last phrase is itself susceptible of different interpretations. Does it mean 'predictable in actual scientific practice' or 'predictable in some idealized version of science' or 'predictable in principle' or what? For the purpose of most of Popper's arguments, 'predictable in some idealized version of science' will suffice as an interpretation. However, it is important to keep in mind that many traditional philosophical claims about determinism, if they are formulatable in terms of some sense of predictability, use the interpretation 'predictable in principle.' Less fashionably, determinism can be characterized in terms of necessary connection between events. If all events in the world are connected necessarily, then determinism holds. That is an ontological approach; the epistemological account using the concept of prediction approximates the necessary connection formulation in strictness only when 'prediction' is taken as 'prediction in principle.' Laplace, of course, is a determinist in the latter sense, with the demon doing the predicting-in-principle.

Popper's strategy is this. Philosophical claims about determinism are often not falsifiable. Popper substitutes a testable claim for the metaphysical statement that all events are completely determined (predictable in principle). Then he challenges the testable formulation. The substitute claim is that every finite prediction task, meaning a prediction of specified precision on a closed isolated system, can be accomplished by some "predictor." A predictor is a machine which we may imagine to be constructed according to the laws of classical physics for the predicting job at hand. That is, Popper has taken the demon of Laplace and replaced it by a classically operating machine.

The predictor, unlike the demon, is part of the physical world and gets its information by interacting with the system it is designed to measure. Popper states that just as indeterminism is linked to the measurement problem in quantum mechanics, there is an analogous problem of interaction in classical physics which leads to indeterminism in that case too. There are several arguments which Popper adduces to prove that there are situations in which predictors must fail. I will present very short sketches of arguments that approximate Popper's unnecessarily long and intricate versions.

The first argument which Popper gives is this. Relying on the claim that a predictor B amplifies the responses it picks up from a system A which it is trying to describe, Popper goes on to add another predictor C, which is describing the situation A + B. In order to measure A + B, C must interact weakly with it and amplify the signals. But then we assume that B is also observing C. This leads to a breakdown of the observer-observed relationship because of the strong two-way interaction. As far as I understand the argument, there is no need to assume that B strongly interacts with C. B has been constructed to observe A, not to interact with the rest of the world in the same way as it interacts with A. It is true that there could be physical systems like those Popper describes, but that isn't enough to establish Popper's claims. What is required to prove his claims is to show that it is impossible to construct a sequence of predictors leading to more and more precise predictions without limit. On succeeding pages, Popper tries to establish the impossibility of such a sequence, by arguing that if such a sequence converges, then after some predictor, say the nth, all the predictors would be so similar as not to be detectable by the nth predictor. Popper appears to be misled by the language of mathematicians about sequences. Given a small positive number epsilon, one can pick a term of the convergent sequence beyond which the terms stay within epsilon of the value to which the sequence converges (or within epsilon of each other). This fact about sequences in no way implies that the epsilon becomes physically insignificant or mathematically inconsequential at some stage. Altogether, Popper has not convinced me that his argument need be taken seriously.

The second argument to be considered is one in which Popper claims that there are unavoidable situations in which a predictor cannot actually come up with the prediction before the event to be predicted occurs. His arguments for this are again elaborate. I don't think elaborate arguments are needed here. Popper's point may be quickly granted. Consider a time interval so short that because the predictor itself operates on physical principles, it can't get the answer out fast enough.

Another argument purports to show that a given predictor cannot, at

time t, have complete knowledge of its states up to and including time t. The act of compiling the knowledge of its past states will alter those states. Popper considers the possibility that the last statement on the machine record is self-coding by, say, Gödel numbering. This possibility is rejected by requiring that the machine must retain records of its calculations, too. Then the self-coding would presumably fail. I don't see the need to challenge this argument either.

