The Quantum World 1403SC Spring 2013

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A General Statement about This Course:

"For the sake of persons of - - - different types, scientific truth should be presented in different forms."

James Clerk Maxwell, 1890.

I presume no knowledge of science on your part. I do presume interest, else why are you here? In the course of this course you will let me know what you don't know but think I might be able to help you know. You will ask questions. **YOU WILL ASK QUESTIONS!!** Asking questions has many benefits. It stops me in my tracks and keeps me from droning on and on incomprehensibly. I will do that if you don't ask questions! It gives your fellow students courage to ask their questions and may make you a **BRAVE SOUL** in their eyes. It enables/forces you to articulate your puzzlement which may, itself, produce a big jump in your understanding. It lets me know what I should be talking about.

I know that some will be afraid that asking questions will make your fellow students think you are a **NINCOMPOOP** rather than a **BRAVE SOUL**. But **THERE ARE NO STUPID *GENUINE* QUESTIONS!** You may not believe that but if you hang with me you will come to see the light.

On the other hand, while not presuming knowledge, my discussion will contain *some* material which will be immediately understandable only by those who do have some knowledge of science and/or mathematics. This is to keep things interesting for everybody. Whenever I do that I will be delighted to explain the material for anyone who does not understand it and is willing to **ASK A QUESTION** about it.

A General Statement about Science:

“Three beliefs pervade most modern accounts of scientific principles and are the principal source of confusion. The first is that in some sense scientific laws are statements made with certainty. The second is that physical measures can be exact. The third is that there is a clearly marked boundary between science and ordinary thought. - - - I shall refer to them briefly as the certainty fallacy, the exactness fallacy, and the ‘base degrees’ fallacy.*”

> *“But when he has attained the topmost round
> He then unto the ladder turns his back,
> Looks in the clouds, scorning the base degrees
> By which he did ascend.”
> *Julius Caesar,* Act II, Sc. I.

Harold Jeffreys, 1931.

For a very large range of subjects science provides us with the most reliable information, knowledge and understanding of those subjects that we have. But there are pervasive and intimidating myths about science that are far from the truth. Science rarely, if ever, offers the final word on anything! Indeed final words, or declarations that certain words have final status, are usually taboo within science and provoke nothing so fast as an effort to prove them erroneous. So the ‘reliable’ scientific information, knowledge and understanding we have on any given subject is likely to change, usually to improve, maybe slowly, maybe rapidly, sooner or later, and again and again. The very great thing about (modern) science is just this deliberate abandonment of final judgement (recognized as unachievable) in favor of the never ending effort to improve upon our existing grasp of the structure of nature!

Not all scientists subscribe to this view of science as thoroughly as I do. One hears these days of the search for a ‘Theory of Everything’! I think such a search springs from a mix of hubris and touching naïve optimism. But even the champions of such a search do not mean by ‘Everything’ what you might think they mean. At best they mean a theory of everything that could qualify as a fundamental law of nature. But I still think the optimism is naïve. For one of *my* prejudices is that nature is, literally, *infinitely* subtle and complex. However much we learn, our grasp, even our grasp of the fundamentals, will always be improvable and extendable. That’s my view anyhow.

So how does science proceed? The old fashioned view was that first one gathered data from ‘objective’ observations and measurements. Then one ‘induced’ (as opposed to ‘deduced’) generalizations from the data. Then one deduced specific conclusions from the generalizations. And then one did experiments to confirm or refute those conclusions. If refuted, the generalizations that led to the tested conclusion must be rejected. If confirmed, we might do some more experiments or we might embrace the generalizations which are then scientifically ‘proven’.

But people (mostly philosophers) kept asking embarrassing questions. What determines the kind of data that need to be gathered? Surely one doesn’t just gather all possible data that come to hand! Just what is the nature of induction and how does one justify it compared to deduction? If the process is so straightforward why do lengthy scientific disputes and disagreements arise and why do we ever have scientific revolutions? After a long period of asking such questions the old fashioned view became suspect.

The contemporary view, still much discussed and debated, is rather subtle but has a basic core, which will suffice for us here. We all proceed from our accumulated past experience, whatever that is, whether we are scientist or lay person. Then, if puzzled and interested in something, we make conjectures, i.e., guesses. Then, if sufficiently motivated, we deduce specific conclusions from these conjectures, i.e. we say “If my conjecture is correct then such and such must be the case.” Then we make observations or perform measurements or design experiments to corroborate or dis-corroborate the conclusions and thereby *raise or lower our confidence* in our conjectures. If our interest persists we may modify our conjectures and/or deduce more conclusions from them and run more tests. We continue this until we are satisfied or get tired or bored. We may then turn to other interesting questions while someone else (often a young ambitious graduate student) sees our partially corroborated conjectures (now regarded as a ‘theory’) as an opportunity to be improved upon or attacked. And so it goes, never reaching a final (certain) end, at best reaching partial pauses, here and there. Long term disagreements can arise whenever the performed tests have altered different peoples confidence in the conjectures by different amounts. Revolutions can arise when we stumble upon data that severely shakes our confidence in Theories (originally conjectures) which we have come to hold in very high regard. This usually happens when we have not yet found the limitations of a very successful Theory and then, suddenly, we find them!

The most important historical development that gave rise to the illusion of finality (certainty) in science was the steadily increasing confidence in the Newtonian conceptual scheme for understanding the motions and forces of nature. For over *two hundred years* a seemingly endless series of tests of that scheme yielded (after repeated careful deliberations) nothing but corroboration after corroboration of the scheme. Perhaps it is understandable that by the end of the nineteenth century most physical scientists thought that Newton had really got it right and all subsequent physical science would just continue to build on Newton.

Then came Relativity Theory and Quantum Theory. The loss of innocence was colossal and traumatic!

But it was also, by now, a long time ago and the perennial process of forgetting lessons of the past looms anew. The process of determining which, if any, among alternative ideas are relevant to reality is an arduous one and usually not as glamorous as the ideas, themselves. Today we are awash in the currents of competing conjectures and theories about the structure and evolution of the universe as a whole – Supersymmetry, String theory, M-theory, Loop quantum gravity, the Inflationary universe, the Cyclic universe, Multiple universes, Branching universes, Eternal time, the End of time – and more. These are mostly wonderfully clever and beautifully crafted ideas and, if we're lucky, some of them may have something to do with reality. But at present they are all desperately in need of supporting empirical data and for some, acquiring such data seems to be a very dim prospect. It may yet turn out that none of them have anything to do with reality! In any case they are all, at present and at best, conjectural science, not established science. The promotional fervor with which they are presented to the public tends to mask that fact!

The Practical Importance of the Quantum World: (Not exhaustive)

Photons: Photocells, Solar Power.

Lasers: Laser Surgery, Laser Disks (CDs & DVDs), Laser Printers.

Electron Waves: Atomic and Molecular Structure (Crystals, DNA), Electron Microscopy, Scanning Tunnelling Microscopy.

Pauli Exclusion Principle: Periodic Table of Elements, Chemistry.

Electron Spin: Magnets, Magnetic Information Storage (Floppy Disks).

Semiconductors: Transistors, Chips, Light Emiting Diodes (LED's).

Radioactivity: Radiation Therapy, Diagnostic Radiology, Carbon Dating.

Nuclear Fission: Nuclear Power, The Bomb.

Nuclear Fusion: Stars, The Sun, The Hydrogen Bomb, Thermonuclear power (someday?)

Nuclear Spin: Magnetic Resonance Imaging (MRI), Magnetic Resonance Spectroscopy (MRS), Neuromagnetometry (NMI).