14. Perceived Locality in quantum mechanics.

A spread-out wave function leads to a perceived localized effect.

One property of (the allegedly existing) classical particles is that they are localized; they produce effects limited to a very small space. Wave functions, on the other hand, can be spread out in space. So the question is whether quantum mechanics, by itself, with no presumption of particles, can give localized effects that imitate classical particles. The answer is yes.

Example 1: Single slit.

The archetypal case where localization seems to conflict with pure (that is, no-particle) quantum mechanics is the single slit experiment. A very weak source of light emits, say, only one photon (light wave function) every minute. The light wave function goes through a single, narrow slit, spreads out and hits a screen covered with film grains. It will hit thousands of grains but, surprisingly, if one searches with a microscope, one will find that, for each wave function, *only one* of the grains hit is *perceived* as exposed (that is, the light changes its chemical structure in a visible way).

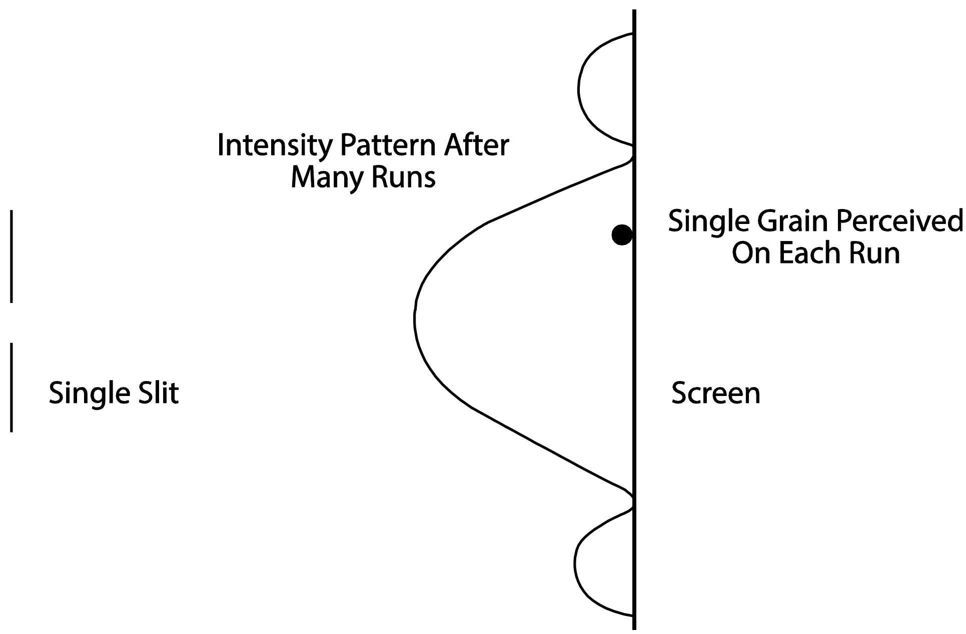

Fig. 14-1

Figure 14-1 Single slit. The wave function is spread out over many grains, and the intensity pattern after many runs is spread out over many grains, but quantum mechanics predicts that only one grain will be perceived as exposed on each run of the experiment.

The picture of this process typically given is that, embedded in the wave function there is an actual particle of light. It travels along with the wave function and hits just one of the grains of film, thereby exposing it. But as we will show, that conceptual construction—adding a particle to explain why only one grain is exposed—is not necessary; quantum mechanics by itself, with only the spread-out wave function, implies that more than one exposed grain will never be **perceived**.

> **Comment:** This is surprising because it's a result we don't expect from *classical* waves. Suppose we have a circle of corks floating in a pond and we throw a rock into the middle. Then every one of those corks will be affected by the outward-moving wave. Why isn't it the same with the light wave (function) and the film grains? Why aren't all of them affected by the wave?

Example 2: Electron scattering experiment.