The final argument I shall mention involves Gödel sentences to show that a predictor can be asked a question about one of its future states that cannot be answered before the state in question has in fact occurred. Again, the argument is devised to produce an exception to the generalization that every event can be predicted before the fact. I will substitute a similar argument for Popper's which is simpler to comprehend. Ask the machine whether, by time t, it will check that a specified formula F of the predicate calculus is a theorem of that system. This is a legitimate question to ask the machine, because the question is "really" about physics: namely, by time t, will the predictor have been in the physical state corresponding to a "yes" answer to that question. Now it is known that there is no effective procedure by means of which a predictor (computer) can decide whether a given formula of the predicate calculus is a theorem. For some formulas F, the machine will not be able to prove F before time t or refute F before time t, and thus cannot answer the stated question before t arrives.

After presenting a similar argument, Popper remarks in a footnote[6] that one can add model-theoretic methods to the calculator, i.e., enable it not only to prove but to check on the satisfiability of formulas. Then he counters that we could ask the machine whether it is consistent: that is, ask if it ever will produce a contradiction in its output. Of course it can't prove that it is consistent. Here Popper is clearly going too far. While he never questions the truth of classical physics, which is an assumption in all of these arguments, he suddenly asks the predictor to guarantee the consistency of, say, arithmetic. Why not, instead, ask the predictor whether it will ever make a wrong prediction. Clearly, the latter demand oversteps the requirements of this discussion, just as does Popper's question to the predictor about the consistency of arithmetic.

We have seen that Popper's arguments are in opposition to the claim

[6] K. R. Popper, "Indeterminism in Quantum Physics and in Classical Physics, Part II," *British Journal for the Philosophy of Science*, 1 (1950), 183.

that there are no situations which cannot be predicted. I have not tried to give a detailed evaluation of these arguments, but only to sketch the sort of lines of argument that Popper utilizes. For my purpose, no more detailed analysis is required because Popper states that "there does not appear any serious obstacle for a calculator to explain in any desired detail its own past states."[7] Thus Popper admits that none of his arguments block the after-the-fact explanation in any conceivable detail of any system of classical physics. Nevertheless, he asserts that, on the basis of the possibility of constructing a series of predictors which strongly interact so that the precision of predictions does not improve as we go through the series, "then Laplace's determinism, and that of others who were influenced by the *prima facie* deterministic character of classical mechanics, is based upon a misinterpretation."[8]

At this stage, Popper's conclusions do not follow from his premises. If we grant that his several arguments about the interaction and self-knowledge problems of predictors are valid, then he has shown that *his* version of determinism is false. But his version of determinism is based on the notion of a prediction machine which is part of the classical physical world, whereas Laplace's demon is not subject to the limitations of Popper's predictors. The most that Popper has done is to cut off one possible way of arguing for Laplace.

It is important to take note of exactly what definition of determinism Popper has adopted in his arguments to refute determinism, because he cites his 1950 article on indeterminism in the 1965 clouds and clocks lecture exactly at the point where he declares that he is an indeterminist.[9] We are, therefore, entitled to conclude that his 1950 indeterminism article is relevant to his 1965 discussion. A borrowed metaphor will aid us in seeing why the 1950 article is not relevant. In the nightmare of determinism, which Popper does take seriously with determinism in the strong sense, we are on a trolley which we cannot get off and whose speed and direction along the single set of tracks are unalterable. The most Popper has shown is that at times, we cannot look forward on the ride, but only look back. So far, Popper hasn't got us off the trolley.

3. Popper and Wiener

It is time to return to "Clouds and Clocks." In an important passage,

[7] *Ibid.*, p. 191.
[8] *Ibid.*, p. 193.
[9] "Of Clouds and Clocks," p. 6.

Popper says: "I believe that the only form of the problem of determinism which is worth discussing seriously is exactly that problem . . . which arises from a physical theory which describes the world as a *physically complete* or a *physically closed* system. . . . It is this 'closure' of the system that creates the deterministic nightmare."[10]

Popper has hit upon a point of fundamental significance for the solution of his problems. In discussing this point, it will be helpful to adopt some terminology of David Bohm from his book *Causality and Chance in Modern Physics* (1957).[11] In Bohm's usage, a system described by the quotation above from Popper is *mechanistic*, in that there is a fixed finite set of variables in terms of which a complete description of the system may be written. Among mechanistic systems, there are both deterministic and indeterministic ones. Classical physics, in its Laplacian interpretation, is mechanistic and deterministic. Quantum mechanics according to the way it is put forward by most physicists is mechanistic and indeterministic. However, all deterministic systems are mechanistic.

