13. Parts of a Wave Function.

Each branch has the same energy, charge, mass, spin.

To show that the properties of the wave function exactly imitate the properties of a classical universe made of particles, it is necessary to show that the *parts* of the wave function—the different branches or versions of reality—"carry" or "possess" many of the same numerical characteristics as the full wave function. For example in the half-silvered mirror case, suppose the original light wave function carries energy E. Then after the mirror, both the horizontal and the vertical parts of the wave function also carry the full energy E; the energy does not split between the two, no matter what the coefficients (Ch. 8) are.

Non-splitting of the energy.

The mathematical demonstration of the non-splitting of the energy is given in A13.1. But it is conceptually clearest to give the idea in diagrammatic form. Suppose we consider again the half-silvered mirror experiment, with the state of the photon (ph) after the mirror being

$$.6\,|ph, H\rangle + .8|ph, V\rangle \quad (1)$$

The wave function splits into two parts, as in Fig. (8-2) in Ch. 8, with the important feature being that the two parts corresponds to **isolated** universes, shown by the two boxes drawings in the figure. Since each universe is isolated, no energy can come in or leak out. Thus energy must be *separately conserved in each universe*, so each part carries the full energy. That is, the energies of the two parts are independent of the coefficients. (Note that there is no overall violation of conservation of energy because energy does not add across branches; roughly, energies only add for products.)

Non-splitting of the charge, mass and spin.

Because of the isolation of the parts of the wave function, the same conclusion holds for many properties. Take charge, for example. If an electron wave function is split into two parts, this argument shows that each part carries the full charge, so that one never sees a particle with a fraction of the full charge of the particle. By using the same reasoning, one can show that each individual part also keeps the full amount of mass and (total) spin.

Comparison to the classical case.

This conservation-on-each-branch rule appears to contradict both classical ideas and certain observations. If we shine a beam of light on a half-silvered mirror corresponding to coefficients .6 to the horizontal part and .8 to the vertical part, then we do *not* find—in contrast to what we might have expected from the above—that the full energy of the beam goes both in both the horizontal and the vertical directions. Instead, 36% of the energy goes in the horizontal direction and 64% in the vertical direction.

Why the dichotomy? What is happening is that the beam of light is composed of the wave functions of many photons. The horizontal and vertical parts of *each photon* do indeed carry the full energy of the photon. But the photon is detected only 36% of the time on the horizontal path, so that detector receives only 36% of the energy (and similarly for the vertical path).

The same thing happens for water waves and sound waves. A small part of the wave carries a correspondingly small part of the full energy because each wave is composed of many, many individual atomic wave functions.

The photoelectric effect.

One more remark here about the lack of evidence for particles. In the early 1900s, there was an observed phenomenon called the photoelectric effect in which light shone on a metal surface splashed electrons out of the metal. In 1905, Einstein proposed that this effect could be explained if one assumed there was an actual particle of light, later named the photon. The principles used were conservation of energy and momentum, presumably carried by the particulate photons (and electrons). This in fact is one of the major arguments in favor of particles.

But we now know (see Ch. 12) that energy and momentum can be thought of as properties of the wave functions (rather than of particles), and that these two properties are conserved in quantum mechanics. Further, the mathematics of quantum mechanics implies there is perception of only one version (Ch. 11) and, as we just argued, that a part of the wave function possesses all the energy and momentum. Thus the reasoning that led to Einstein's particle hypothesis is flawed (he couldn't have known this before the advent of quantum mechanics in 1926 and a full understanding of the properties of the wave function) because the photoelectric effect and the related Compton scattering of photons can be explained using properties of the wave function alone. Therefore these two experiments do not constitute evidence for particulate photons and electrons.

Evaluation:

It would appear from a superficial glance at quantum mechanics that we should observe electrons (for example) with fractional charge when the wave function splits. And indeed this argument may persuade a few physicists that there must be an *actual particle*, of charge – *e*, lurking within one of the parts of the wave function. But a look at the simple argument in A13.1 or at conservation of energy, charge and so on in the two separate diagrams of Fig. 13-1, would quickly convince them otherwise. Thus it is certain that the particle-like properties do not split when the wave function splits.

Further we see that the arguments of Chs. 10-13 imply that Einstein's deduction of the particle nature of light from the photoelectric effect, one of the major arguments for particles, is flawed because the photoelectric effect can be deduced from the properties of the wave function alone.