# COMPLEMENTARITY WITHOUT PARADOX

## A PHYSICIST'S REPLY TO PROFESSOR AUSTIN

*by James L. Park*

### Complementarity, Dualism, and Paradox

Probably because of the spectacular achievements of physics within its own proper domain of competence, the great ideas underpinning that science have always tended to fascinate scholars in other, sometimes remote, academic fields. As a result, in a basically commendable interdisciplinary spirit, attempts have occasionally been made to adapt certain especially attractive physical principles to problems associated with areas as diverse as biology, psychology, law, economics, theology, and others. Unfortunately, scholarly projects in this vein have, perhaps more often than not, been characterized by flagrant misinterpretations and grotesque distortions of the very physics which presumably motivated such endeavors in the first place.

The nineteenth century saw attempts to relate the concept entropy to certain interpretations of the cryptic imagery of the biblical Book of Revelation. In this century the two great modern physical principles "relativity" and "complementarity" have regularly been invoked by advocates of *verbally* similar "principles" in non-physical fields. Consider, for example, the doctrines of cultural relativity, aesthetic relativity, and moral relativity. Are these ideas related to Einstein's physical relativity in any way more profound than identity of nomenclature? It seems doubtful. Similarly, but to a lesser extent than relativity, Bohr's "complementarity" has been extended in several directions by replacing its original technical meaning in quantum mechanics by vague notions which have all the logical value of mere puns on the word "complementarity."

William H. Austin sets forth a program for the adaptation of complementarity to the problem of paradoxes in theology. The underlying theme seems to be that through deft application of complementarity

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quantum theorists have learned to live with physical paradoxes; hence theologians might be able to cope more effectively with some of their own paradoxes by developing an appropriate complementarist philosophy.

Like most other extensions of complementarity to non-physical realms, Austin's work is predicated upon too superficial an understanding of basic quantum theory. In particular, the popular contention, exploited by Austin, that quantum physics is founded upon a hopelessly paradoxical dualism of incompatible models is simply false. *Present-day quantum mechanics, including its philosophical structure of complementarity, contains no paradoxes.* To believe otherwise is to misunderstand complementarity.

Austin in effect identifies complementarity with the notorious wave-particle duality which plagued the early quantum theorists. To bolster this interpretation, he repeats some of the standard historical argumentation which to this day continues to disgrace the naïve opening chapters of many quantum mechanics textbooks. The Compton effect is cited as evidence that light is sometimes corpuscular, and the Davisson-Germer experiment is taken to imply that electrons are sometimes undulatory. Contemporary physicists who have pondered these matters at all realize that such experiments do not mean, as Austin suggests, that an electron, for example, must be regarded as some kind of dialectical entity torn between being impossibly both a wave and a particle. On the contrary, the electron is not *both;* it is *neither.* Nevertheless, there does exist a *single physical theory*—quantum mechanics—which explains not only the Davisson-Germer experiment but also all experiments which induced the pre-quantum physicists to picture electrons as particles; this in itself indicates that the so-called dualism and associated paradoxes are illusory.

What, then, is meant by complementarity?

## The Meaning of Physical Complementarity

To answer the foregoing question, it seems appropriate to begin with a succinct and somewhat abstract description of the fundamental structure of quantum physics. Against this background, the root meaning of complementarity can then be discussed rationally. Once a basic understanding of complementarity is achieved, it is not difficult to identify the common but illicit reasoning which generates the historic "wave-particle duality" and then to exorcise logically that old viewpoint, supplanting it by what might be called a "$q$-system unity," which is quite unparadoxical.

As in the rest of physics, the objects of study in quantum theory are called physical "systems." Examples are electrons, electromagnetic fields, atoms, planets, etc. To study a given system under prescribed conditions of interest, that is, a given system *prepared* in a specified manner, the experimenter performs *measurements* upon that system. A measurement is a rather specialized operation characterized by the fact that it yields a number. More explicitly, associated with every system is a set of constructs called "observables," each of which may be measured. Typical observables are position, energy, spin, etc. When a measurement of an observable $\alpha$ is performed on a system, the number which emerges is called the *result of the $\alpha$ measurement.* It is the purpose of physical theory in general and of quantum theory in particular to interpret, regularize, and make predictions about these measurement results.