We will now proceed to the discussion of Popper's proposed solution to the problem of providing a replacement for the closed physical system, a replacement which, he hopes, will permit a solution to the mind-body problem and to the problem of how rational discourse can govern behavior. Very briefly, Popper's scheme is this. To break out of the mechanistic impasse, he must destroy the notion that all systems are completely describable in terms of a closed set of physical variables. First, the false opposition between determinism (complete predictability) and utter randomness or chaos must be refuted. This refutation is accomplished by means of the notion of plastic control. Popper's aim is to describe every organism as "a hierarchical system of *plastic controls*—as a system of clouds controlled by clouds."[12] On the level of ideas, plastic control is exemplified by the regulation of thought by critical discussion and argument, the familiar Popper doctrine of conjecture and refutation, stated here in a more complex form where solutions to problems beget more problems. For a physical example of plastic control Popper chooses the soap bubble, which consists of a gas inside and a fluid film outside which "control each other"—cloud controlling cloud.

Second, other variables besides physical variables are introduced to

[10] *Ibid.*, p. 8.
[11] New York: Harper Torchbooks, 1961.
[12] "Of Clouds and Clocks," p. 25.

counter the mechanistic view of a closed *physical* system. Popper holds an interactionist view of the mind-body relationship. Mental states interact with physical states. The interaction is to be conceived on the pattern of plastic control. The organism, a system of mental states and physical states, is neither wholly a clock nor wholly a cloud, but, as I said, clouds controlling clouds.

Third, a form of the theory of evolution is invoked to explain how mental control of some aspects of the organism came about, and also how organisms alter their behavior patterns. The problem-solving or conjecture-refutation scheme is seen as a speeded-up version of evolution. These three points form the heart of Popper's proposed solution to the problems mentioned above.

Now I propose to compare the general features of Popper's solution to Norbert Wiener's approach in *Cybernetics, or Control and Communication in the Animal and the Machine* (1948).[13] Wiener begins his chapter I with a contrast between meteorology and astronomy as statistical and nonstatistical sciences, just as Popper introduced clouds and clocks. In chapter I, which is called "Newtonian and Bergsonian Time," Wiener is concerned with irreversibility, statistical laws, and information. Thus, we do not expect an exact analogue to Popper's discussion. Yet the ideas of Popper's lecture appear in that chapter, as well as in other writings of Wiener. Wiener says, "To return to the contrast between Newtonian astronomy and meteorology; most sciences lie in an intermediate position, but most are rather nearer to meteorology than to astronomy."[14]

Though Wiener does speak of clouds and clocks (clocks are the seventeenth-century craftsman's image of the heavens), he prefers to speak, instead, of the "transition from a Newtonian, reversible time to a Gibbsian, irreversible time."[15] This transition culminates in Heisenberg's quantum theory. But, rather than offering new hope for biological vitalists, they find that the "chance of the quantum theoretician is not the ethical freedom of the Augustinian, and Psyche is as relentless a mistress as Ananke."[16] Wiener is here referring to the fact that biology has been taken into the sphere of physics, and subsumed under a mechanistic scheme.

[13] 2nd ed. (Cambridge, Mass.: MIT Press, 1965).
[14] *Ibid.*, p. 35.
[15] *Ibid.*, pp. 37–38.
[16] *Ibid.*, p. 38.

To show that my comparison of Popper and Wiener is not just a matter of a few coincidences of phrases, I will demonstrate that there are problems which they both recognize and that their projected solutions have analogous features. First, to connect Popper's use of the theory of evolution with Wiener's, consider another quotation from Wiener: "In tidal evolution as well as in the origin of species, we have a mechanism by means of which a fortuitous variability, that of the random motions of the waves in a tidal sea and of the molecules of the water, is converted by a dynamical process into a pattern of development which reads in one direction."[17] Wiener and Popper both apply the theory of evolution to contexts of physical causality in general.

