# 15. Particle-like trajectories. Classical if-then logic.

## Trajectories in a bubble chamber.

One of the phenomena often cited as evidence for particles are the particle-like trajectories seen in bubble chambers. These trajectories are quite smooth, exactly as if a particle had left a trail of bubbles in its wake. So the usual conclusion is that there is indeed an actual particle that traces out the trajectory. But we will show that the particle concept is not necessary to explain the trajectories because no version of the observer will ever perceive anything other than a classical trajectory.

> It may be helpful to explain how a bubble chamber works. It has liquid hydrogen in it (they are actually a bit dangerous!) at a pressure such that it is still liquid but is just above the boiling temperature. When a particle is shot into the chamber, it ionizes some of the hydrogen molecules. Because the liquid is ready to boil at the slightest disturbance, these ionized molecules cause the liquid to actually start boiling in a small volume around them. This creates a small but visible bubble. The perceived trajectory then consists of a string of bubbles which form a smooth, narrow path. The point addressed here is how quantum mechanics can lead to the perception of a single, smooth, narrow trajectory when the wave function that goes into the chamber is spread out over, say, a few centimeters or more.

## Localization of the electron wave function upon detection.

We will use reasoning similar to that in the previous chapter for the detection of a spread-out electron-like wave function. But instead of grains of film, we will use hydrogen molecules as the 'detectors.' The molecules are either ionized (indicated by an asterisk) or not ionized, and, if ionized, they are at the center of a bubble. For this illustration, we will use just two layers, A and B, of three hydrogen molecules each, with the B molecules directly behind the A molecules. We assume the electron wave function is not greatly affected (small angle scattering) when it hits the A molecule. After the electron has hit the first layer, the total wave function can be represented as in Fig. 15-1, which is the same as Fig. 14-2, with the B layer of hydrogen molecules just along for the ride;

