Faith in the Rolled One: On Quantum Indeterminacy

We've all had our passions, tastes or choices questioned at one point or another. I remember being asked multiple times what it is about Mathematics that I like – with my response invariably delving into it's *transparency*: how the pieces fit together so elegantly even before you've got to any solution; how everything just *makes sense* leaving no ambiguity or microscopic phenomenon for you to ponder upon. In other words, it's the satisfaction that you get out of knowing there is an explanation - something that can more or less be extended across all scientific disciplines.

But what about disciplines of science where such satisfaction is evasive; where the complete picture does not consist of pieces falling into place neatly, but instead is an incredibly dynamic scenario with pieces vanishing, appearing and 'rolling' at random? Is the inherent elegance of science still preserved in such cases? Can 'not knowing' ever make sense to someone whose only pleasure lies in figuring everything out? **On that note, let me tell me you a little bit about a theory that exemplifies 'not knowing' like no other - Quantum Physics.**

Richard Feynman credited with the mean feat of popularizing theoretical physics, once said in an interview:

> "I don't *have* to know an answer. I don't feel frightened by not knowing things; by being lost in a mysterious universe without any purpose — which is the way it really is, as far as I can tell, possibly. It doesn't frighten me."

I wonder if this is reflective of the satisfaction pervading the lot of physicists throughout the world who have learnt to breathe with the 'fact' that they can never definitely know if it 'will be'- all they have is the privilege of saying is that 'it might be'. Simply put, if you ask someone not 'quantized' enough whether you're actually sitting where you are, the most likely response is "Duh!" Ask a Physicist and the response would go something like this, "Assuming that you're a point particle (indeed, scientists love assumptions that dumb down lesser mortals), I can say that the wave-function in real space transformed from your associated de Broglie wave has a maximum amplitude at x = 'here', which implies that there is a high non-zero probability that you are actually here. However, depending on your exact waveform you're also likely to exist a few meters off from here. Just out of curiosity, any chance you've got a Gaussian distribution?"

All this possibly portrays Quantum Physics as disturbingly unpredictable – almost completely shattering the classical physicist's image of a completely deterministic universe. Einstein himself (despite his own contribution to the development of quantum theory) was not comfortable with the idea of a world where one couldn't predict the definite state of a system knowing its current state, thus his famous "God does not play dice with the universe". Ask why and you hit what Stephen Hawking terms as 'a fundamental, inescapable property of the world'- Heisenberg's uncertainty principle. It's a simple but profound formulation in which the whole of quantum mechanics is grounded today. In other words: find a way to evade Heisenberg and you would have to rewrite all books on theoretical physics. Oh wait! To evade him you need to know where he is and how fast he's moving, right? And that's where he gets you. Twiddle.

Plainly put, the uncertainty principle says that you can never measure both the position and the momentum of a particle accurately. There is always an uncertainty in the measurement of the particle's position and an uncertainty in the particle's momentum; and the product of the two uncertainties is always greater than a certain quantity related to Planck's constant. Bypassing the Mathematics behind the principle, many authors have tried explaining it in different ways - amongst which Hawking is perhaps the most reader-friendly:

> "In order to predict the future position and velocity of a particle, one has to be able to measure its present position and velocity accurately. The obvious way to do this is to shine light on the particle… However, one will not be able to determine the position of the particle more accurately than the distance between the wave crests of light, so one needs to use light of a short wavelength…. This quantum(of light) will disturb the particle and change its velocity in a way that cannot be predicted… the more accurately one measures the position, the shorter the wavelength of the light that one needs and hence the higher the energy of a single quantum. So the velocity of the particle will be disturbed by a larger amount. In other words, the more accurately you try to measure the position of the particle, the less accurately you can measure its speed, and vice versa."

Simple. But is it satisfying enough? Probably not. My own first reaction was, "So it's the experimenter silly enough not to come up with a better way of measuring stuff: how does his inability transform into a fundamental principle?" But long before picking up Feynman's Lectures on Physics I had done my own thought experiment to answer the above question. Thought experiments, incidentally, I was later surprised to learn, are the methodology of choice of most Physicists to explore various concepts that deal with such fundamental shifts in classical thought: Einstein, for instance, made extensive use of such *experiments* during his formulation of Special Relativity. For now, let's just walk into *my lab*. Do pardon the austerity; I am too busy with Physics to decorate it.

Let's begin. I start by using the shortest possible wavelength of light to measure the position of an electron as accurately as possible. Now the goal is to obtain the momentum of the electron as I measure its position at lets say x. To do that, allow the electron to go on and collide with another particle of much smaller mass so that all of the electron's momentum is transferred to the particle at rest. Measure this momentum (let's call it Mehr-Momentum just for kicks) and we will know what the momentum of the electron was after it was disturbed by the light used to measure the position. Now, knowing the wavelength of the photons initially used and hence their momentum, I could again use the law of conservation of momentum to determine what the momentum of the electron was before it went ahead and collided.

And now I have the two quantities: momentum and position at x, with the uncertainty in them not necessarily being greater than that defined by the principle. So, what's the problem? Look again. I was able to obtain both the position and momentum of the particle simultaneously for a certain point in space, except for a fatal glitch: the particle was not at x anymore when I obtained its momentum for x. It had moved on. That leaves quantum physics laughing in my face saying, "Any monkey can make calculations about the past. We're talking about predictions here." Again, twiddle.

So yes, *predict* is the key here. The central dogma of determinism demands that we know the *present* - not the past - in order to *predict* the future state of a system. One is therefore compelled to accept that the uncertainty principle is not a consequence of our experimental limitations but a direct result of the fact that the act of observation itself cannot be separated from the system. This very postulate about the 'observer's interference in the universe' barring an objective formulation of theories about the universe, is what Einstein and other proponents of a "hidden variables interpretation" of quantum mechanics are not comfortable with. The mainstream (the Copenhagen) interpretation builds upon the uncertainty principle and claims that all the information you can ever get about a particle is contained in its wave-function as obtained by the solution of the Schrödinger's equation. Einstein, on the other hand, favored an interpretation with hidden variables that contained information responsible for the randomness.

With some scientists themselves being in a state of skepticism, it's not hard to understand the layman's discomfort with Quantum Mechanics. Questions such as, "But how can you not know?", "How is it a wave and particle at the same time?" are perhaps natural, considering that we live in a world where Newtonian mechanics *makes sense*. One has to move away from the dimensions of everyday life and be immersed in those of atoms and molecules to see classical Physics break down. And therein emerges the theory of Quantum Mechanics: something even more bizarre than the observations it tries explain. But when what appears to be a bizarre amalgam of conjectures and messy Mathematics goes on well beyond experiment to prove itself in your computers and space missions, its high time you appreciate its postulates and recognize it as one of the most intricately beautiful theories ever.

In hindisight, there is of course no shutting your eyes to alternative possibilities; provided those possibilities are ready to face the adjudicator called experiment. For instance, there are predictions about using the hypothetical gravitons to 'see' particles and defying the uncertainty principle. That possibility, however, does not falsify what we now hold to be true. It would be the same as saying, that if we discover a certain 'lambda virus' tomorrow all our theories about the causes of a certain disease can be proved wrong - even if those theories have helped us treat a million patients. So be it. Bring on the lambda and experiment will judge. *My* lab is open: ready to extract sense out of the nonsensical.

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