Second, both are indeterminists. In the second volume of his autobiography, Wiener states, "My early work on probability theory, as exemplified in my studies of the Brownian motion, had convinced me that a significant idea of organization cannot be obtained in a world in which everything is necessary and nothing is contingent."[18] Here, Wiener denies determinism in its strong, ontological form. Third, both break the closure of physical systems by introducing new variables not heretofore included in the physicist's account. In the case of Popper, we have seen that mental states are allowed to interact with physical states. In Wiener's case, the concept of information enters: "Information is information, not matter or energy. No materialism which does not admit this can survive at the present day."[19] Beyond this similarity, however, information for Wiener does not play the same role as ideas do for Popper. Wiener might be called a neo-materialist on the mind-body relation; Popper is an interactionist.

Finally, what about Popper's plastic control? In Wiener's work, plastic control is exemplified by the novel and ingenious statistical methods for which Wiener is famous. One of the great insights of Wiener was the idea that the mathematics of communication and control lies properly in the realm of statistical theory, not in such simple models as the Boolean algebra of switching circuits. Popper, perhaps, has failed to see the basically statistical nature of cybernetics. In "Clouds and Clocks," he rejects the computer models of organisms because "these systems, although incorporating what I have called plastic controls, consist essentially of complex

[17] *Ibid.*, p. 37.
[18] N. Wiener, *I Am a Mathematician* (Garden City, N.Y.: Doubleday, 1956), p. 322.
[19] *Cybernetics*, 2nd ed. (Cambridge, Mass.: MIT Press, 1961), p. 132.

relays of master-switches. What I was seeking, however, was a simple physical model of Peircean indeterminism . . ."[20]

The point of comparing Popper and Wiener is to underscore the idea that Popper's problems can be attacked with mathematical tools as well as with simple metaphors. Popper's lecture is sketchy, but Wiener's book is programmatic. Whether there is anything in the program for philosophers will have to be determined by a careful analysis of the arguments used by Wiener and his successors among the mathematical statisticians, cyberneticians, and information theorists.

4. Conclusion

In the lecture discussed above, Popper was primarily concerned with the consequences of Laplace's views for rationality and related problems. My interest is rather in the problem of what picture of physical science should replace the Laplacian picture.

An insight of David Bohm will be helpful to us. Bohm sees that philosophers and physicists take general features of prevailing physical theory and project or extrapolate them as if they were permanent features of science.[21] For example, Laplace in his time was expressing his faith that the Newtonian program of the eighteenth century would be a success. That is, scientists would continue to discover new forces, but these forces would be describable by differential equations allowing exact prediction and retrodiction. In effect, then, Laplace was extrapolating from a certain general feature in Newtonian science.

Wiener reverses Laplace's extrapolation. Instead of emphasizing the precision of mathematics, he stresses the character of measurements:

> No scientific measurement can be expected to be completely accurate, nor can the results of any computation with inaccurate data be taken as precise. The traditional Newtonian physics takes inaccurate observations, gives them an accuracy which does not exist, computes the results to which they should lead, and then eases off the precision of these results on the basis of the inaccuracy of the original data. The modern attitude in physics departs from that of Newton in that it works with inaccurate data at the exact level of precision with which they will be observed and tries to compute the imperfectly accurate results without going through any stage at which the data are assumed to be perfectly known.[22]

[20] "Of Clouds and Clocks," p. 27.

[21] See, for example, *Causality and Chance in Modern Physics* (New York: Harper Torchbooks, 1957), pp. 69–70.

[22] *I Am a Mathematician*, p. 258.

The suggestion is that, in a general statistical approach to physical phenomena, the mathematics conforms more realistically to the data. But a statistical approach does not have the pictorial appeal or the intuitiveness of mathematical argument of the Laplacian scheme. Thus it seems that, without a clear and compelling account of the statistical approach, we have not yet replaced Laplace's paradigm, but only rejected it.