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The Philosophy of Modern Physics

Realism

Compared with other fields of science, modern physics[1] stands out with respect to the philosophical questions associated with it. For instance, Google searches for "interpretation of quantum mechanics" and "interpretation of chemistry" give 256 000 and 131 hits, respectively[2]. In other words, there is a factor of almost 2000 times more hits for the interpretation of quantum mechanics than for chemistry. These searches can be refined to show even more clearly that there is apparently a need for interpretation when dealing with "quantum", but that this interpretation is not needed when dealing with chemistry, for instance. Comparing the number of hits in a Google search may perhaps not be a very scientific procedure for measuring importance, but it still raises an obvious question: what is it about modern physics that makes it like that? This text is a short exposé of why quantum mechanics has been the object of many philosophical discussions.

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At the core lie the two concepts: realism and locality. Locality can, in short, be explained as the principle that things can only be directly affected by other things in their close vicinity. Einstein even called non-locality a 'spooky action at a distance'. Realism means that objects have their properties even before a human observes them, or in more colloquial terms: there is a *real* world that is independent of human observations. Local realism is thus a very intuitively attractive property of any theory. In fact, the philosopher Karl Popper once said "denying realism amounts to megalomania (the most widespread occupational disease of the professional philosopher)". However, since the first law of philosophy says that for each philosopher there exists an equal but opposite philosopher, Popper's statement should not be accepted without a further analysis.

The analysis can start with stating the fact that the world of quantum mechanics is quite peculiar and unintuitive. The list of unintuitive phenomena in quantum mechanics is very long and the Heisenberg uncertainty principle will be given the honour of representing all of them in this context. The principle says that the certain properties of an object, such as, for example velocity and position, cannot be measured simultaneously, and this is not due to inaccurate measuring methods but is a fundamental property of nature. This clearly seems to contradict our everyday

1: For simplicity, "modern physics" and "quantum mechanics" will be used here interchangeably. Although not necessarily completely correct, the subtleties involved are not relevant here.

2: For chemistry, the searches were for "interpretation of chemistry" – "interpretation of chemistry test results".

experience: I look at the table in front of me and can say exactly where it is (right in front of me) and what velocity it has (it has zero velocity, it does not move). Apparently, I am either mistaken about my table *or* the laws of quantum mechanics do not hold for tables. It is the first alternative that is the correct one: I do not know *exactly* where it is or *exactly* its velocity; however for macroscopic objects such as tables, the effects of the principle are too small to be noticed or to be of any relevance. Therefore, it still makes sense to have traffic laws, for instance, that say that a car on some occasions must come to a complete stop, even though that is physically impossible if we have a rough idea where the car is. On the other hand, for microscopic objects such as electrons and protons, the Heisenberg uncertainty principle makes all the difference and cannot be ignored. This principle, and many other unintuitive effects, caused Niels Bohr to say "If quantum mechanics hasn't profoundly shocked you, you haven't understood it yet."

The Copenhagen interpretation

How can these unintuitive effects be explained and what does it all mean? Niels Bohr attempted to answer that question. He was a very influential 20th century Danish physicist and one of the originators of what came to be called *the Copenhagen interpretation*. There is no strict definition of the Copenhagen interpretation but it basically says that a system can be described completely by a so-called wave function and the wave function is nothing but an abstraction. The Copenhagen interpretation has been summarized by David Mermin as "shut up and calculate"[3], meaning that since the equations are known and will yield the same results no matter what interpretation we make of them, there is really no point in discussing different interpretations. Heisenberg said "it is possible to ask whether there is still concealed behind the statistical universe of perception a 'true' universe in which the law of causality would be valid. But such speculations seem to us to be without value and meaningless, for physics must confine itself to the description of the relationships between perceptions."

