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Critique of "Quantum Enigma: Physics Encounters Consciousness"

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Abstract The central claim that understanding quantum mechanics requires a conscious observer, which is made by B. Rosenblum and F. Kuttner in their book "Quantum Enigma: Physics encounters consciousness", is shown to be based on various misunderstandings and distortions of the foundations of quantum mechanics.

1 Introduction

When discussing the quantum theory and its interpretation in physics, Bohr often emphasized the importance of describing fully the experimental apparatus. Part of such a description consists of selecting the proper words to describe the observations. In 1948 he put it as follows [1]:

> Phrases often found in the physical literature as 'disturbance of phenomena by observation' or 'creation of physical attributes of objects by measurements' represent a use of words like 'phenomena' and 'observation' as well as 'attribute' and 'measurement' which is hardly compatible with common usage and practical definition and, therefore, is apt to cause confusion. As a more appropriate way of expression, one may strongly advocate limitation of the use of the word *phenomenon* to refer exclusively to observations obtained under specified circumstances, including an account of the whole experiment.

Unfortunately, these admonitions are generally ignored by the authors of *Quantum Enigma* (QE) [2], and as a consequence this book will cause plenty of the confusion predicted by Bohr. In the following section, I will quote selected paragraphs that contain what I consider to be some of the most serious distortions which I found in this

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book, followed by my critique. In support of this critique, I include in the last section some relevant quotations from Einstein, Bohr, Heisenberg, and Schrödinger, who laid the foundations of modern quantum theory, and by some other prominent contemporary physicists, concerning quantum mechanics and the measurement process. These quotations contradict many of the claims and unsupported assertions made in this book about the interpretation of quantum theory. In particular, all these physicists *deny* the supposed role of *consciousness* in physics, for which there isn't any experimental support whatsoever. But the claim that consciousness plays a role in quantum mechanics ("our bias," as the authors write) is the underlying message which the authors of QE would like to implant on their readers.

The authors of QE also offer quotations from prominent scientist in support for their claims. For example, Martin Rees, the Astronomer Royal and current president of the Royal Society in London, is quoted as saying [2, p. 193]:

> In the beginning there were only probabilities. The universe could only come into existence if someone observed it. It does not matter that the observers turned up several million years later. The universe exists because we are aware of it[1] [2, p. 193].

In contrast, however, Murray Gell-Mann, the winner of a Nobel Prize for his fundamental contributions to particle physics, is quoted in QE as saying that

> The universe presumably couldn't care less whether human beings evolved on some obscure planet to study its history; it goes on obeying the quantum mechanical laws of physics irrespective of observation by physicists [2, p. 156].

The authors' response is that "in talking about classical physics, Gell-Mann's *presumption* [my emphasis] would go without saying [2, p. 168]. But Gell-Mann is talking about quantum mechanics which governs *all* the fundamental process in our the universe. The authors' distinction here between classical and quantum mechanics is a red herring. The examples discussed in QE are concerned with *elementary* or *single* quantum processes. Evidently, the authors are unaware that there is a distinction between analyzing such processes and the multiple quantum processes that occur in macroscopic systems like living creatures, stars, and galaxies.[2]

[1] The authors of QE do not give sources for the numerous quotations in their book. Therefore, I asked Martin Rees where he had made this statement and he responded: "I am perplexed by the quote. It seems rather 'Wheelerish'—not at all the sort of thing I would have said." This quotation was inserted as a caption to a figure in an article that Rees had written for the New Scientist (August 6, 1987). This figure is a copy of a drawing made by John Wheeler which also appears on page 200 of QE, and that the caption paraphrases Wheeler's words in a script entitled "Law without law." The original caption starts with "The universe viewed as a self-excited circuit." Apparently, Wheeler was in a playful mood, because he remarked "caution: consciousness has nothing whatsoever to do with quantum processes" (see quotation at the end of the next section).

[2] For example, consider the evolution of a star like the sun. This evolution is primarily based on quantum phenomena, with classical gravitational forces primarily providing the confinement for the atomic process. Thus, the production of energy is due to nuclear reactions governed by quantum processes in the interior of the star, which requires also the phenomenon of quantum tunneling, the emission of radiation, which is governed by the laws of quantum field theory, and the eventual collapse of a star like the sun into a white dwarf or neutron star, which depends on the quantum mechanical degeneracy pressure of electrons

In fact, it is Gell-Mann's statement and not the one attributed incorrectly to Rees (see footnote 1), that represents the generally accepted view that *all* processes in the universe evolve in accordance with the laws of quantum mechanics *without* any need whatsoever of conscious observers. In cases where classical mechanics is adequate to explain the observations, it is regarded as an approximate theory.