In classical physics a highly pictorial, concrete interpretation of measurement results was always at hand, for it had turned out that no contradictions arose if observables, together with numbers called their values, were regarded as *inherent attributes* of the systems. For instance, an energy measurement was simply viewed as an operation which revealed which energy value did in fact belong to the system of interest.

In quantum physics, no such visual representation of systems and observables will be consistent. Measurement results cannot be construed as revelations of unknown premeasurement (or postmeasurement) properties of systems. For example, concerning an energy measurement upon a system, the quantum physicist cannot justifiably say, "I performed an energy measurement on the system and discovered that the system had an energy of 37 ergs." Rather, the most complete, quantum-theoretically admissible, physically meaningful report he can make is simply this: "I performed an energy measurement on the system and the numerical result which emerged was 37 ergs."

The mathematical basis for the foregoing remarks about the contrast between classical and quantal observables is too involved to review here in any depth. However, perhaps the key technical point should be mentioned: the mathematics of quantum theory includes *probabilities which cannot be related to ignorance,* that is, probabilities which are, so to speak, attributes of Nature herself. For detailed treatments of these matters, the reader may consult the literature.[1]

Consider now this question: What, in terms of measurement results, constitutes maximal information about a given physical system prepared in a specified manner? As noted above, the simple classical interpretation of measurement results as indicators of innate properties of systems must be discarded, for in quantum physics it is impossible to conceive a system with Cartesian clarity as an object thoroughly labeled with a number for each observable. In the absence of such a picture, maximal physical information takes a subtler, more abstract form, namely, a table of probabilities for the emergence of the various possible measurement results when measurements are performed upon the system of interest. It is not in general possible to combine the measurement results into a visualizable model, but this does not deprive them of physical meaning. The probabilities are measurable and, moreover, they may be predicted, and the predictions are testable. Indeed quantum mechanics employs the full machinery of scientific method, but it does not, in fact cannot, and fortunately need not, use pictorial models.

To see what complementarity is, we have only to restate, in different terminology, the points made in the preceding paragraph. In classical physics, measurement results associated with a system prepared in some specified manner might be described as *supplementary;* they can be combined to form a well-labeled picture of the system. In quantum physics, although such measurement results cannot be so conjoined, the totality of measurement results from a system[2] is of great physical significance. Thus, while the measurement results do not meaningfully supplement each other in a picture, they certainly do *complement* each other in that their totality has scientific value. Hence the term "complementarity."

There are other ways, less mysterious than the complementarist jargon, of describing the essential character of quantum observables. In particular, the reader is referred to Margenau's latency theory,[3] which contrasts the *possessed* observables of pre-quantum physics to the *latent* observables of quantum theory. A system whose observables are latent carries no fixed values for its observables; numerical values emerge only in response to measurement. Against this background, quantum theory is rationally comprehensible even though no visual models are employed. Strangely enough, there are some philosophers who cannot believe this. For example, Austin cites Hesse as the author of what he calls "plausible arguments" against Margenau's view that visualizable models are dispensable. Another critic of the latency theory is Mehlberg,[4] who says that it is "a helpful way of speaking because of its pointing to the undeniable inconsistency of the situation, but it is certainly unable to remove the latter." As a practitioner of quantum physics who regularly and without inconsistency utilizes the latency viewpoint, I can only regard such criticism as reactionary longing for superseded mechanistic ideals.

Thus far, although the meaning of complementarity has been thoroughly explained, no *paradoxes* have arisen. Why then does Austin look to complementarity for an example of theology-like paradox in science? His inspiration apparently comes from the all too common, but philosophically unsound, identification of complementarity with that historic doctrine of confusion from the early days of quantum theory known as the "wave-particle duality." Bohr himself perhaps aggravated this situation by his colorful, sometimes obscure, but never technical writings on complementarity in which he frequently described *gedanken* experiments in wave and/or particle terminology. Perhaps unfortunately, Bohr kept one foot firmly planted in the classical world by insisting repeatedly that the observation language of physics is and must always remain classical, a dictum not universally granted among physicists of the present generation. In any case, by combining complementarity as explained earlier with this notion that classical physics *must* be the language of the laboratory and then applying a bit of questionable logic, some thinkers are disposed to "conclude" that quantum theorists are forced to mix and juggle contradictory classical models of physical systems. Thus arises the wave-particle duality and the seeming intrusion of fundamental paradoxes into modern physics.