But is describing relationships between perceptions all we want to do? Throughout history, philosophers have been occupied with the question of what is *really* going on. A similar question was discussed in 19th century France between Napoleon and the two brilliant scientists Laplace and Lagrange. Napoleon asked Laplace: "M. Laplace, they tell me you have written this large book on the system of the universe and have never even mentioned its Creator." Laplace answered "I did not need to make such an assumption." Lagrange then said "Ah, but it is a beautiful assumption. It explains many things." Laplace's response was: "This hypothesis does explain everything, but it does not permit to predict anything. As a scholar, I must provide you with works permitting predictions." Predictions are certainly important, but is *understanding* not equally important? Some people might even go so far to say that it is the quest for understanding that makes research different from engineering.

A random, non-local, non-real world?

Quantum mechanics is inherently random in that even though the wave function contains all measurable (or observable) information about a

3: D. Mermin, Physics Today, May 2004.

system, it can nonetheless only provide with probabilities of events occurring. The randomness is not due to our lack of understanding or insufficient information about a system, it is an intrinsic property of nature. Einstein, among others, found that problematic and *hidden variables* were involved. The hidden variables are variables whose randomness would disappear if we knew them, but we may never know them (hence they are called hidden). At first, this idea might not seem so bad: things we cannot explain are hidden in the hidden variables. Even though this idea probably will make some people sleep better at night, according to Bell's theorem[4] it is not possible for a local theory to "reproduce[e] exactly the quantum mechanical predictions".

Grøblacher and co-workers[5] write "Most working scientists hold fast to the concept of 'realism' – a viewpoint according to which an external reality exists independent of observation. But quantum physics has shattered some of our cornerstone beliefs. According to Bell's theorem, any theory that is based on the joint assumption of realism and locality […] is at variance with certain quantum predictions. Experiments [have] confirmed these quantum predictions, thus rendering local realistic theories untenable. Maintaining realism as a fundamental concept would therefore necessitate the introduction of 'spooky' actions that defy locality. […] Our results suggest that giving up the concept of locality is not sufficient to be consistent with quantum experiments, unless certain intuitive features of realism are abandoned."

Free will and quantum confusion

An ever present question in physics is that of determinism. If nature is governed by a set of rules, where does that leave free will? Unfortunately, many fantastic features of modern physics, especially the inherent randomness, have given rise to misunderstandings; most notably, what is called quantum mysticism (or quantum confusion). Quantum mysticism is the viewpoint that the facts of quantum mechanics have rendered objective reality obsolete, many times with references to eastern mysticism as in the case of Fritjof Capra and his book *The Tao of Physics* (1975). Jeremy Bernstein said[6] about that book that "At the heart of the matter is Mr. Capra's methodology – his use of what seems to me to be accidental similarities of language as if these were somehow evidence of deeply rooted connections." One of the most confused (not necessarily unintended confusion since the field of misleading others can be quite lucrative) is Deepak Chopra who sees quantum mechanics as the bridge between mind and body.

Where are we today?

What conclusions can we draw from all this? No experiments have ever been made to contradict the Copenhagen interpretation, even though it is easy to share Einstein's scepticism. Philosophizing does not seem to improve predictability in any way, but it does often lead to the wrong conclusions, for instance, quantum confusion. There is a fine line between wild goose chases, creative new ideas, misleading, and simple waste of

4: J. S. Bell, Physics 1, 195 (1964).
5: Grøblacher *et al.* Nature 446, 871 (2007).
6: J. Bernstein, Science observed, New York: Basic Books (1982).

time. One option is to paraphrase Mermin by saying "shut up while calculating", leaving room for some philosophizing while still adopting the simple scientific principle of Laplace to avoid assumptions that do not lend themselves to predictions of outcomes of experiments.

Where we are today will be left as an open question and this brief exposé will conclude with the words of W. H. Zurek who writes[7]: "The message seems to be that there is really no problem […]. This is quite consistent with the aim of introductory quantum mechanics courses, which has been (only slightly unfairly) summed up by the memorable phrase 'shut up and calculate'. Discussion of measurement is either dealt with through models based on the Copenhagen interpretation 'old orthodoxy' or not at all. An implicit (and sometimes explicit) message is that those who ask questions that do not lend themselves to an answer through laborious calculations are 'philosophers' and should be avoided."

7: W. H. Zurek, Reviews of Modern Physics 75, 715 (2003).