The physicist inside the ambiguous room: an argument against the need of consciousness in the quantum mechanical measurement process

Carlo Roselli

Received: 5 June 2021 / Accepted: 22 March 2022 / Published online: 20 April 2022
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

Abstract
The aim of this paper is to invalidate the hypothesis that human consciousness is necessary in the quantum measurement process. In order to achieve this target, I propose a considerable modification of the Schrödinger’s cat and the Dead-Alive Physicist thought experiments, called “PIAR”, short for “Physicist Inside the Ambiguous Room”. A specific strategy has enabled me to plan the experiment in such a way as to logically justify the inconsistency of the above hypothesis and to oblige its supporters to rely on an alternative interpretation of quantum mechanics in which a real world of phenomena exists independently of our conscious mind and where observers play no special role. Moreover, the description of the measurement apparatus will be complete, in the sense that the experiment, given that it includes also the experimenter, will begin and end exclusively within a sealed room. Hence, my analysis will provide a logical explanation of the relationship between the observer and the objects of her/his experimental observation; this and a few other implications will be discussed in the fourth section and in the conclusions.

Keywords The measurement problem in quantum mechanics · Superposition of macroscopically distinguishable states · Consciousness causes collapse hypothesis · Schrödinger’s cat · Wigner's friend · Observer’s consciousness · Collapse of the wave function
1 Introduction

This paper describes an alternative version of The Dead-Alive Physicist (DAP) experiment [42], and is aimed, as well as the DAP but through a considerably different approach, at highlighting the inconsistency of the “idealistic” interpretation of quantum mechanics (QM).

The term “idealistic” is here used to refer to the (orthodox) Copenhagen view of atomic phenomena taken to the extreme. This view is based on two essential points: (1) a quantum system is in a state of genuine indeterminacy until it is measured; (2) the act of measurement forces the quantum system to adopt one of its potential states with a probability that can be calculated by means of the wave-function (WF) which is appropriate for that system and for the measurement to which it is subject.

Thus, according to the Copenhagen interpretation of QM, an elementary quantum phenomenon is not a phenomenon until an irreversible measurement process takes place, and this would require some sort of explicit specification of the boundary that separates quantum from non quantum mechanical systems; indeed, the measurement process is conceived as an interaction between the quantum system and the macroscopic measuring apparatus.

Unfortunately, the Copenhagen interpretation does not explain where and when a measurement process takes place. This omission gives rise to the so called “measurement problem”, which weakens its claim to completeness.

Indeed, this interpretation is not the only possible interpretation of QM that is subject to the measurement problem which, in more general terms, may be considered as that of defining a satisfactory transition process between micro-systems characterized by quantum state uncertainty and macro-systems obeying the deterministic laws of classical physics.

Furthermore, the Copenhagen interpretation of QM gives rise to some thought-provoking demonstrations, usually called “paradoxes”, such as the Einstein–Podolsky–Rosen (EPR) [1], Schrödinger’s Cat [2] and Wigner’s friend [10] experiments, which render questionable the theory’s claim to completeness, unless one assumes that human consciousness plays a fundamental role in the implementation of the quantum measurement process.

Eugene P. Wigner, following the books published in 1932 and 1955 by the mathematician John von Neumann [3, 4] and a little book published in 1939 by the physicists Fritz London and Edmond Bauer [5], developed an argument in favour of the consciousness assumption, leading to the thesis of the wave-function (WF) collapse at biological-mental level, \(^1\) here more simply called “idealistic interpretation” of QM.

From the 1930’s onwards, the measurement problem has been at the centre of a scientific-philosophical debate with the purpose of establishing when (or whether)

\(^1\) There are two main theses arguing that consciousness and quantum mechanical measurement are connected to each other: one thesis (von Neumann, London and Bauer, Wigner, Stapp; see refs 3–5 and 22) holds that the observer’s consciousness causes the collapse of the wave function, thus claiming to complete the quantum-to-classical transition, while the other thesis (Penrose; Penrose and Hameroff; see refs 18–21) aims at demonstrating the opposite, i.e. that consciousness emerges from the so called “Orchestrated Objective Reduction”.
the collapse of the WF occurs [6–27]. The debate on this issue has given rise to endless discussions among physicists and, so far, there has been a lack of consensus regarding which interpretation might be correct.

