14.5: Footnotes

1. This is under the assumption that all the uranium atoms were created at the same time. In reality, we have only a general idea of the processes that might have created the heavy elements in the nebula from which our solar system condensed. Some portion of them may have come from nuclear reactions in supernova explosions in that particular nebula, but some may have come from previous supernova explosions throughout our galaxy, or from exotic events like collisions of white dwarf stars.
2. What I'm presenting in this chapter is a simplified explanation of how the photon could have been discovered. The actual history is more complex. Max Planck (1858-1947) began the photon saga with a theoretical investigation of the spectrum of light emitted by a hot, glowing object. He introduced quantization of the energy of light waves, in multiples of hf, purely as a mathematical trick that happened to produce the right results. Planck did not believe that his procedure could have any physical significance. In his 1905 paper Einstein took Planck's quantization as a description of reality, and applied it to various theoretical and experimental puzzles, including the photoelectric effect. Millikan then subjected Einstein's ideas to a series of rigorous experimental tests. Although his results matched Einstein's predictions perfectly, Millikan was skeptical about photons, and his papers conspicuously omit any reference to them. Only in his autobiography did Millikan rewrite history and claim that he had given experimental proof for photons.
3. But note that along the way, we had to make two crucial assumptions: that the wave was sinusoidal, and that it was a plane wave. These assumptions will not prevent us from describing examples such as double-slit diffraction, in which the wave is approximately sinusoidal within some sufficiently small region such as one pixel of a camera's imaging chip. Nevertheless, these issues turn out to be symptoms of deeper problems, beyond the scope of this book, involving the way in which relativity and quantum mechanics should be combined. As a taste of the ideas involved, consider what happens when a photon is reflected from a conducting surface, as in example 23 on p. 699, so that the electric field at the surface is zero, but the magnetic field isn't. The superposition is a standing wave, not a plane wave, so $|\mathbf{E}|=c|\mathbf{B}|$ need not hold, and doesn't. A detector's probability of detecting a photon near the surface could be zero if the detector sensed electric fields, but nonzero if it sensed magnetism. It doesn't make sense to say that either of these is the probability that the photon “was really there.”
4. This interpretation of quantum mechanics is called the Copenhagen interpretation, because it was originally developed by a school of physicists centered in Copenhagen and led by Niels Bohr.
5. This interpretation, known as the many-worlds interpretation, was developed by Hugh Everett in 1957.
6. See page 889 for a note about the two different systems of notations that are used for quantum numbers.
7. After f, the series continues in alphabetical order. In nuclei that are spinning rapidly enough that they are almost breaking apart, individual protons and neutrons can be stirred up to ℓ values as high as 7, which is j.
8. See Barnes et al., “The XYZs of Charmonium at BES,” arxiv.org/abs/hep-ph/0608103. To avoid complication, the levels shown are only those in the group known for historical reasons as the Ψ and J/Ψ.