Eugene Wigner, who also was a Nobel prize winner, and belongs among the great physicists who developed quantum mechanics, was the only one who invoked consciousness, primarily to break the celebrated von Neumann chain associated with the reduction of the wave function after a measurement process. Naturally, he is quoted prominently in QE, once in the introduction and the second time in the last chapter, saying that

> When the province of physical theory was extended to encompass microscopic phenomena through the creation of quantum mechanics, the concept of consciousness came to the fore again: it was not possible to formulate the laws of quantum mechanics in a fully consistent way without reference of the consciousness see [2, p. 4 and p. 179].

Wigner was very interested in the foundations of quantum mechanics, wrote many seminal papers about this subject, and his views cannot be dismissed easily. It is therefore important to point out that in his last papers on the interpretation of quantum mechanics Wigner changed his position to a considerable extent. He wrote that

> This writer's earlier belief that the role of the physical apparatus can always be described by quantum mechanics implied that "the collapse of the wavefunction" takes place only when the observation is made by a living being—a being clearly out of the scope of our quantum mechanics. The argument which convinced me that quantum mechanics validity has narrower limitations, that it is not applicable to the description of the detailed behaviour of macroscopic bodies is due to D. Zeh [5].

But the authors of QE ignored his last papers on this subject.

John Bell, who is regarded as having made some of the most significant modern contributions to our understanding of quantum theory, remarked that

> I see no evidence that it is so [that the cosmos depends on our being here to observe the observables] in the success of contemporary quantum theory. So I think it is not right to tell the public that a central role for conscious mind is integrated into modern atomic physics. Or that 'information' is the real stuff of physical theory [6].
>
> I think the experimental facts which are usually offered to show that we must bring the observer into quantum theory do not compel us to adopt that conclusion [7].

or neutrons [3]. Even the explosion of more massive stars into supernovas gives rise to quantum nuclear processes leading to the emission of neutrinos. Since the start of the Big Bang all these processes have been going on without the need of any "observers," conscious or otherwise. The most striking evidence of the Big Bang is the low-temperature black-body radiation which was created in the early universe by quantum processes, obviously without any observers around [4].

For a long time I have argued along the same lines that I found recently in an article by A. Leggett [8], a Nobel prize winner who has given considerable thought to the quantum measurement paradox,

> ...it may be somewhat dangerous to 'explain' something one does not understand very well [the quantum measurement process] by invoking something [consciousness] one does not understand at all!

But instead of "it may be dangerous," I would say "it does not make sense."

These last three comments firmly contradict the central claims of the authors of QE concerning a supposed role for consciousness in physics.[3]

2 Critique of Selected Quotations from QE

Each of the quotations from QE listed below is written in typewriter style, and its location in QE is identified by the page number (p) and the line number counted either from the bottom (b) or the top (t) of the page. My criticisms follow after each of these quotations.

> This is a controversial book. But nothing we say about *quantum mechanics* is controversial. The experimental results we report and our explanation of them with quantum theory are completely undisputed (p. 3 t. 1).

Invariably, however, experimental results are reported in this book in a very sketchy and inaccurate manner, which leads to the confusion predicted by Bohr (see Sect. 1). Moreover, as will be shown below, the statement that "our explanation of them [the experiments] with quantum theory are completely undisputed" usually turns out to be incorrect.

> That physics has *encountered* consciousness cannot be denied (p. 4 b. 13).

Presumably Bohr, Heisenberg, Einstein, and many other great physicists I quote in this critique have been living in denial. Only very few prominent physicists, e.g. E. Wigner, have argued for a role of consciousness in the measurement process, but later in his life, however, Wigner changed his views, persuaded by the work of Zeh [5]. But such exceptional cases do not justify ignoring the warning of Bell "that it is not right to tell the public that a central role for consciousness is integrated into modern physics."

> The quantum enigma, conventionally called the "measurement problem," appears right up front in the simplest quantum experiment (p. 5 t. 9).

[3] I share Steve Hawking's impulse "to reach for my gun" [2, p. 120] whenever Schrödinger's cat story is told. This cat story is notorious. It requires one to accept that a cat, which can be in innumerable different states, can be represented by a two-state wavefunction, a bit of nonsense which Schrödinger himself originated. However, a movie camera installed in the box containing the cat would *record* a cat that is alive until the unpredictable moment that the radioactive nucleus decays opening the bottle containing cyanide thus killing the cat. It is claimed that Schrödinger never accepted the statistical significance of his celebrated wavefunction.

