Against Measurement: CHM676 Extra Credit

Due 11/15/2019

1 Introduction

As outlined in the lecture, the "usual" interpretation of quantum mechanics features a stark contrast between two types of dynamics. According to Postulate 5, experimental measurements induce an abrupt (and non-deterministic) "collapse" of the system state into the eigenstate corresponding to the result of the measurement – the infamous "quantum jump". In *between* measurements, in contrast, Postulate 6 states that the wavefunction evolves *smoothly* and deterministically according to Schrödinger's wave equation.

The role of the *measurement process* in quantum dynamics cannot be overstated here: Whether a quantum system evolves deterministically or randomly (smoothly or jump-ily) is determined solely by the question of when and how the system is subjected to experimental measurements.

Given the central role played by "measurement" in quantum dynamics, one might suppose that the term "measurement" is used in the postulates according to a mathematically (or at least physically) precise formal definition. Unfortunately, this is not the case. What is worse, attempts to formalize the definition leads to a fundamental "measurement problem" in the interpretation of quantum mechanics. Loosely speaking, the *measurement problem* is simply that it appears to be impossible in the original "Copenhagen interpretation" of quantum mechanics to identify definitely *when* in the course of a measurement the wavefunction collapses – i.e., when the dynamics transition from deterministic to random.

As a simple example, suppose we perform a measurement to check the spin of a quantum particle that (prior to measurement) is in superposition of "spin up" and "spin down" states. At what point in the course of the measurement does the particle's spin achieve a definite value? Is it when the particle interacts with the electromagnetic field used to measure it? Or perhaps when that field causes electrons to flow in a detecting coil? Maybe when the arrow on our instruments dial actually begins to move? Or, better yet, not until a human observer becomes conscious of the dial's movement?

The fundamental difficulty is that, according to our postulates, *all steps in this process* – from the motion of the particle to the response of the human observer – ought to be themselves described by quantum mechanics. In fact, if we consider all components (including the observer) as a composite quantum system, the dynamics should be determined exclusively by the Schrödinger equation, leaving no opportunity for "wavefunction collapse" to enter the discussion at all. Although this problem has received increased attention in recent years (and although modern interpretations have managed to reframe it in a variety of different formats), little progress has been made on producing a generally-satisfactory resolution, let alone one that is experimentally testable.

2 Instructions

The article "Against Measurement" by John Bell [*Physics World* 3 (8) 33 (1990)] discusses these difficulties in some detail. Your assignment is to read Bell's paper thoroughly, think carefully about the implications, and answer the questions below.

Your answers should be e-mailed to my Purdue address in pdf format, either typed or *legibly* hand-written and scanned. Use the subject line “CHM676 Extra Credit: Against Measurement”. Use the file name “`<lastname>_against_measurement.pdf`”. Answers to each question should consist of 1 - 4 cohesive and grammatically complete sentences. Credit will be assigned primarily based on a demonstrated effort to think carefully about the problem, not on technical proficiency. The assignment is worth 2 of the 10 available extra credit points for the course (2% of a letter grade.)

3 Questions

1. What are Bell’s basic objections to the use of the word “measurement” in quantum mechanics?
2. Bell repeatedly uses the phrase “shifty split”. What is this “split” between? Why is it “shifty”?
3. According to Bell, why did Dirac view the “measurement problem” as not worth worrying about?
4. Bell describes the Landau/Lifshitz approach to quantum measurement as insisting on “the inhumanity of it all.” What does he mean?
5. What is Bell’s objection to the Landau-Lifshitz description of quantum mechanics?
6. Why does Bell attach such significance to the distinction between “and” vs. “or” in the context of Kurt Gottfried’s description of quantum measurements?
7. Nico Van Kampen was known not only for his intellectual capacity, but also for his acerbic wit and scathing criticism of physical theories he viewed as not well-grounded in reality.[1] According to Bell, what is Van Kampen’s view of Hugh Everett’s “many worlds” interpretation of quantum theory?[2] What would Van Kampen say about Eugene Wigner’s assertion that “the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device”? (The quote is from an essay describing the famous “Wigner’s friend” paradox.[3])
8. How does the Ghiradi-Rimini-Weber scheme try to solve the measurement problem?

[1] For example, he wrote a bitter condemnation of the entire microscopic approach to response theory that we’re currently developing. The paper was published in 1971 in *Acta Physica Norvegica* and is somewhat difficult to find; contact me if you want a copy.

[2] Everett, Hugh; Wheeler, J. A.; DeWitt, B. S.; Cooper, L. N.; Van Vechten, D.; Graham, N. (1973). DeWitt, Bryce; Graham, R. Neill (eds.). *The Many-Worlds Interpretation of Quantum Mechanics.* Princeton Series in Physics. Princeton, NJ: Princeton University Press. ISBN 0-691-08131-X. Available at: `https://cqi.inf.usi.ch/qic/everett_phd.pdf`

[3] Wigner “Remarks on the Mind-Body Question“ in: I. J. Good, ”The Scientist Speculates”, London, Heinemann