Quantum Foundations survey

(untitled)

2

Thank you for taking part in this *Nature* survey. The following pages will ask you about your opinions on the foundations of quantum physics.

During the year of the 100th anniversary of quantum mechanics, reporters at *Nature* hope to gather a snapshot of what physicists who work with quantum theory day-to-day believe is really happening during phenomena such as measurement and entanglement.

Your contribution will remain anonymous, but you have the option to volunteer your name and email at the end of the survey if you would be happy to be contacted by a reporter.

The results of the survey will form the basis of a news feature in *Nature*, and the data (anonymised) will be made available. The survey will not be used for any other purpose.

Because the *Nature* article will ultimately be written for a broad and lay audience, we have crafted the questions with those readers in mind.

If you have any questions about the survey, please contact reporter Lizzie Gibney, at elizabeth.gibney@nature.com.

(untitled)

47

1. **About you (demographics)**

Where do you, or did you, do your research?

- In academia
- In industry
- Both academia and industry
- I am not a researcher

142

2. What is your current career stage?

- PhD student
- Early career
- Mid career
- Advanced career
- Retired
- I am not a researcher

122

3. Which of the following fields do you publish in (please check all that apply)

- [ ] Quantum information/computing/communication/thermodynamics
- [ ] Particle physics/field theory/string theory
- [ ] Cosmology/gravity theory
- [ ] Atomic/molecular/optics/condensed matter
- [ ] Quantum foundations or philosophy
- [ ] I do not publish scientific papers
- [ ] Other - Write In

153

4. Are you...

- ○ A theorist
- ○ An experimentalist
- ○ Both an experimentalist and a theorist
- ○ Neither / not applicable

(untitled)

156

5. The survey begins by asking about your favoured overall interpretation of quantum theory; and then asks for your views on some key elements of quantum theory. The second part of the survey will ask about your view of the importance of different interpretations of quantum mechanics.

Descriptions are designed to use non-technical language where possible.

If there are places where you feel that the non-technical language is too

imprecise, we encourage you to pick the answer you feel most comfortable with and add additional information or explanation in the provided free-text box.

1. Which of the following, in your opinion, provides the best interpretation of quantum phenomena and interactions? (please pick only one; in the next question you can express your confidence in your answer)

- The “Copenhagen interpretation”* (classical and quantum domains are separate, nonlocality is real (changes to part of a system can influence the whole, no matter where they are).
- Bohm-de Broglie pilot wave theory (particles are guided with respect to position by pilot waves; the apparent randomness of quantum physics is due to ignorance regarding the initial positions of all particles and action at a distance is real).
- Everett/Many-Worlds/Consistent Histories (the quantum state only ever evolves smoothly and with no element of randomness; branching into different worlds explains the appearance of collapse and randomness in each branch).
- Epistemic/information-based approaches (the wavefunction represents only information).
- Spontaneous-collapse theories (suggests a physical collapse and that the Schrödinger equation must be modified so that it does not always evolve smoothly, such as GRW, CSL, Orch-OR).
- Retrocausal theories (future measurements can influence past), including transactional interpretation.
- Relational quantum mechanics.
- Superdeterministic theories (measurement choices and particle properties are predetermined).
- Other (please elaborate).

157

*the Copenhagen interpretation is not a self-consistent interpretation, but has become a popular description for physicists to say they adhere to.

158

6. If you wish to add supplementary comments to your response, you can do so here:

160

7. **1a. How confident are you in your answer above about the best interpretation?**

- Confident: I think this is the correct interpretation.
- Fairly confident: I think this is an adequate interpretation.
- Not confident: I think this is just the best interpretation I am aware of or one that is useful as a tool in certain situations.

(untitled)

124

8. The survey now asks you six questions about key elements of quantum theory.

2. Which of the following do you believe best solves the quantum measurement problem (that is, the inconsistency between the well-described and smooth evolution of properties according to the Schrödinger wave equation and the probabilistic outcomes of measurements)?

- The wavefunction alone does not provide a complete description of the systems described, and additional variables play a role in the appearance of measurement outcomes.
- The apparent discontinuity arises because the act of measurement involves a change from a fundamentally probabilistic quantum description to a classical one with definite outcomes and real observables.
- The wavefunction continues to propagate through multiple universes/branches. The appearance of a single outcome is based on a given observer existing in only one of them.
- Since the wavefunction gives only information, the ‘collapse’ of the wavefunction is not a physical process and so there is no measurement problem in the first place.
- Schrödinger’s equation should be modified such that, when it is used to describe a system consisting of not only a measured subsystem but also measuring equipment, the equation does predict (approximately) definite outcomes.
- An alternative solution or combination of the above (please elaborate):
- I don't have a view.

144

9. If you wish to add supplementary comments to your response, you can do so here:

(untitled)

126

10. **3. Is action at a distance real?**

That is, does measuring the properties of one particle instantaneously (faster than the speed of light) influence its entangled partner such that it affects the result of future measurements?