The measurement problem can be summarized as the question why macroscopic detectors like a Geiger counter or a photographic plate, which are ultimately made of atoms, are never found in a *superposition* of quantum states. The authors of QE claim that *consciousness* is what destroys this superposition. But if there are several observers, whose consciousness is responsible for this collapse of superposition? If both authors of QE look at the *same time* at a photographic film recording an atomic event, who "caused" the collapse of superposition? And what happens when you have a thousand observers, as is often the case in current high-energy physics when often billions of events are observed?

> Try summarizing the implications of quantum theory, and what you get sounds mystical.... To account for the demonstrated facts, quantum theory tells us that an observation of one object can instantaneously influence the behaviour of another greatly distant object—*even if no physical force connects the two*. Einstein rejected such influences as "spooky interactions," but they have now been demonstrated to exist (p. 12 b. 14).

The "facts" that have been demonstrated are *correlations* between distant particles which are predicted according to quantum mechanics as a consequence of *conservation laws*. For example, due to conservation of energy and momentum in a two particle scattering event, the observation of the momentum of one of the scattered particles determines the momentum of the other scattered particle if the initial state is known. This correlation is expected both in classical and in quantum theory, and there is nothing "mystical" about it. There are also correlations of polarizations of entangled photons which are predicted by quantum theory that have been confirmed by experimental observation. These correlations are consequences of the *conservation law* of angular momentum. The claim that Einstein *rejected* these correlations is incorrect (for some quotations of his views of quantum theory see Sects. 2 and 3).

> For example, according to quantum theory, an object can be in two or many places at once—even far distant places. Its existence at the particular place it happens to be found becomes an actuality upon its (conscious) observation (p. 7 b. 9).

Both statements are wrong. Quantum theory is a theory that predicts the probability of observing physical attributes of a particle, such as position and momentum. The probability of finding a particle in "two or many places at once" is *always* zero. The question can be asked as to where a particle is located in between observations, but this question is *metaphysical*, and lies outside the realm of scientific inquiry. The claim that it requires *consciousness* to make the location of an object an "actuality," which is repeated like a mantra throughout QE, is not supported by any evidence, and it is demonstrably incorrect.

> But they [our physics colleagues] will find nothing *scientifically* wrong with what we say. The physics facts we present are undisputed (p. 13 b. 12).

This claim, which is being promoted in QE to an unsuspecting public, is untrue, as will be demonstrated here in many examples.

> The waviness[4] in a region is the probability of *finding* the object in that region. Be careful—the waviness is not the probability of the object being there. There is a crucial difference! The object was not there until you found it there. Your happening to find it there *caused* it to be there. This is tricky and the essence of the quantum enigma (p. 75 b. 12).

The muddled second half of this statement is incorrect. The absolute square of the wave function gives the probability for the outcome of an experimental observation such as the localization of an atomic particle. A particle can be localized by an appropriate recording device, a Geiger counter, a photographic plate, etc., independent of any particular human observer. One need only to realize that different observers who examine such a recording all reach the same conclusion about the region of localization to see that the remark "your happening to find it there *caused* it to be there" does not make any sense. An observer does not *cause* the occurrence of an atomic event. This is like believing that you can bend spoons with your mind. No one has given evidence for such effects.

The authors of QE claim that

> In quantum theory there is no atom in addition to the wavefunction of the atom. This is so crucial that we say it again in other words. The atom's wave-functions and the atom are the same thing; "the wave function of the atom" is a synonym for "the atom" (p. 77 t. 6).
> Since the wavefunction is synonymous with the atom itself, the atom is simultaneously in both boxes. The point of that last paragraph is hard to accept. That is why we keep repeating it (p. 103 t. 3).

In other words, since matter consist of atoms, presumably while reading these line you are sitting on a chair made up of wavefunctions. Of course, the wavefunction of an atom is not a synonym for the atom. Atoms have mass, charge, total spin, and energy levels, which are *invariant* properties, while the wavefunction describes the evolution of its dynamical variables. According to quantum theory, the square of the wave function gives the probability that the measurement process yields allowed values for a set of commuting variables. For this purpose it is necessary to study an ensemble of atoms which initially are prepared under identically the same physical conditions. This is fundamentally different from claiming that the wavefunction is *synonymous* with the atom itself. The probability of observing an atom *simultaneously* at two different locations, by an actual measurement, is always *zero*. Hence, it is wrong to claim that the atom "is *simultaneously* in both boxes."