Starting from the orthodox view of QM, the *idealistic interpretation* assumes that it is the observer’s consciousness the fundamental factor which is able, in some unspecified and mysterious manner (Wigner refers to “a deus ex machina” [11, p. 188]) to collapse the quantum system down into one only of its possible states.

Here *consciousness* would not be playing a merely passive role in the measurement process, but would be the only factor capable of determining the transition from the ambiguous realm of potentials to the unequivocal realm of actual events. This is the kind of vision I mean when referring to the idealistic interpretation of QM.

By its very nature, the idealistic interpretation is difficult to evaluate, both in purely conceptual terms and, obviously, at the empirical-experimental level.

The objective of the thought experiment described hereafter is to demonstrate how the idealistic interpretation of QM, also known as “consciousness causes collapse (of the WF) hypothesis” (CCCH), is forced to conclusions incompatible with the

---

**Fig. 1** Illustration of the sealed room in the interval of time between a few seconds after 1:00 PM and 2:00 PM; inside the room, P is unconscious under the TCB effect.
assumption that human consciousness\(^2\) is necessary for providing a complete explanation of quantum measurement process.

2 The PIAR experiment

In this section we will describe a thought experiment, in which a Physicist named “\(P\)” is inside an impenetrable room (Fig. 1).

On the wall behind \(P\), the apparatus \(L\) (powered by a battery) is programmed to emit, at a precise time, a photon in a direction along which is placed a beam splitter (BS), that forms with it an angle of 45°. Two photo-detectors, \(D_T\) and \(D_R\), both with 100% efficiency, are separated by an angle of 90° and located beyond the BS at the same distance from \(L\); \(D_T\) is fixed, along the direction of the transmitted photon on the wall opposite to \(L\); \(D_R\) is fixed, along the direction of the reflected photon on top of a box and connected to a hooked hammer inside it; a Switch-On-Button (SOB) is placed under the hammer which, if pushed, activates a bell (\(B\)).

The experiment is planned as follows:

1. \(L\) will emit a photon at 2.00 PM.
2. \(P\) has deliberately drugged himself\(^3\) one hour beforehand, at 1.00 PM, with a dose of a powerful narcotic, crucial for the experiment, called “\(TCB\)” (Temporary Consciousness Breaker) and 100% guaranteed to cut out conscious awareness for two hours and to prevent the later recall of events that occurred during the time of drug action; therefore, \(P\) will regain consciousness precisely at 3.00 PM; I say precisely at 3:00 PM, but I mean “precisely” when you can claim that \(P\) is no more under the \(TCB\) effect.\(^4\)
3. If \(D_T\) registers, the hammer will remain hooked and \(B\) inactive.
4. If \(D_R\) registers, the hammer will be unhooked and, falling on the SOB, will activate \(B\) for over an hour.

---

\(^2\) We don’t know how our consciousness works and do not have any idea of its nature. Nonetheless we are undoubtedly certain to possess it as the intimate and most familiar of our experiences. In general, consciousness is defined as the faculty that allows a human subject to be aware of her/his self and of her/his mental activities, as well as the faculty to learn from the perception of external events to which these activities are directed. Leading contemporary scientists in the field [28–33] have tried to lay the foundations for a science of consciousness, but none of them has yet been able to boast a promising theoretical approach. The Australian philosopher of the mind David J. Chalmers [34] argues that, to open a window towards the understanding of consciousness, it would be required to solve the so called “difficult problem”, consisting in finding a correlation between the functional mechanisms engendered by the neural activity of the brain and conscious experience, i.e. the phenomenon that allows the owner of that brain to feel specific effects in the first person..

\(^3\) In this paper, the pronouns ‘he’, ‘him’, etc. referred to the physicist \(P\) are used in a neutral sense, i.e. regardless to the sex.