It is tempting to dismiss the wave-particle duality simply by a remark to the effect that the premise insisting upon the *necessity* of a classical observation language is unacceptable. However, to avoid getting further into that controversy, we shall take a different tack. Suppose the observation, or laboratory, language does sound "classical." What of it? It does not follow that the theoretical physicist will employ classical models to explain the data (measurement results) gathered in that "classical" laboratory. For example, even if Wilson cloud chamber electron tracks are initially described in terms of particles, and observations of Davisson-Germer electron diffraction patterns are reported in the language of waves, the quantum theorist who analyzes and scientifically explains both these phenomena is interested in *neither* particles nor waves; he is concerned only with *electrons,* theoretical entities, which are not particles, waves, vortexes, demons, or anything else visualizable. If the systems, like electrons, with which quantum theory is concerned are to have any special name, it should be something neutral, such as quantum system, or *q*-system, which suggests no classical picture.[5] From a proper quantum-theoretic perspective, there is no logical difficulty at all in comprehending both the cloud chamber tracks and the diffraction pattern in terms of one single genus of physical system, namely, the non-particulate, non-wavy electron, a typical $q$-system. Thus there is no wave-particle duality; there is only a "$q$-system unity" of a "complementary" but unparadoxical nature.

## Concluding Remarks

The major point of this note has already been stated several times: Complementarity, properly understood, entails no paradoxes; in particular, the notion of "wave-particle duality" is a ridiculous portrayal of quantum physics. This being the case, Austin's program for the study of theological paradoxes along complementarist lines seems to *be founded upon what many modern physicists, myself included, would* consider a misconception destined only to produce a quagmire of insignificant if not meaningless analogies. Consider, for example, Austin's sample of a "complementarist" analysis in theology: "As with the wave packet, the concept of God as a good parent, just but merciful, tends to break down in extreme situations in which one or the other of the more strictly plausible models comes to the fore." This theological statement in itself may be significant; but as an analogy to quantum mechanics, the statement is absurd. Wave packets *never* "break down" in favor of "more strictly plausible models." Indeed wave packets (or their generalizations, called "state vectors") may be employed to describe phenomena ranging from the extremely particulate motion of planets to the exceedingly undulatory diffraction of light. Again, there is no dualism.

Finally, it should perhaps be stressed that the present analysis was not intended to be a diatribe against investigations like Austin's, which embrace the seemingly disparate fields of physics and theology. On the contrary, I deplore the tradition of severe artificial compartmentalization of knowledge which so often confronts the interdisciplinary scholar. I even feel that quantum mechanics, in its espousal of abstract concepts which are not open to direct observation, may form a bridge to philosophy and perhaps even theology. But that bridge cannot be anchored on the side of physics in a popular idea of complementarity; it must be based squarely on a full understanding of the epistemology of quantum mechanics.

### NOTES

1. John von Neumann, *Mathematical Foundations of Quantum Mechanics*, translated by R. T. Beyer (Princeton, N.J.: Princeton University Press, 1955); James L.

Park, "Problems Concerning Measurement: A Study of the Foundations of Quantum Theory," Ph.D. thesis, 1967, Yale University.

2. The devastating effects of the measurement operation in microphysics usually make it necessary to reprepare the system after each measurement or to use many identical systems similarly prepared, but this technicality need not concern us here.

3. Henry Margenau, *Open Vistas* (New Haven, Conn.: Yale University Press, 1961).

4. Henryk Mehlberg, "Comments on Landé's 'From Duality to Unity in Quantum Physics,'" in *Current Issues in the Philosophy of Science,* ed. H. Feigl and G. Maxwell (New York: Holt, Rinehart & Winston, 1961), p. 369.

5. For the case of the so-called elementary particles, Margenau (*op. cit.*) has suggested the etymologically sensible term "onta."