> Accordingly, before a look collapses a widely spread-out wavefunction to the particular place where the atom is found, the atom did not exist there prior to the look. The look brought about the atom's existence at that particular place—for everyone (p. 77 t. 9).

This is a powerful "look" indeed, but again, this is incorrect. In spite of Bohr's repeated warning of the importance of carefully choosing appropriate language

[4]This name was introduced by Bell, and refers to the absolute square of the wavefunction.

to describe the observation of atomic events, this warning is again ignored here. Statements like "before a look collapses ... a wavefunction" or "the look brought about... the atom's existence" do not make any sense or have any meaning whatsoever. According to the description of some of the founders of the quantum theory who are quoted in the next section, a meaningful statement is that the reduction or collapse of a wavefunction occurs after a recording has been made by an *irreversible* amplification of an atomic event by a macroscopic detector, like a Geiger counter or a photographic plate. The combination of eye lens, retina, optical nerve and neural memory cells can be regarded as a detector for the special case of photons in a visible frequency range, but such a detector is unique to a single observer.

> The most accurate way of describing the state of the unobserved atom is to put into English the mathematics describing the state of the atom before we looked to see where it is: The atom was *simultaneously in two states*: in the first state, it is in-the-top-box-and-not-in-the-bottom-box, and simultaneously in the second state it is in-the-bottom-box-and-not-in-the-top-box (p. 79 t. 15).

This so called "accurate" description is actually pure metaphysics, since it is not possible to established the location of an "unobserved" atom. According to quantum theory, before an observation is made there is only a *probability* of finding the atom in either the top or the bottom box. The essence of quantum physics is that nothing definite can be said about the location of the atom before a measurement of it is made. For example, we can send a beam of photons into a box and detect the scattered photons. This can establish approximately the localization of the atom *at the time* of the interaction of the photon and the atom, but not at any time before this interaction took place.

> The talk we offer in a quantum mechanics class for physics students is that when we look in a box and find no atom, we instantaneously collapse the atom's waviness [wavefunction] into the other box (p. 108 t. 11).

The statement refers to the possibility that even though a detector is not triggered the wavefunction of the system is changed. This appears to contradict the requirement that the detector must make a recording to alter the wavefunction of the system. In fact, the presence of a detector to determine, for example, the location of an atom, also alters the evolution of the wavefunction, and consequently the probabilities of various outcomes. Therefore, if a detector is not triggered, there is a finite probability that the atom did not take the path crossing the detector. But there is also a non-vanishing probability that the atom crossed the detector without triggering it. Therefore, it can not be concluded with certainty in what box the atom is located until a second detector triggers and determines its location. Certainly *consciousness*, i.e. "we look in a box and find no atom, we instantaneously collapse the atom's waviness ...," has nothing whatsoever to do with the explanation of this subtle property of quantum mechanics.

> But randomness was not Einstein's most serious problem with quantum mechanics. What disturbed Einstein, and more people today, is quantum mechanics' apparent denial of ordinary physical reality—or, maybe the same thing, the need to include the observer in the physical description—an intrusion of consciousness into the physical world (p. 80 t. 8).

While Einstein was concerned with the nature of physical reality, it is highly misleading to indicate that it is the "same thing" to imply that he was concerned with the "intrusion of consciousness into the physical world." On the contrary, he made it clear that the generally accepted statistical interpretation of the wavefunction is an "*objective* description" whose concepts clearly make sense independently of the observation and the *observer* (see the next section for the full quotation in his letter to Born a year before his death).

> John Bell felt that the quantum mechanical description will be superseded.... It carries in itself the seeds of its own destruction.... He feels that "the new way of seeing things will involve an imaginative leap that will astonish us" (p. 87 t. 5).

The authors of QE fail to point out that this quotation appeared in an article written jointly by Bell and myself about 40 years ago [16]. But neither of them bothered to ask for my current views on this subject. I will take the opportunity to make a disclaimer here. In our paper we also said, tongue in cheek, that

> The experiment may be said to start with the printed proposal and to end with the issue of the report. The laboratory, the experimenter, the administration, and the editorial staff of the Physical Review are all just part of the instrumentation. The incorporation of (presumably) conscious experimenters and editors into the equipment raises a very intriguing question.... If the interference is destroyed, then the Schödinger equation is incorrect for systems containing consciousness. If the interference is not destroyed, the quantum mechanical description is revealed as not wrong but certainly incomplete.