\(^4\) For simplicity and also in order to avoid involvement in the complex field of neuroscience, the time you can claim for the emergence of \(P\)’s consciousness is here fixed at 3:00 PM. However, note that, even if one insisted on appealing to neuroscience and objected that the emergence of \(P\)’s consciousness occurs gradually, we would reply that, in parallel, also \(P\)’s perception/measurement of \(NR/SR\), i.e. the bell ringing/not ringing, will occur gradually; in other words, both the events will become, concomitantly, more and more vivid over a given time interval.
Let us now briefly consider how the quantum theory describes the experiment: the photon is emitted from L at 2:00 PM, collides with BS and splits in two beams, one transmitted, \( T \), moving along the direction of the detector \( D_T \), and the other reflected, \( R \), moving along the direction of the detector \( D_R \), with a probability amplitude (in this example) of \( 1/\sqrt{2} \) for each detector to register the arrival of the photon. According to the Copenhagen interpretation of QM, the WF \( \psi \) of the photon, after reaching BS, is described as the following superposition of states:

\[
|\Psi\rangle_{\text{Photon}} = \left\{ |T\rangle + |R\rangle \right\}/\sqrt{2}.
\]  

The combination of these two parts evolves as a linear superposition according to the Schrödinger equation and travels along two different paths, until the instant in which, in agreement with the wave-function collapse (or wave-packet reduction) postulate based on the Born rule, one presumes that a measurement process has occurred. This is the instant in which the WF collapses and one only of the possible alternatives becomes real, with probability given by the square of the associated modulus (hence, in our example, probability \( \frac{1}{2} \) for both alternatives).

If we assume, as Wigner\[11, \text{p. 181 and p. 187}\], “the existence of an influence of consciousness on the physical world” and that “the measurement is not completed until a well-defined result (impression) enters our consciousness”, that is until the WF collapses down into either one of its two component parts, then inside the room there is not one unique defined state as long as \( P \) is under the TCB effect, but a linear superposition of the two states described above, which, while time is passing, is propagating along the whole macroscopic measurement system (Fig. 2) and will be suppressed when it reaches \( P \)’s consciousness. Consequently, there are two possibilities or chains of events, here called \( E(T, R) \), which will travel according to the superposition principle until an observation/measurement takes place:

- \( E_T \): \( T \) (part of the WF transmitted), \( D_T \) registers, the hammer remains hooked, \( B \) inactive, \( P \) regains consciousness at 3:00 PM in the Silent Room (also denoted with “SR”).
- \( E_R \): \( R \) (part of the wave function reflected), \( D_R \) registers, triggers the hammer, \( B \) starts ringing, \( P \) regains consciousness at 3:00 PM inside the Noisy Room (also denoted with “NR”).

Thus, a complete measurement apparatus will be available, by this meaning that the experiment, since it includes also the experimenter, will begin and end within the sealed room.

### 3 Formal description of the PIAR experiment

All supporters of the CCCH may believe that any QM experiment, no matter whether applied to a cat or to a human being, must give rise, in the end, to the same conclu-
sions drawn by Wigner from his thought friend’s experiment\textsuperscript{5} and from his additional and stronger hypothesis [11, pp.185–196] concerning the role of consciousness in the quantum measurement process.

In discussing the PIAR experiment described in the previous section, we will put on, for a while and embarrassingly, the clothes of an idealistic-orthodox physicist

\textsuperscript{5} Wigner’s friend, here called “F”, is a physicist left alone inside a laboratory with the task of checking \textit{attentively} whether or not a detector has emitted a flash (has registered the arrival of a photon or not). Wigner is waiting outside and suspects that F (as well as all other human beings) may have weird perceptions and be in the superposition of macroscopically distinct states |F has perceived a flash$\rangle + |F$ has not perceived a flash$\rangle$. Finally, Wigner enters the lab and asks F whether or not he perceived a flash. His reply (yes or no) should remove any doubt as to whether the wave-function collapse has occurred. However, Wigner will question whether it is acceptable or not to establish that the collapse into one only of the two possible alternatives is determined by his action (his request and reception of an unambiguous answer). He poses this question since his initial way of interpreting the state of the system gives rise to a rather embarrassing paradox, from which he has three possible ways of escape: (1) accept a relative form of \textit{solipsism}, in the sense that he believes to be, among all living creatures, the only one who has unambiguous perceptions, (2) assume that QM is an incomplete theory, (3) assume that QM is not applicable to human beings; conclusively, he refutes solipsism and, being a firm supporter of QM completeness, opts for the last solution, assuming that there are beings, at least human beings, endowed with \textit{consciousness} that constitutes an ultimate reality and plays an active role in determining the measurement process by rules that are not susceptible to scientific description.
about QM, in order to verify whether or not there are the conditions for P’s consciousness to bring about the WF collapse.

