NS 280: Week #12 Handout, 2002.04.15
by Douglas Leonard

Overheads Not in Reader

Please see the handout: Course Reader Supplement #4.

Announcements

- If you did not meet with me to discuss your book review yet, please sign up for an office hour soon; the available hours can always be found at: http://helios.hampshire.edu/ dclNS/inventingreality/officehour/currentweek

Assignment for Wed., April 17

For Wednesday, finish up the reading that was originally assigned for last week:
- Reader, p. 204 - 205. Gibbon, from In Search of Schrödinger’s Cat.
  This section discusses Rutherford’s experiments that elucidated the nature of the atom: That nearly all of its mass was confined to a very small region (the nucleus).
- Reader, p. 206 - 207. Gibbon, from In Search of Schrödinger’s Cat.
  This section gives a good sense of just how small atoms are, and perhaps why our intuition breaks down when we attempt to study them and find out how they “really” behave.
- Reader, p. 208. Fred Wolf, from Taking the Quantum Leap.
  Just a reminder of everything that is about to be destroyed by quantum mechanics!

Assignment for Monday, April 22

**WARNING: Approach this reading assignment with CAUTION!** While the reading selections have been carefully chosen to give you a sense of the peculiarities of quantum mechanics, they include some mathematics that might be difficult for you. I do NOT expect you to fully understand all of the mathematical equations presented here (if you do, GREAT!), but I do want you to wrestle with the material a bit, and make sure you understand the ideas. So, do not be alarmed if some of the math is over your head – just give it your best shot – but do spend the time needed to make sure that the concepts are sinking in!

- Reader, p. 209 - 220. Feynman, from The Feynman Lectures on Physics.
  We went through this one quickly in class; now, spend the time that is needed to fully grasp the nature of the quantum world. As said above, do not be alarmed if some of the mathematics presented in this passage is hard for you: but don’t let it get in the way of your understanding the BIG picture: That (1) electrons exhibit both wave- and particle-like properties, and (2) that we can not determine the exact path that a particle will take through space, but instead must rely on “only” calculating the relative probabilities for all the possible paths that it could take. Since the concepts are tricky, let me now accompany you through this chapter. I will point out especially advanced topics that are included for the curious, but are not necessary to understand the basic ideas:

  Section 37-1: Feynman starts by destroying the notion that things on a very small scale behave in a familiar manner.

  Section 37-2: Here, Feynman sets up the classic Double-Slit experiment, using bullets to demonstrate the expected behavior of particles in such an apparatus. The basic result of this section: particles do not interfere with each other.
Section 37-3: This section has some tricky material. To get its essence, try to read it first by skipping over the mathematical sections, especially the last 2 paragraphs – all Feynman is doing there is giving a rigorous mathematical description to what “interference” is; you can certainly grasp its essence without the mathematical description. However, after you feel you’ve got a good conceptual understanding, come back again and now grapple with the math a bit, but don’t spend too much time, especially on equations 37.2 - 37.4. The big picture: this section is the same as the previous section, except that now Feynman describes the expected behavior of water waves being sent through such an apparatus. The bottom line: waves exhibit interference.

→ **Advanced information:** We have said in class that the intensity of a wave was related to its *amplitude* (i.e., how tall it is; its height); in fact, the true relationship is that the intensity of a wave is proportional to the *square* of its amplitude, as is described by Feynman in this section. That is, \( I = |h|^2 \), where \(|h|\) is the absolute value of the displacement of the wave from the medium’s undisturbed height, and \( I \) is the intensity. Feynman also discusses the concept of a “phase difference”, where a difference of \( \pi \) is considered “out of phase”. This stems from the full description of wave behavior (which we have not done), in which the phase (i.e., what part of a wave you’re looking at) of a wave is described in radian units, where \( \pi \) radians = 180° = 1/2 of a wave. There is also a discussion of complex numbers (e.g., \( e^{i \omega t} \), where \( i = \sqrt{-1} \)), which you may or may not have seen in mathematics before. Again, the true mathematical underpinning of the wave description of nature uses complex numbers to help keep track of how the wave is propagating. That’s all he’s discussing here.

Sections 37-4 and 37-5: Now Feynman describes what electrons do in the double-slit experiment; evidently, they show interference effects! There is a small amount of mathematics, a few paragraphs below equation 37.5, that might be confusing. Don’t worry about it – all Feynman is saying is that the electron behavior shows interference effects, and is inconsistent with the “bullet” (i.e., particle) experimental results.

Section 37-6: Here Feynman describes what happens to the interference pattern if we *observe* the two slits in such a way (i.e., by shining a light on them) that we can tell which hole each electron went through. The surprising conclusion is that once we can tell which hole it went through, *the interference pattern disappears*. This is rather odd. Feynman then goes on to describe the specific effects that that shining a light on an electron has; in order to do this, he (re)introduces the notion that photons carry momentum (symbolized by \( p \)) such that \( p = h/\lambda \). Don’t worry too much about this equation, but do recognize that, like material particles, light itself can impart momentum to an object.

Sections 37-7 and 37-8: This final summary of quantum behavior starts out a bit mathematically; again, it is not necessary to follow all of it. Focus on the *ideas*, especially the ones that Feynman stresses by putting them in *italics*! The final section of the chapter states the famous Heisenberg Uncertainty Principle in more mathematical language than was done back on p. 217.

● **Reader, p. 221 - 222. Wolf**, from *Taking the Quantum Leap*.

An interesting bit of whimsy on the first meeting between the young Werner Heisenberg and the older Niels Bohr.

**Weekly Thought Question**

What has been your favorite *thing* that we have covered in this class? Start by clearly explaining what this favorite “thing” is, and then try to say why you like(d) it so much. (Note that “thing” can be taken quite generally: it can mean, for instance, an *idea*, a *person*, a *time period*, etc.).

2