In a footnote we added that "we emphasize not only that our view is that of a minority but also that current interest in such questions is small. The typical physicist feels that they have been long answered, and that he will fully understand just how if ever he can spare twenty minutes to think about it." (As a graduate student, one of the authors, Bruce Rosenblum, reports that he "assumed that if I spent an hour or so thinking it [the wave particle duality] through, I'd see it all clearly" [2, p. 10].)

At the time that we made these comments, I did not understand that a Geiger counter, a photographic film, the retina of the eye and associated neural connections. or any other detector creates a more or less permanent record by means of physical and/or chemical processes that are *irreversible*. As in thermodynamics, such processes involve a very large number of atoms which are involved through an amplification process essential to the creation of a recording.[5]

A major failure of QE is that this essential feature of the measurement process in quantum theory is not even mentioned. It is worth remembering that irreversibility

[5]Following Bohr's admonition to discuss the details of the measuring apparatus, we note that a typical photographic film consist of an irregular array of silver bromide ionic crystals suspended on an emulsion. The absorption of a photon ejects an electron which gives rise to a catalytic reaction where a very large number of silver ions transform into silver atoms. After the film is processed these silver atoms give rise to a spot which absorbs visible light shining on it, thus producing a dark spot which approximately marks the position on the screen where the photon had landed. The cascade of silver ions into silver atoms produced by the photon is the amplification which gives rise to an irreversible process, and therefore it can not be described by the evolution of a simple wavefunction.

already was a conundrum for classical physics because the basic equations are time reversal invariant. The same invariance applies to the basic equations in quantum mechanics. The emergence of irreversibility occurs in systems with large number of particles, which is the case with recording devices, and constitutes the foundations of statistical thermodynamics [4].

> There is no official Copenhagen interpretation. But every version grabs the bull by the horns and asserts that an *observation produces the property observed* (p. 100 t. 11).

Read, for example, the quotations of Bohr, Heisenberg, Einstein and others quoted here and in the next section to see that none of them ever made such statement as "produces the property observed" when referring to an observation.

> Even students completing a course in quantum mechanics, when asked what the wavefunction tells, often incorrectly respond that it gives the probability where the object is (p. 103 t. 7).

Actually, the students' response is essentially correct if it is modified by stating that "the absolute square of the wavefunction is the probability where the object will be found" in an experiment designed to establish the position of the object.

> Our concern is with the consciousness central to the quantum enigma—the awareness that appears to affect physical phenomena. Our simple example was that your observation of an object wholly in a single box *caused* it to be there, because you presumably *could* have chosen to *cause* an interference pattern establishing a contradictory situation, whereby the object would have been a wave simultaneously in two boxes (p. 168 t. 18).

It is hard to imagine that more confusion about the meaning of quantum theory could be encapsulated into a single sentence. To begin with, an experimental set up to observe in which of two boxes an atom is located does not "cause" such a localization. Instead, an observer who examines the output of a recording finds the location of the atom in accordance with a probability distribution given by the absolute square of Schrödinger's ψ function appropriate to the experimental arrangement. A different experimental setup may lead to observations of interference patterns by coherent atomic beams, but these patterns are not "caused" by the "awareness" of the observer. The interference patterns can be recorded on a photographic film and seen there by anyone examining this film. It is completely ridiculous to propose that someone who sees the interference pattern on the film "caused" it to be there. The claim that by "choosing" the experimental set up the observer "caused" a particular outcome is a bizarre use of the word "cause" which has nothing whatsoever to do with quantum theory. Bohr must be turning over in his grave.

According to the authors of QE, *consciousness* is supposed to enter into quantum theory because the observer can choose ("free will") the experimental setup, which demonstrates in this case complementary aspects, wave or particle behaviour, of a photon, electron or other atomic objects. But the choice of experiment can also be made, for example, by flipping a coin.

> Does such a demonstration necessarily require a *conscious* observer? Couldn't a conscious robot, or even a Geiger counter, do the observing? That most commonly voiced objection to consciousness being required comes up—and is refuted—in our next chapter. For now, just recall that, according to quantum theory, if that robot or Geiger counter were not in contact with the rest of the world it would merely entangle to become part of a total superposition state—as did Schrödinger's cat. In that sense it would not truly *observe* (p. 168 b. 12).