To this end, the orthodox interpretation of quantum mechanics would describe the WF $\psi$ of the system, in the time interval between 2:00 and 3:00 PM, during which P is unconscious, as the following superposition of product states:

$$|\Psi\rangle_{\text{System}} = \{|T, D_T\rangle \otimes |\text{SR}\rangle + |R, D_R\rangle \otimes |\text{NR}\rangle\}/\sqrt{2}. \quad (2)$$

3.1 Three remarks regarding the experiment

(i) - The expedient of the TCB has a fundamental function. In fact, supposing that it were not used, according to the CCCH, P would cause the WF collapse precisely as soon as he realizes to be either in the state ‘Silent Room’ or in the state ‘Noisy Room’.

(ii) - Note that in this experiment, as already mentioned at the end of Sect. 2, P will be the only observer, and he will be in the condition to make an observation only when he is no more under the TCB effect, i.e. at 3:00.

(iii) - Human beings have access to their own internal states, perhaps similarly to cats or other animals, but, differently from these, they have the faculty of developing very sophisticated analytical thinking due to their cumulative culture.

4 The PIAR experiment disproves the consistency of the CCCH

Up to just before 3:00 PM there is no conscious being in the game, and Wigner would say, consistently with the assumption of the TCB and his views about reduction, that the superposition is there (as depicted in Fig. 2). Then, Wigner would assert that P, as soon as conscious at 3:00 PM, will receive the impression that the bell is either ringing or not ringing and, in both cases, his consciousness will cause the collapse of the wave function.

Indeed, one might object that P, differently from Wigner’s friend (see footnote 5), who is attentive throughout the course of the experiment, as soon as conscious at 3:00 PM, may not be immediately attentive, i.e. may not be in the condition he would need to measure the outcome SR. In other words, one might argue that P becomes conscious before realizing that he is in the Silent Room and, according to the CCCH, his consciousness would cause the collapse of the wave function.

Anyway, it should be noted that the above objection, if considered an obstacle for the achievement of our goal, could be overcome by planning the experiment through a different approach, e.g. substituting the outcome “Silent Room” with a clearly distinguishable noise.

Yet, such a change would require some complicate changes in the illustrations of Figs. 1 and 2. Therefore, we prefer to follow a simpler way, that consists in ignoring the outcome SR and taking into account, from now onwards, only the possible outcome NR (the case in which P perceives the sound of the bell). So, let us now go ahead following step by step and cautiously our rational analysis.
Since the CCCH implies by definition a causal order between two events, conscious perception of a well-defined outcome and the WF collapse, we will examine whether, in the context of this experiment, there is a way to logically disprove the former as a causal agent of the latter. Hence, in order to achieve this aim, we will adopt a line of reasoning putting forward two crucial points.

First point: while planning the PIAR experiment, we could recognize in it the occurrence of three distinct events: the emergence of P’s consciousness, P’s perception/measurement of the outcome and the WF collapse.

After the experiment has started, P is under the TCB effect and will regain consciousness at 3:00 PM, the same time he perceives (as we have established above) the outcome NR.

At this stage it will not be hard to understand, as will be explained shortly, that the WF collapse into the state “Noisy Room” cannot be caused by P’s consciousness.

Second point if you were a supporter of the CCCH and claimed that the WF collapse takes place when P regains consciousness, you would be easily misled to conclude that the emergence of P’s consciousness (from now onwards also denoted with “C”) and the WF collapse into the state “Noisy Room” are two events representing, respectively, the cause and the effect.

In this case, you might suppose that these two events imply a well-defined causal order. But we would reject this conclusion, arguing that the CCCH will be never invalidated until the above two events are thinkable as causally ordered, i.e. written as C -> NR (event C is causally ordered before event NR).

