Oxford Questions seek to pull back the curtain on the foundations of quantum physics

July 18 2013, by Lisa Zyga

Box 1. The Oxford Questions.

(1) Time, irreversibility, entropy and information

- (a) Is irreversibility fundamental for describing the classical world?
- (b) How is irreversibility involved in quantum measurement?
- (c) What can we learn about quantum physics by using the notion of information?

(2) The quantum–classical relationships

- (a) Does the classical world emerge from the quantum, and if so which concepts are needed to describe this emergence?
- (b) How should we understand the transition from observation to informed action?
- (c) How can a single-world realistic interpretation of quantum theory be compatible with non-locality and special relativity?

(3) Experiments to probe the foundations of quantum physics

- (a) What experiments can probe macroscopic superpositions, including tests of Leggett–Garg inequalities?
- (b) What experiments are useful for large complex systems, including technological and biological?
- (c) How can the progressive collapse of the wave function be experimentally monitored?

(4) Quantum physics in the landscape of theories

- (a) What insights are to be gained from category-theoretic, informational, geometric and operational approaches to formulating quantum theory?
- (b) What are productive heuristics for revisions of quantum theory?
- (c) How does quantum physics cohere with space–time and with mass–energy?

(5) Interaction with questions in philosophy

- (a) How do different aspects of the notion of reality influence our assessment of the different interpretations of quantum theory?
- (b) How do different concepts of probability contribute to interpreting quantum theory?

The Oxford Questions were developed by theorists, experimentalists, and philosophers of physics in order to elucidate the areas of physics in which genuine progress may be made in the foreseeable future. Credit: G. A. D. Briggs, et al.

(Phys.org) —Relativity and quantum theory form the backbone of modern physics, but a group of physicists stresses that daily use of these theories can numb the sense of wonder at their immense empirical success. At the same time, fundamental questions on the foundations of these two theories remain. In 2010, experimentalists, theorists, and philosophers of physics convened at a conference at the University of Oxford called Quantum Physics and the Nature of Reality. They produced a set of "Oxford Questions" aimed at identifying some specific open problems about the nature of quantum reality in order to stimulate and guide future research.

The Oxford Questions are presented in a new Perspective Paper published by physicists G. A. D. Briggs at the University of Oxford, J. N. Butterfield at the University of Cambridge, and A. Zeilinger at the University of Vienna in a recent issue of *Proceedings of the Royal Society A*.

At the conference, the scientists emphasized that they wanted to "avoid rehashing various aspects of the status quo in debates about the foundations of quantum physics." Instead, their set of questions focuses on issues that can be specifically investigated with current methods and theories. The five broad categories of questions are (1) time, irreversibility, entropy, and information; (2) the quantum-classical relationships; (3) experiments to probe the foundations of quantum physics; (4) quantum physics in the landscape of theories; and (5) interactions with questions in philosophy. (See accompanying figure for details.)

"The Oxford Questions seek to take problems which would be widely recognized by the academic community, and to articulate topics on which there is a prospect of making genuine progress in the foreseeable future," Briggs told *Phys.org*. "In this way, we hope that the Oxford Questions will provide an agenda for successful research by philosophers, theorists, and experimentalists. Some of this will require the expertise of more than one discipline. The Oxford Questions include issues on which there is currently a divergence of views even among experts."

Taking a broader perspective, the physicists explain that the Oxford Questions can be thought of as addressing two larger "clouds" on the horizon that may threaten the success of 20th century physics, just like the anomalies confronting classical physics did at the end of the 19th century.

The first cloud is the quantum measurement problem: "the difficulty of explaining completely, in terms of quantum theory, the emergence of a classical world, i.e., a world so accurately described by classical physics with its definite values—a world free of superposition and entanglement." The scientists call this cloud "the cat in the room," and explain how several of the Oxford Questions probe the measurement problem more deeply.