The operation of a Geiger counter is well understood, and it satisfies the condition necessary to establish an observation, namely the irreversible amplification of an atomic signal to create a semi-permanent record of an atomic event. The only important contact of a Geiger counter to the "rest of the world" is a power cable, which has to be plugged into a wall socket from which electricity flows from a power plant. A battery would also be sufficient.

> Classical physics, Newtonian physics, is completely deterministic. An "all-seeing eye," knowing the situation of the universe at one time, can know its entire future. If classical physics applied to everything, there would be no place for free will (p. 169 t. 11).

This familiar quotation, due to Pierre Simon Laplace in the 18th century, was later shown to be wrong by Henri Poincaré. Laplace was not aware that Newtonian mechanics could lead to chaotic motion, and that in practice classical theory also is not deterministic, because of "sensitivity to initial conditions."[6] The implication that quantum mechanics is somehow essential to *free will*, which is supported by some philosophers of science, is not valid.[7]

2.1 The Encounter "Officially" Proclaimed (p. 180 t. 1)

> In his rigorous 1932 treatment "The Mathematical Foundations of Quantum Mechanics," John von Neumann showed that quantum theory makes physics encounter with consciousness *inevitable* [my emphasis] (p. 180 t. 1).

But in the next sentence, one finds that this "inevitable encounter" occurs because von Neumann has treated a Geiger counter by a trivial wavefunction consisting of the superposition of only two states: whether it is in a "fired" or in an "unfired" state. This model of a Geiger counter, however, is *incorrect*, because it does not describe the *essential* property of such a detector, which is to be able to make a permanent *record* of an atomic event. Such a recording requires an *irreversible* process.

> You're prompted to investigate how the robot chose which experiment to do in each case. Suppose that you find that it flipped a coin. Heads it did the-look-in-the-box experiment; tails the interference experiment. You find something puzzling about this: The coin's landing seems inexplicably connected with what

[6] Doubters should play with the double pendulum in the entrance of our physics dept., which I had built by our mechanics shop to demonstrate chaotic dynamics.

[7] Some time ago I had an argument about this issue with the Berkeley philosopher John Searle. However, he did not seem to be aware that the *noise* due to finite temperature thermal fluctuations in the firing of neural brain cells is more important than the zero-temperature quantum fluctuations or effects of the uncertainty principle.

> was presumably in a particular box-pair set. Unless ours is a strangely deterministic world, one that conspired to correlate the coin landing with what was in the box pairs, there is no physical mechanism for that correlation (p. 183 b. 15).

The outlandish notion that there exists a correlation between the "coin landing" and the outcome of an experiment is tied to the previous unsupported claim that an observer can "cause" this outcome. This is the consequence of the sloppy language which Bohr had warned should be avoided.

> You therefore replace the robot's coin flipping by the one decision mechanism you are sure is not connected with what supposedly exists in a particular box-pair set: *your own free choice*. You push a button telling the robot which experiment to do with each box-pair set. You now find that by your conscious free choice of experiment you can prove either that the objects were concentrated or that they were distributed. You can choose to prove either of two contradictory things. You are faced with the quantum enigma, and consciousness is involved (p. 183 b. 8).

If you have had the patience to come this far, you finally will have found out how, according to the authors of QE, *physics encounters consciousness*: by replacing the decision making of a robot who flips coins with the *free will of a conscious observer*. This claim, however, does not make any sense, because as a "conscious observer" you can also make decisions based on flipping coins rather than on your free will. Following the logic of the authors of QE, you would have to conclude that *physics encounters coin flipping*. It should be pointed out that while a few eminent physicists such as Eugene Wigner believe that consciousness plays a role in the *collapse* of the wavefunction, he did not argue that this role has anything to do with "free will." This is a new and unsubstantiated twist to the role of consciousness given by the authors of QE. Such a bias should not be foisted on the general public as a generally accepted notion in modern physics.[8]

> If we consider the robot argument from the viewpoint of quantum theory, the isolated robot is a quantum system, and von Neumann's conclusion applies: the robot entangles with the object in the box pairs, and the object's wavefunction