- Yes
- Yes – but not due to measurement and instead due to pre-existing hidden variables associated with the entangled particles.
- No – something else accounts for experiments that seem to show correlation between outcomes (e.g. free will or other loopholes).
- No – correlations between particle behaviours are real but there is no physical way of accounting for them.
- No – wavefunction “collapse” is simply a matter of updating beliefs.
- No – separate universes branch apart when a measurement occurs in one of a pair of entangled particles.
- An alternative view (please elaborate):
- I'm not sure.

155

11. If you wish to add supplementary comments to your response, you can do so here:

(untitled)

134

12. **4. For a given system, does there exist a boundary between classical and quantum objects?**

- Yes but it is not sharp.
- Yes and it is sharp.
- No.
- I'm not sure.

146

13. If you wish to add supplementary comments to your response, you can do so here:

(untitled)

135

14. **5. What is the wavefunction?**

- A mathematical tool that accurately predicts experimental outcomes and their probabilities (and nothing else).
- A subjective description of our beliefs about experimental outcomes.
- A complete representation of physical reality.
- A partial representation of physical reality.
- Something else (please elaborate):
- I don't have a view.

148

15. If you wish to add supplementary comments to your response, you can do so here:

169

16. **5a. For single-particle quantum systems, the wavefunction can generally be understood as propagating in ordinary, 3D, physical space. But for a system with more than one particle, the wavefunction instead propagates in the abstract higher-dimensional 'configuration' space.**

In such situations, what, if anything, exists in ordinary 3D physical space?

- Something that emerges from and/or can be calculated from the wavefunction.
- Something distinct from the wavefunction.
- Nothing: the abstract high-dimensional space is the fundamental physical space.
- Something else (please elaborate):
- I don't have a view.

170

17. If you wish to add supplementary comments to your response, you can do so here:

(untitled)

136

18. **6. In the famous double slit experiment, does the electron pass through both slits when it is unobserved?**

- Yes.
- No.
- This question is meaningless when asked about a quantum object.
- I'm not sure.

151

19. If you wish to add supplementary comments to your response, you can do so here:

(untitled)

138

20. **7. Does a measurement (as described in the measurement problem question) require an observer?**

- Yes and they must be conscious.
- Yes but consciousness is not relevant (and an ‘observer’ can include interaction with a macroscopic environment).
- No.
- I'm not sure.

152

21. If you wish to add supplementary comments to your response, you can do so here:

(untitled)

161

22. The survey now asks five questions about your view of the importance of these different interpretations of quantum theory.

8. Is it important to attempt to interpret the mathematics of quantum mechanics in a physical or intuitive way?

- Yes, for philosophical reasons.
- Yes, for progress in physics.
- Yes for both philosophical reasons and to progress in physics.
- No.
- I don't have a view.

168

23. If you wish to add supplementary comments to your response, you can do so here:

162

24. **9. Do you think new experimental results will help to decide between viable approaches to quantum foundations (studies of the underlying assumptions and principles of quantum theory)?**

- Yes (if you like, please add an idea of the experiments through which you think this may occur).
- No, I do not think experimental results will be able to distinguish between interpretations.
- I'm not sure.

167

25. **10. How have developments in quantum information theory (that is, both using quantum states for information processing and looking at quantum theory in terms of information) contributed to physicists' understanding of quantum foundations?**

- They have inspired new ways of thinking about quantum theory and are likely to keep doing so.
- They have inspired new ways of thinking about quantum theory but have now run their course in terms of their utility to quantum foundations.
- They have not contributed/they are irrelevant to quantum foundations.
- Their contribution is not yet clear.
- Something else (please elaborate):
- I don't have a view.

(untitled)

164

26. **11. Do you think that quantum theory will in the future be superseded by a more complete theory?**

- Yes, it will be completely replaced by something completely different and better.
- Yes, but elements will survive.
- No, quantum theory will remain unchanged in any future theories.
- I don't have a view.

165

27. **12. What do you think about the current level of attention given to quantum foundations (that is, studies of the underlying assumptions and principles of quantum theory) in most physics departments?**

- Not enough.
- Too much.
- Just right.
- I don't have a view.

(untitled)

166

28. Where in the world have you studied or worked? (Please check all that apply).

- [ ] Africa
- [ ] Asia
- [ ] Europe
- [ ] North America
- [ ] Oceania
- [ ] South America

22

29. What is your gender?

- Female
- Male
- Non-binary
- Other
- Prefer not to say

121

30. What is your religion, if any? (This box may be left blank, if preferred).

108

31. Would you be willing to talk to a *Nature* reporter about your views in this survey?

- Yes
- No

12

Your contributions by default will remain anonymous, but please leave your name and email if you would be open to a journalist contacting you for possible follow-up, or to be on a panel. (If you do not want to leave your name or email, just click 'send').
These details will not be shared with any third parties. See our privacy policy for more information.

13

32. Name:

14

33. Email address:

1

Thankyou for sharing your views on the foundations of quantum theory.

This survey is now complete and you may close this page.