Questions and answers on quantum physics

Q: *Why "quantum physics" is named as it is?*

A: In 1905 Albert Einstein explained the photoelectric phenomena by assuming that light can be absorbed in certain “packets”, only. He suggested that light has an elementary “quanta”; the photon, as it was then called. This contributed to the birth of a new physics in an important way. Many other quantities (that were previously considered “continuous”) were also discovered to be quantized. Thus the emerging new physics was named “quantum physics”.

Q: *So the essence of quantum physics is that everything has a quanta?*

A: Not really. In fact, it is not even true. For example, if we take an H-atom, we find that it has certain *energy levels*. But it is not true that “energy is quantized”. If we now take a different atom, we find different energy levels; the actual levels does not reflect some universal property of energy — rather, it is specific to the system in question. By the way, such things can happen in classical physics, too. For example, if we have a cord, it can only vibrate at certain frequencies. However, different cords can vibrate at all sort of different frequencies — altogether, in classical physics there is no natural unit of frequency.

Q: *Then what is the essence of quantum physics? What makes it so different from classical physics?*

A: Quantum physics takes account of the *uncertanity* present in nature. (By the way, you should also note, that quantum physics is not a single theory; rather, it is a general framework. More specifically, one talks about *quantum mechanics*, *quantum thermodynamics*, *quantum field theory*, etc.) Here the word “uncertanity” is not meant in the sense that we don’t know something (so that *we* would be uncertain of something). Quantum physics claims that reality isn’t something crystal clear; instead, it is somewhat misty. When we describe the electron’s position in an H-atom by a certain spherical “cloud”, we do so not because *we* are not sure where it is (which would be a simple lack of information on the observer’s side). Rather, the electron *itself* is not sure about its position (“intrinsic uncertanity”), and in some sense it is really both here and there and a little bit all around.

Q: *So quantum physics must use probability theory?*

A: Yes, but it uses a “built in” probability theory which is different from the classical one. There is actually a mathematical difference between probabilities arising from lack of knowledge and intrinsic uncertanity. When we use classical probability theory, we tacitly assume that at each experimental round, each measurable quantity (described in the theory by a random variable) assumes a value — independently from the fact whether we have measured it or not. In reality, at each experimental round we can only measure *some* quantities. It turns out that the statistics emerging from experimental data actually contradicts the assumption that at each experimental round, all quantities had a value (and that only we did not know them). On the other hand, the probability theory used in quantum physics does not make such assumptions and in fact the predictions made by using quantum physics are in perfect agreement with experimental data. From the point of view of abstract mathematics, the main difference is that the event-lattice used in classical probability theory is *distributive*, whereas the one used by quantum physics isn’t.

Q: *I’ve heard that in quantum physics a lot of fancy mathematical objects like Hilbert spaces are used, and that in particular, measurable quantities are described by self-adjoint operators. Are these things related to what you have just explained?*

A: Yes, these are mathematical elements of the “built in” probability theory used by quantum physics.

Q: *How about the particle-wave duality?*

A: It is just another example of uncertanity. Consider light, which was already mentioned in the beginning of our discussion. It can only be emitted and absorbed in certain units; this is what have suggested the photon-theory. Yet to describe its propagation one is forced to talk about waves. (Even if we deal with a single photon!) Actually, this is true not only for light: it is a general fact regarding every elementary particle. So from the classical point of view, the situation is rather paradoxical: a particle can sometimes behave like a wave. From the point of quantum physics, there is no paradox. The particle is a particle, but its position is uncertain. It can be both here and little bit also there, so actually even a single particle can produce interference phenomena.