Indeed, we will soon realize that the above causal order does not suit the PIAR experiment, because this is planned in such a way that the appearance of P’s consciousness and P’s perception of the outcome NR will be recognized as two events not causally ordered.6

At last, we are going to highlight hereafter the decisive point that enables us to discredit the CCCH: according to this view, the WF collapse is thought of as the immediate effect caused by P’s perception of the outcome; but P, in this unusual experiment, at 3:00 PM is subject to two distinct events at the same time: the emergence of his consciousness and his perception of the outcome NR. Please note that P becomes conscious while the bell is ringing and, certainly, not before; more seemingly, P will regain his consciousness gradually (as explained in footnote 4).

We would now like to make clear another crucial passage of the PIAR experiment: as soon as the TCB effect is terminated, P appears conscious; but conscious of what? Conscious of being conscious? To this question we find it more reasonable to answer that P becomes conscious of something coming from the physical world situated outside his mind and that this “something” should be referred to the only event present inside the sealed room at 3:00 PM, that is the sound of the bell, which P undergoes

---

6 It can be observed that P’s consciousness and P’s perception of the outcome NR are two compatible events, i.e. the occurrence of one of them does not exclude the occurrence of the other and they can take place at the same time (more precisely, in our experiment P undergoes the two events C and NR in unison).
concomitantly with the emergence of his consciousness. So, a causal order such as C -> NR (and, implicitly, as C -> WF collapse), is logically inadmissible.

Summing up, in the PIAR experiment there are two events, “the emergence of P’s consciousness” and “the WF collapse”, which, as already substantiated above, are unthinkable as causally ordered, by this meaning that each of them happens on its own and that, therefore, they cannot in any way influence each other.

Finally, we can conclude that the outcome “Noisy Room” that P perceives at 3:00 PM does not coincide with the WF collapse, but is a consequence of the collapse occurred long before, reasonably when the photon interacted somehow with the detector D_R.

This conclusion implies that the CCCH is inconsistent, despite a widely shared belief that it is not falsifiable (see for example J. Acacio de Barros and Gary Oas [35]).

5 Conclusions

If the above analysis is accepted as well-grounded, a supporter of the idealistic interpretation of QM should rely on an alternative interpretation, in which the role of the conscious observer is merely relegated to take note of the experimental results.

One can easily understand that the conclusion drawn at the end of the previous section has further implications, such as:

(a) - the concept of “collapse of the WF independently of consciousness” emerges from the logical structure of this thought experiment based on the TCB stratagem, since it allows to see in a new light the relationship between subject and object of observation, as shown in Sect. 4;

(b) - in the PIAR experiment, QM is exceptionally applied to a human being, in spite of Wigner’s conviction that it is not, applicable, as stated at the end of footnote 5, point 3.

(c) - if it were not conceivable an experiment capable of disproving the CCCH, this latter would still represent a possible and, for a few scientists, an even more suitable alternative to other interpretations of quantum mechanics.

(d) - in the realistic QM theories based on the collapse postulate, the boundary between quantum and classical systems should be rescaled down, reasonably to the transition point between the quantum system described in (1) and the components of the photo-detector with which it interacts;

(e) - in the collapse theories, Schrödinger’s cat experiment can no longer be considered a paradox: before opening the box, the cat (as well as all the macroscopic measuring apparatuses inside the room until P is unconscious) is in a statistical mixture of states, ‘dead’ or ‘alive’;

(f) - the falsification of the CCCH rules out also the hypothesis that the collapse of all the wave-functions involved in our Universe (according to the hypothesis shared by many scientists that consciousness is regarded as an emergent phenomenon) occurred when the first conscious human being appeared in it, thus avoiding to render the big-bang a senseless theory;
I personally think that the validity of the PIAR experiment is tenable with regard to one central hypothesis: the fact that, in certain controlled circumstances, conscious perception phenomenon, including self-awareness, could be suspended in a human subject. In other words, there could be an interval of time during which the subject is totally deprived of self-awareness and the faculty of consciously perceiving signals coming from the external surroundings. While this assertion may probably be open to doubt from a philosophical point of view, it appears sufficiently backed-up by common sense (and also by certain experiential data).

In synthesis, the starting point of this work is that the idealistic interpretation requires the superposition of macroscopically distinct states as well as the conscious perceptive faculty of the observer. This is necessary for consciousness to play a fundamental role in the wave-function collapse process.

Nevertheless, it is possible to devise at least a thought experiment (e.g. the PIAR), which disproves the hypothesis that the wave-function collapse is caused by the observer’s consciousness.