[8] It is easy to demonstrate that the persistent claim of the authors of QE that it is necessary to choose or flip a coin to decide which of their two *gedanken* experiments should be performed can be avoided by performing *both* experiments at the same time. Light of appropriate frequency and variable intensity is shined on the two slits through which individual atoms of fixed momentum are directed. Then a scattered photon and an appropriate detector can record through which slit an atom passed, while a photographic plate can record the position where the atom lands later on. All the spots that are recorded on the photographic plate are then separated into two classes of events: (a) events where a scattered photon is detected and (b) events where no scattered photon is detected. According to quantum theory, events of class (b) show an interference pattern characteristic of the two slit experiment although it is modified by the presence of the radiation field. Events of class (a), however, do not show this interference pattern. The fraction of the events in class (a) and (b) depends on the intensity of the light shining on the two slits: the weaker the intensity the greater the number of events in class (a) and vice versa. It is assumed here that the detector of scattered photons is very efficient, otherwise the interference pattern will be further smeared out, because it contains also events where a scattered photon from an atom was not detected. See also the description given by Feynman [18, 19].

> does not collapse into a single box until a conscious observer views the robot's printout (p. 184 t. 1).

The notion that the "robot entangles with the object," implying that the robot, or for that matter any macroscopic measuring apparatus like a Geiger counter or a photographic film, can be represented by a wavefunction ψ is *incorrect*. The essential property of macroscopic systems like robots is that these systems are able to create a record of an atomic event by a mechanism of amplification which is irreversible. This mechanism has nothing whatsoever to do with consciousness.

In conclusion, I like to quote John Wheeler [15]

> Caution: "Consciousness" has nothing whatsoever to do with the quantum process. We are dealing with an event that makes itself known by an irreversible act of amplification, by an indelible record, an act of registration. Does that record subsequently enter into the "consciousness" of some person, some animal or some computer? Is that the first step into translating the measurement into "meaning"—meaning regarded as "the joint product of all the evidence that is available to those who communicate." Then that is a separate part of the story, important but not to be confused with "quantum phenomena."

This quotation appears in QE, p. 165, but in a truncated form. What is left out is Wheeler's definition for the word *meaning*. The authors of QE comment to Wheeler's remark

> We take this as an injunction to physicists (as physicists) to study only the quantum phenomena, not the *meaning* of the phenomena.

But Wheeler's *injunction* clearly is *against* claiming that consciousness has something to do with quantum phenomena, which is the central theme of QE. It is not an injunction against studying the cognitive processes in the brain associated with consciousness, which are "a separate part of the story, important but not to be confused with quantum phenomena."

3 Remarks on the Quantum Measurement Process by Some of the Founders of the Quantum Theory, and by Prominent Contemporary Physicists

Below, I have included some quotations on quantum measurement and the role of the observer by the founders of quantum theory and some prominent contemporary physicists, which are relevant to my critique of QE.

N. Bohr (1958)

> Far from involving any special intricacy, the irreversible amplification effects which the recording of the presence of atomic objects rests rather reminds of the essential irreversibility inherent in the very concept of observation. The description of atomic phenomena has in these respects a perfectly objective character, in the sense that no explicit reference is made to any individual observer and that therefore, with proper regard to relativistic exigences, no ambiguity is involved in the communication of information [9].

W. Heisenberg (1958)

The probability function does—unlike the common procedure in Newtonian mechanics—not describe a certain event but, at least during the process of observation, a whole ensemble of events.... When the old adage "Natura non facit saltus"[9] is used as a basis of criticism of quantum theory, we can reply that certainly our knowledge can change suddenly and that this fact justifies the use of the term "quantum jumps" [or collapse of the wavefunction].
Therefore, the transition from the "possible" to the "actual" takes place during the act of observation. If we want to describe what happens in an atomic event, we have to realize that the word "happens" can apply only to the observation, not to the state of affairs between two observations. It applies to the physical, not the psychical [my emphasis] act of observation, and we may say that the transition from the "possible" to the "actual" takes place as soon as the interaction of the object with the measuring device, and therefore with the rest of the world, has come into play; it is not connected with the act of registration of the result by the mind [my emphasis] of the observer. The discontinuous change in the probability function [collapse of the wavefunction], however, takes place with the act of registration, because it is the discontinuous change of our knowledge in the instant of registration that has its image in the discontinuous change of the probability function.... Certainly quantum theory does not contain genuine subjective features, it does not introduce the mind of the physicist as a part of the atomic event [10].

A. Einstein (1949)

One arrives at very implausible theoretical conceptions, if one attempts to maintain the thesis that the statistical quantum theory is in principle capable of producing a complete description of an individual [my emphasis] physical system. On the other hand, those difficulties of theoretical interpretation disappear, if one views the quantum mechanical description as the description of ensembles of systems.
I reached this conclusion as the result of quite different types of considerations. I am convinced that everyone who will take the trouble to carry through such reflections conscientiously will find himself finally driven to this interpretation of quantum-theoretical description (the ψ function is to be understood as the description not of a single system but of an ensemble of systems) [11].