There is another case where the particle picture is even more automatically assumed by physicists. Suppose we put a proton in the middle of a sphere, of radius 1 meter, and cover its inside surface with film grains. We then shoot an electron (through a small hole in the sphere) at the proton. The wave function for the electron hits the proton and spreads out in a spherical wave, with parts of the wave hitting every film grain. But again a microscopic search will show that only one grain is exposed.

The conceptual picture almost always assumed is that there is an actual, particulate electron embedded in the wave function, and it is this particulate electron that hits and exposes the single grain. However, the same argument that is used in the light case can also be used to show that quantum mechanics alone implies more than one exposed grain will never be perceived. That is, one can show that the spread-out wave function has a *perceived* localized effect in both examples; just one localized film grain is perceived as exposed (independent of the size of the grains)! Thus perceived localization does not imply the need to assume the existence of particles—actual, particulate electrons, photons and so on—because quantum mechanics by itself leads to the *perception* of a localized effect.

> **Comment:** We are implying there is no actual electron that hits just one of the grains. This will be a stretch for many physicists and non-physicists alike! What was it that was shot at the proton? What are all the experiments on elementary particles *on* if there are no particles? The answer is that electron-like *wave functions* are shot at the proton (wave function). All the experiments of elementary particle physics are on particle-*like* wave functions (or more precisely state vectors—see A6.2).

How perceived localized effects come about in quantum mechanics.

To illustrate why only one grain is perceived as exposed, we will use an electron wave function spread out so it is about to hit three grains of film. Quantum mechanics tells us the interaction between the electron wave function and the grains will be the sum of three separate processes: the top third of the wave function interacts with (that is, it can expose) only grain 1; the middle third can expose only grain 2; and the lower third can expose only grain 3. (See A14.1 for a more thorough treatment.) (Note: The results of Ch. 13 ensure that a *part* of the wave function has the full energy of the electron, so each part has sufficient energy to alter the grain structure.) The result is indicated in Fig. 14-2.