If this analysis is shared as logically compelling, then one is left with the immediate issue of what the best alternative to the idealistic interpretation should be, and clearly this is an entirely different (and daunting) problem.

However, I feel that the ordinary idea behind the PIAR experiment is that there are two ingredients given by the wave-function and the observer’s consciousness, which cannot in general be clearly separated, at least in such a way as to make the latter a causal agent in the collapse of the former.

If this is true, then a fruitful way to tackle the measurement problem can only be one that treats the above two ingredients in a single coherent framework.

Recent advances in the quantum de-coherence and a re-examination of Everett’s Many Worlds Interpretation suggest that such a framework could be constructed entirely within the boundaries of the theory itself; see, for instance, Roland Omnès [36], Maximilian Schlosshauer [37] and David Wallace [38], but clearly this is not the only route; see also Bernard d’Espagnat [39], the very recent works of Art Hobson [40, 41] and Carlo Roselli, Bruno R. Stella [42].

Furthermore, the PIAR experiment, for being capable to disprove the consistency of the CCCH, could also represent a good reason for strengthening some of the actual quantum mechanical spontaneous localization models, where observers have no special role: I am referring to Ghirardi, Rimini and Weber theory (GRW), to Penrose and to Hameroff-Penrose interpretations, in which the WF is assumed to be as a physical reality and its collapse as an objective dynamical process, that in Penrose’s approach is supposed to be induced by gravity.

I would like to close this paper quoting a sentence by Steven Weinberg [43]:

“I read a good deal of what had been written by physicists who had worried deeply about the foundations of quantum mechanics, but I felt some uneasiness at not being able to settle on any of their interpretations of quantum mechanics that seemed to me entirely satisfactory”.

Acknowledgements My special gratitude goes to the late GianCarlo Ghirardi Professor Emeritus of Physics, Università di Trieste, for his help in clarifying several questions; I am very indebted to Carlo Rovelli Professor of Physics, Université de Aix-Marseille, for the suggestions that helped me carry out this thought
experiment; my sincere thanks go to Art Hobson Professor Emeritus of Physics, University of Arkansas, Livio Triolo Professor (retired) of Mathematical Physics, Università Tor Vergata di Roma, Gianni Bat-timelli Professor (retired) of Physics, Università La Sapienza di Roma, for their useful advice in different stages of this work. Finally, I send an exceptional thanks to my wife Susan Jane Beswick for her scrupulous control of the English language of the text.-.