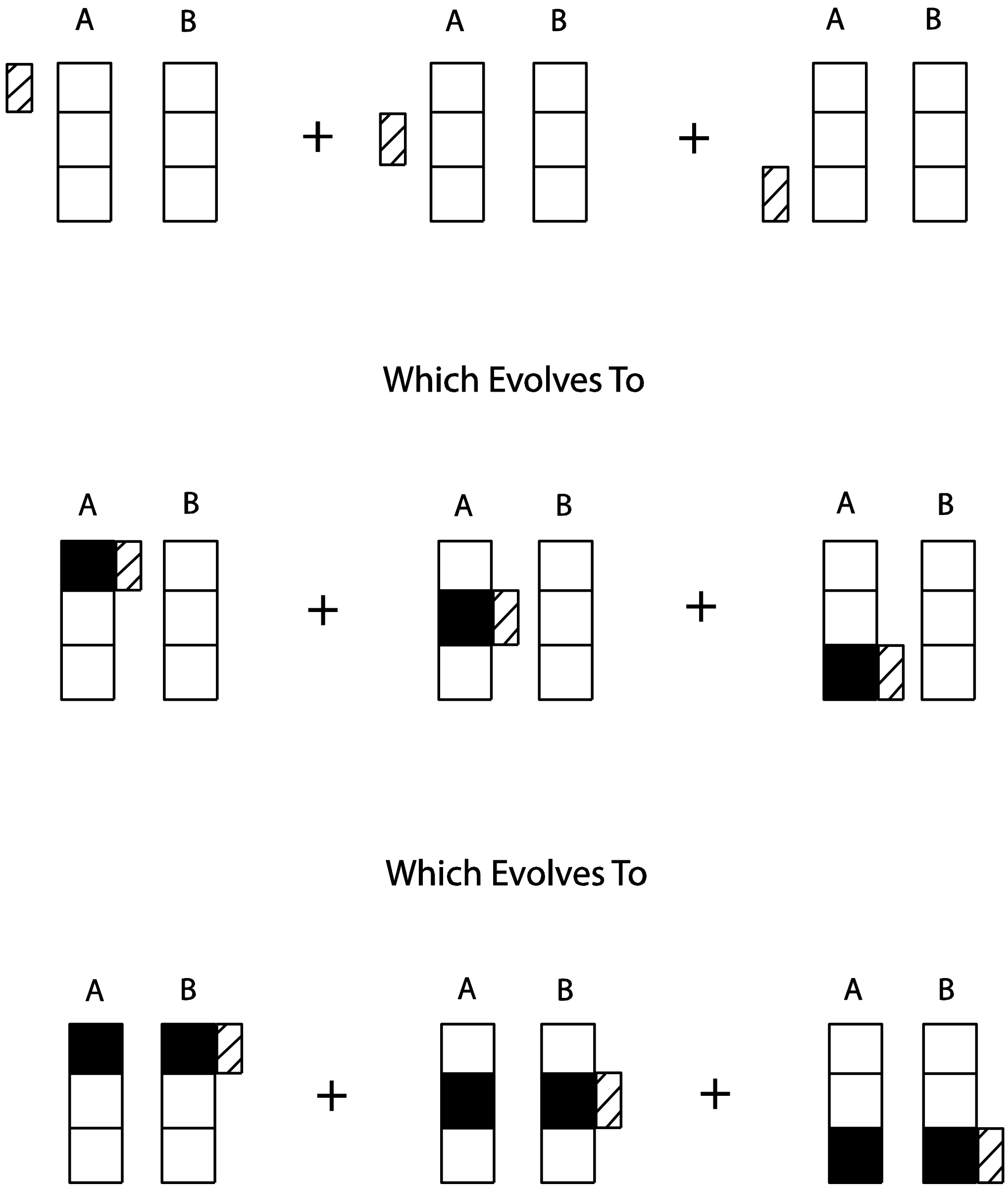


Fig. 15-1

Figure 15-1. Detection of an electron in a bubble chamber with two layers of 'detectors.' The filled-in squares indicate the nucleation of a bubble. This diagram starts with the second diagram of Fig. (14.2). In the third diagram here, one sees the beginnings of a smooth, non-disjoint trajectory.

There are two important points here. The first, as in Ch. 14, is that the total state vector (wave function) is now the sum of three parts. And the second is to note that, on a particular branch, the mathematics of quantum mechanics guarantees that, just after layer A is reached, the electron wave function on that branch is now localized just past the molecule it ionized.

**The trajectories.**

Each version of the electron now moves to the right and triggers only the molecule in layer B which is in front of it. Thus on each branch we have the beginnings of a trajectory. Thus if we were to put an observer in the illustration, then each of the three versions of the observer (one for each version of reality, represented by the boxes) will perceive the A and B hydrogen molecules on the **same single line** as producing bubbles and the others not. So for each of the three parts of the total wave function, we have the beginnings of a trajectory; if the observer perceives a bubble in the vicinity of hydrogen molecule A1, for example, then the observer will also perceive a bubble in the vicinity of hydrogen molecule B1, but not in the vicinity of molecules B2 or B3. This shows schematically that **each version of the observer will always perceive a smooth (not disjoint), localized (not spread out) trajectory** in quantum mechanics in spite of the fact that there is a spread-out wave function and no actual, localized particle moving in a smooth trajectory.

**If-then causality.**

Another way to look at this result is as an illustration of classical if-then causality. **If** hydrogen molecule A2 is perceived as nucleating a bubble, **then** the electron wave function on that branch is localized to the region of molecule A2, and that localized electron wave function will be perceived as ionizing hydrogen molecule B2, which will also nucleate a bubble. But the other molecules in the B layer will not be perceived as being nucleation centers in the A2-B2 universe. Thus because of the nature of the quantum mechanical interactions **classical if-then causality within each separate universe is built into quantum mechanics**. This feature of quantum mechanics is (presumably) the source of if-then logic in the physical world.

**Summary.**

Yet again, this is a remarkable result. In spite of the facts that quantum mechanics has spread-out waves, that it gives several versions of reality, and that it contains no objective, localized particles, it still exactly imitates our perception of an objective, particle-like, localized, if-then reality, including trajectories!

**Evaluation.**

The inputs here are the results of Chs. 10 and 11, and the implication from the equations of motion that detection at a localized position on a given branch localizes the wave function to that position. From these two, it follows that one always sees a narrow, smooth—not spread out or disjoint—trajectory. So all physicists who agree with the reasoning of Chs. 10 and 11 (and I presume that includes virtually all physicists) would agree with the results here.