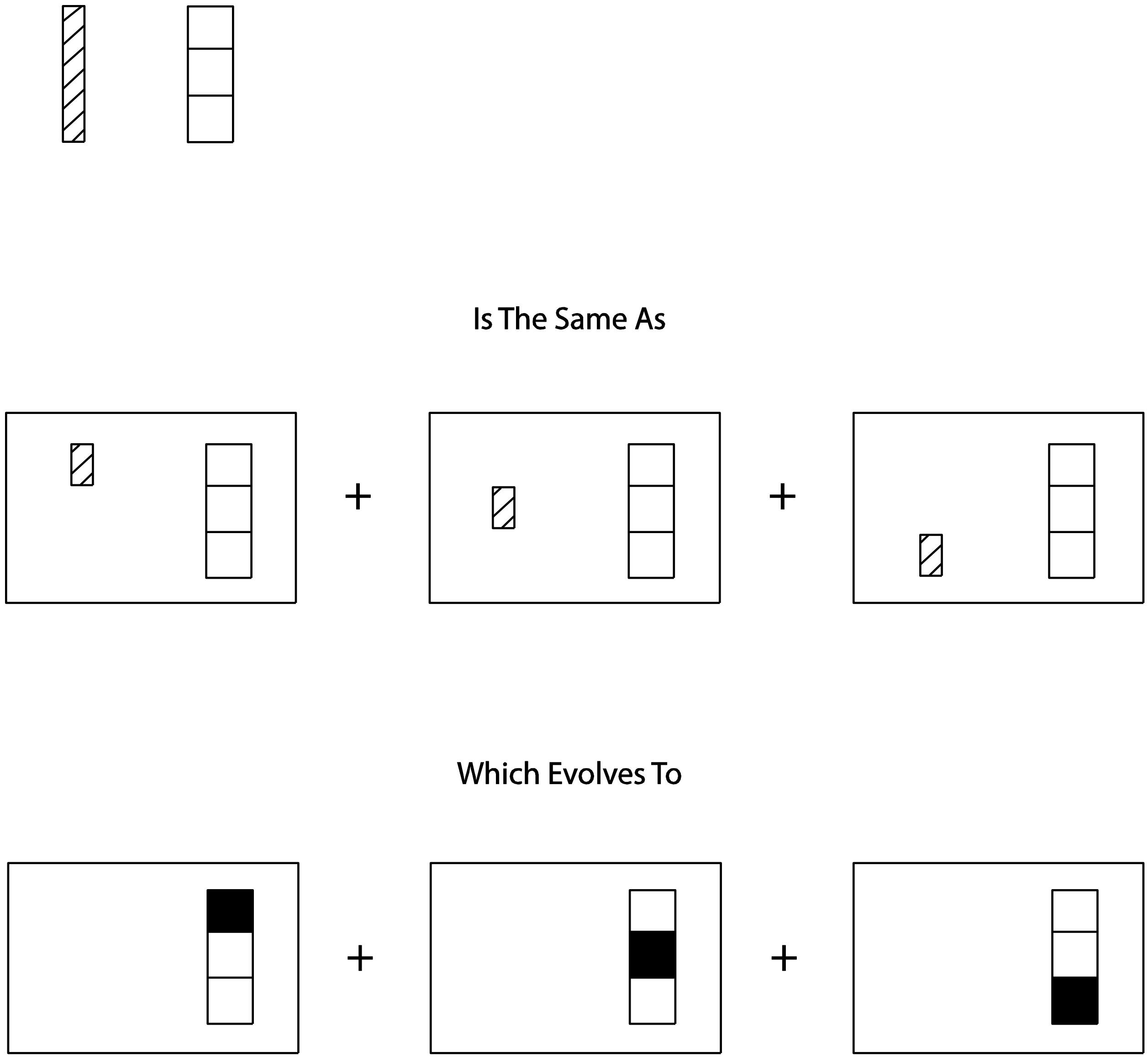

Fig. 14-2

Figure 14-2. Explanation of why only one grain is perceived as exposed when the wave function hits all three grains. Each version of the observer perceives what is in just one of the three final diagrams.

We see that at the end there are three diagrams, with just one grain exposed in each diagram. Now we know from Ch. 10 that each of the three terms exists in a separate, isolated universe, and we know that the version of the observer in each universe can only perceive what happens in that universe. But since only one grain is exposed in each universe, each of the three versions of the observer will perceive one and only one grain exposed.

To summarize the argument, by using the reasoning of Ch. 11, we see that **only one grain will be <u>perceived</u> as exposed** in spite of the incoming electron wave function being spread out over three grains! Thus it is not necessary to assume there are localized particles in order to explain the **perception** of localized (only one **localized** grain exposed) results; quantum mechanics by itself is sufficient! More than one exposed grain is never perceived in quantum mechanics.

> **Comment:** It is truly amazing that the spread-out wave function leads to localized perceptions! The wave function mathematics exactly reproduces the effect—exposure of only one localized grain—that we think of as being caused by very small particles!

Baseball.

There is one other particle-related effect that can also be explained by quantum mechanics alone. It is presumably possible to have large objects—a baseball for example—with its center of mass wave function spread out over a large region, say a meter. Those who advocate the existence of an objective (single-version) reality separate from the wave function would say that if there is no objective, single-version baseball, this implies we would perceive a baseball smeared out over a meter. But that is not correct. Using ideas similar to those above on localization, it can be shown (A14.2) that one will perceive a baseball localized to just one position, exactly as we expect.

Summary.

The outcome expected from a classical **particle** picture—the perception of one and only one localized grain exposed, or a sharply localized baseball—is exactly imitated by the **wave** function mathematics. Thus, since the wave function alone can explain the perception of localized effects, those effects cannot be used as evidence for the existence of particles. The same reasoning shows that perception of only one localized grain cannot be used as evidence for collapse of the wave function.

Evaluation.

This comes as a surprise to many physicists and they would initially be skeptical. Nevertheless quantum mechanics prohibits the perception of more than one exposed grain or a spread-out baseball. The arguments in this chapter, as well as those of Chs. 10-13, are missing from the standard quantum mechanical education of physicists, but there is no doubt of their correctness.