Solutions for homework three, due 21 October 2004

1. There are many possible answers to this. Two I discussed in class follow. If someone uses different examples that is fine, but it is important to include some explanation, not just state a name.

Perhaps the most striking piece of evidence that light is a wave comes from the challenge by Poisson to Fresnel, that if light is a wave then in the center of the shadow of a circular obstacle (a long way beyond the obstacle) one should see a bright spot. Arago did the experiment and found the spot, so that Poisson’s challenge led to the strongest possible confirmation of the wave hypothesis.

Further confirmation came from Maxwell’s theory of electricity and magnetism, which has solutions consisting of transverse electromagnetic waves traveling at the speed of light. In other words, if it walks like a duck and quacks like a duck, etc., then it is a duck!

2. While Newton argued strongly that light is carried by particles, he did not have concrete evidence to support that, and he himself discovered wave properties, the Newton rings found when a curved glass rests on a flat glass plate, and there is interference alternately enhancing one and another color. He attributed these effects to variable ‘ease’ of fit of the light particles in spaces of different length, but even that could be viewed as tacitly admitting that light has wave properties, even if, as he (correctly) believed, light also has particle properties.

The first direct evidence that light behaves like a collection of particles was the successful Einstein prediction of how the photoelectric effect should work. He said that if the energy in the light comes in small packets, each with energy hf, where h is Planck’s constant and f is the light frequency, then the maximum kinetic energy of electrons knocked out of a metal would be \( E = hf - W \), where W is the amount of energy the electron needs just to get out of the metal.

Another, even more direct experiment was the Compton effect, in which X rays knock electrons out of atoms in some thin layer of material. Now the binding of the electron in the atom involves negligible energy compared to that supplied by the X ray photon, so that the electron may be considered as initially at rest in empty space. Then conservation of energy and momentum gives a simple formula for the way the photon wavelength changes with scattering angle when it scatters on the electron. The wave picture would have implied that the wavelength would be the same for scattered light as for the incoming light beam.
3. [FOR EXTRA CREDIT] If the n=1 shell is filled there are 2 for spin times \( n^2 = 1 \) for space wave function electrons in it. If the n=2 shell is filled there are 2 for spin times \( n^2 = 4 \) for space = 8 electrons. This gives 2+8=10 electrons. The nuclear charge \( Z \) of an atom is equal to the number of positive charge units carried by protons in the atomic nucleus, and also is equal to the number of negative charge units carried by electrons, which is the same as the number of electrons in the atom, because each one carries one negative charge unit. Thus the atom overall has zero net electric charge. The periodic table available in the links says that this element with \( Z = 10 \) is neon.

4. The special thing about filled shells is that the outside of the atom is smooth and hard, so that pulling out an electron is especially difficult, and adding an electron also is difficult, because it has trouble sticking to the outside of the atom. If, for example, an atom has one extra electron outside a closed shell, like sodium, then it is fairly easy for that electron to stick to another atom. If a atom has one missing electron in the outer shell, like fluorine, then that becomes a natural place to attach another electron. That is why sodium and fluorine tend to form an ionic compound. When two or more touching atoms each have partly filled outer shells, they tend to share their outermost electrons, so that the electron wave functions become more spread out, which implies longer typical wavelength and therefore smaller typical momentum and energy than if the atoms were far apart and not sharing their outer electrons. This mutual sharing of electrons makes a covalent compound.