References

1. Einstein, A., Podolsky, B., Rosen, N.: Can Quantum Mechanical Description of Physical Reality Be Considered Complete? Phys. Rev. 47, 777–780 (1935)
2. Schrödinger, E.: Die gegenwärtige Situation in der Quantenmechanik, Naturwissenschaften 23, Heft 48, 807–812: (1935)
3. von Neumann, J.: Mathematische Grundlagen der Quantenmechanik. Julius Springer, Berlin (1932)
4. von Neumann, J.: Mathematical Foundations of Quantum Mechanics. Princeton University Press, Princeton (1955)
5. London, F., Bauer, E.: La Théorie de l’observation en mécanique quantique. Hermann, Paris (1939)
6. Bohm, D.: A suggested interpretation of the quantum theory in terms of “hidden” variables. Phys. Rev. 85, 166–193 (1952)
7. Bohm, D.: Quantum Theory. Prentice-Hall, New York (1952)
8. Everett, H.: ‘Relative State’ Formulation of Quantum Mechanics. Rev Mod. Phys 29, 454–462 (1957)
9. Wigner, E.P.: Remarks on the mind-body question. In: The scientist speculates, Good L. J., (ed.), Heinemann, London (1962)
10. Wigner, E.P.: The problem of measurement. Amer J. Phys. 31, 6–15 (1963)
11. Wigner, E.P.: Symmetries and Reflections. Greenwood Press (1978)
12. Wheeler, J.A.: Assessment of Everett’s ‘Relative State’ Formulation of Quantum Theory. Rev Mod. Phys 29, 463–465 (1957)
13. DeWitt, B.S.: The Many Worlds Interpretation of Quantum Mechanics, Princeton Series in Physics, University Press, Princeton (1973)
14. Zurek, W.H.: Decoherence and the transition from quantum to classical. Phys. Today 44, 36–44 (1991)
15. Albert, D.Z.: Quantum Mechanics and Experience. Harvard University Press, Cambridge (1992)
16. Ghirardi, G.C., Rimini, A., Weber, T.: Unified dynamics for microscopic and macroscopic systems. Phys. Rev. D 34, 470 (1986)
17. Ghirardi, G.C., Grassi, R., Pearle, P.: Relativistic dynamical reduction models: general framework and examples. Found. Phys. 20, 1271–1316 (1990)
18. Penrose, R.: The Emperor’s New Mind. Oxford University Press, Oxford (1989)
19. Penrose, R.: Shadows Of The Mind. Oxford University Press, Oxford (1994)
20. Penrose, R.: The Large, the Small and the Human Mind. Cambridge University Press, Cambridge (1997)
21. Hameroff, S., Penrose, R.: Orchestrated Reduction of Quantum Coherence in Brain microtubules: A model for consciousness. Math. Comput. Simulation 40, 453–480 (1996)
22. Stapp, H.P.: Mind, Matter and Quantum Mechanics. Springer, Berlin (1993)
23. Gell-Mann, M., Hartle, J.: Strong decoherence. In: Feng, D.H., Hu, B.L. (eds.), Quantum classical correspondence. The 4th Drexel Symposium on Quantum Nonintegrability, pp. 3–35, International Press, Cambridge MA: (1997)
24. Rovelli, C.: Relational Quantum Mechanics. Internat J. Theoret Phys. 35, 8, 1637–1678 (1996)
25. Tegmark, M.: The Interpretation of Quantum Mechanics: Many Worlds or Many Words? Fortschr. Phys. 46, 855–862 (1998)
26. Haroche, S.: Entanglement, decoherence and the quantum/classical boundary. Phys. Today 51, 36–42 (1998)
27. Bell, J.S.: Speakable and Unspeakable in Quantum Mechanics, Collected Papers on Quantum Philosophy. Cambridge University Press, Cambridge (2004)
28. Dennett, D.C.: Content and Consciousness, London, Routledge & Kegan Paul (1968)
29. Nagel, T.: The View From Nowhere. Oxford University Press (1986)
30. Edelman, G.M.: Bright Air, Brilliant Fire, On the Matter of the Mind, by Basic Books (1992)
31. Searle, J.R.: *The Mystery of Consciousness*, by the New York Review of Books, Broadway, New York: (1997)
32. Searle, J.R.: *Mind. A brief Introduction*. Oxford University Press, Inc. (2004)
33. Damasio, A.: *Self Comes to Mind, Constructing the Conscious Brain*, © Antonio Damasio: (2010)
34. Chalmers, D.J.: *The Conscious Mind: In Search of a Fundamental Theory*. Oxford University Press (1996)
35. de Barros, J.A., Oas, G.: *Can we Falsify the Consciousness-Causes-Collapse Hypothesis in Quantum Mechanics?* Found. Phys. 47, 1294–1308 (2017)
36. Omnès, R.: *Converging realities: Toward a common Philosophy of Physics and Mathematics*. Princeton University Press, Princeton (2004)
37. Schlosshauer, M.: *Decoherence and the Quantum-to-Classical Transition*. Springer, Berlin (2007)
38. Wallace, D.: *The Emergent Multiverse: Quantum Theory according to the Everett Interpretation*. Oxford University Press, Oxford (2012)
39. d’Espagnat, B.: Quantum Physics and Reality. Found. Phys. 41, 1703–1716 (2011)
40. Hobson, A.: Review and suggested resolution of the problem of Schrödinger’s cat. Contemp. Phys. 59, 16–30 (2018)
41. Hobson, A.: *Entanglement and the measurement problem*, arXiv:2002, [quant-ph] (25 Feb 2020)
42. Roselli, C., Stella, B.R.: *The Dead-Alive Physicist experiment: a case study against the hypothesis that consciousness causes the wave function collapse in the quantum mechanical measurement process*, Found. Phys. 51, 21, (2021)
43. Weinberg, S.: *The Trouble with Quantum Mechanics in Third Thoughts*. Harvard University Press, Cambridge (2018).

**Publisher’s note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.