A. Einstein (1953)

All the same it is not difficult to regard the step into probabilistic quantum theory as final. One only has to assume that the ψ function relates to an ensemble, and not to an individual case.... The interpretation of the ψ function as relating to an ensemble also eliminates the paradox that a measurement carried out in *one* part of space determines the *kind* of expectation for a measurement carried out later in *another* part of space (coupling of parts of systems far apart in space) [12].

[9] Nature does not act in jumps.

A. Einstein (1954)

The concept that the ψ function completely describes the physical behaviour of the individual single system is untenable.[10] But one can well make the following claim: if one regards the ψ function as the description of an *ensemble* it furnishes statements which—as far as we can judge—correspond satisfactorily to those of classical mechanics and at the same time account for the quantum structure of reality. In this interpretation [Born's statistical interpretation of quantum mechanics] the paradox of the apparent coupling of spatially separated parts of systems also disappears. Furthermore, it has the advantage that the description thus interpreted is an *objective* description whose concepts clearly make sense independently of the observation and the observer [13].

O. Stern, quoted by Pauli (1954)

As O. Stern said recently, one should no more rack one's brain about the problem of whether something one cannot know anything about exists all the same, than about the ancient question of how many angels are able to sit on the point of a needle. But it seems to me that Einstein's questions are ultimately always of this kind [17].

R.P. Feynman (1963)

Nature does not know what you are looking at, and she behaves the way she is going to behave whether you bother to take down the data or not [18].

[10] Einstein reached this conclusion by the following argument:

> My assertion is this: the ψ function cannot be regarded as a complete description of the system, only as an incomplete one. In other words: there are attributes of the individual system whose reality no on doubts but which the description by means of the ψ function does not include.
> I have tried to demonstrate this with a system which contains one 'macro-coordinate' (coordinate of the centre of a sphere of 1 mm diameter). The ψ function selected was that of fixed energy. This choice is permissible, because our question by its very nature must be answered so that the answer can claim validity for every ψ function. From the considerations of this simplest case, it follows that—apart from the existing macro-structure according to the quantum theory—at any arbitrarily chosen time, the centre of the sphere is just as likely to be in one position (possible in accordance with the problem) as in any other. This means that the description by ψ function does not contain anything which corresponds with a (quasi-)localization of the sphere at the selected time. The same applies to all systems where macro-coordinates can be distinguished.
> In order to be able to draw a conclusion from this as to the physical interpretation of the ψ function we can use a concept which can claim to be valid independently of the quantum theory and which is unlikely to be rejected by anyone: any system is at any time (quasi-)sharp in relation to its macro-coordinates. If this were not the case, an approximate description of the world in macro-coordinates would obviously be impossible ('localization theorem'). I now make the following assertion: if the description by a ψ function could be regarded as the complete description of the physical condition of an individual system, one should be able to deduce the 'localization theorem' from the ψ function and indeed from any ψ function belonging to a system which has macro-coordinates. It is obvious that this is not so for the specific example which has been under consideration [13].

Stated in another way, the Schrödinger equation has solutions for ψ, such as a plane wave (fixed energy), which do not correspond to the description of the motion of any individual macroscopic object like Einstein's sphere which has also sharply localized position. But this solution does describe an *ensemble* of identical spheres which have centers distributed uniformly along the direction of motion, all moving with the same velocity.

J. Wheeler (1986)

No elementary quantum phenomenon is a phenomenon until it's brought to a close by an irreversible act of amplification by a detection such as the click of a Geiger counter or the blackening of a grain of photographic emulsion [14].

J. Bell (1986)

I think the experimental facts which are usually offered to show that we must bring the observer into quantum theory do not compel us to adopt that conclusion [7].
The problem of measurement and the observer is the problem where the measurement begins and ends, and where the observer begins and ends... there are problems like this all the way from the retina through the optic nerve to the brain and so on. I think, that—when you analyse this language that the physicists have fallen into, that physics is about the result of observation—you find that on analysis it evaporates, and nothing very clear is being said [7].

N. van Kampen (1988)

Theorem IV. Whoever endows ψ with more meaning than is needed for computing observable phenomena is responsible for the consequences... [20].

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