The analogous "elephant in the room" is the search for a quantum theory of gravity, which is the second cloud. The physicists think there are several reasons why reconciling general relativity and quantum theory is so elusive. One reason is that, whereas relativity theory is grounded on reasonable physical principles, it's unclear whether quantum theory is based on comparable principles. Another reason is the dire lack of experimental data. Testable characteristics of quantum gravity arise only under conditions of such high energy, short distances, and short times that they are inaccessible to researchers. For example, the physicists note that the Planck length (10^{-35} m) is as many orders of magnitude from the diameter of a quark (10^{-18} m) as that diameter is from the familiar scale of a centimeter.

Although these two clouds highlight the problems with quantum physics, the physicists also point out that the Oxford Questions arise in large part from empirical work from the last 100 years that has shown the immense success of the basic postulates of relativity and quantum theory. They give many examples in which these postulates have proven to be successful in domains far beyond their original ones:

"Why should the new chronogeometry, introduced by Einstein's special relativity in 1905 for electromagnetism, be extendible to mechanics, thermodynamics and other fields of physics? And why should the quantum theory devised for systems of atomic dimensions ($10^{?10}$ m) be good for scales both much smaller (cf. high-energy experiments $10^{?17}$ to $10^{?20}$ m) and vastly larger (cf. superconductivity and superfluidity, or even a neutron interferometer, involving scales of a fraction of a metre or more)? Is there an upper limit to the scale on which quantum theory should be expected to work? There is a sense in which all properties of matter are quantum mechanical. Topics as diverse as phase changes of alloys and conduction in semiconductors have all yielded to quantum theory. New quantum mechanical models are being developed for a growing range of superconductors, magnets, multiferroics and topological insulators.

"The point applies equally well when we look beyond terrestrial physics. General relativity makes a wonderful story: the theory was created principally by one person, motivated by conceptual, in part genuinely philosophical, considerations—yet, it has proved experimentally accurate in all kinds of astronomical situations. They range from weak gravitational fields such as occur in the solar system, where it famously explains the minuscule precession of the perihelion of Mercury (43" of arc per century) that was unaccounted for by Newtonian theory, to fields 10 000 times stronger in a distant binary pulsar, which in the last 30 years has given us compelling evidence for a phenomenon (gravitational radiation) that was predicted by general relativity and long searched for."

Overall, the aim of the Oxford Questions is to continue expanding these applications and unifying these concepts of quantum physics, just as scientists have been doing for the past several decades.

To describe the present state of physics, the physicists here use an analogy by the theoretical physicist Carlo Rovelli. He compares the present situation in physics to that of the early 17th century when Galileo and Kepler were working on the mechanics of early modern science. Looking back at that time, today's scientists view Galileo's and Kepler's ideas as a mixed bag of insight and error; future scientists may see the ideas of today's brightest researchers in much the same way.

In the meantime, the physicists are using the Oxford Questions to guide their own research. For Briggs, this has led to digging deeper into the philosophical aspects of quantum theory.

"In my own laboratory at Oxford, we benefit from a 'Philosopher in Residence' who is distinguished for his contributions both to physics and to philosophy," Briggs said. "He has already contributed to elucidation of how interpretations of quantum reality can be tested theoretically and experimentally, and he has contributed to the design of practical experiments. We have formulated a new research program entitled 'Experimental Tests of Quantum Reality.' This will address the three topics in the third category of the Oxford Questions. The program has been funded in full and will start on 1 October 2013."

The physicists also plan to follow up on the Oxford Questions as they make progress in searching for answers.

"The grant for 'Experimental Tests of Quantum Reality' will organize a conference in 2014, which will be similar in format to the 2010 conference 'Quantum Physics and the Nature of Reality' at which the Oxford Questions were formulated," Briggs said. "This will provide an opportunity to formulate new questions in the light of progress made. In the following year we shall organize a smaller conference specifically for theologians and church leaders, with the aim of enabling them to benefit from the advances in understanding."

More information: G. A. D. Briggs, et al. "The Oxford Questions on the foundations of quantum physics." *Proceedings of The Royal Society A*. DOI: 10.1098/rspa.2013.0299 (free)