6. Versions of Reality.
The half-silvered mirror.

The most peculiar aspect of quantum mechanics, the one that sets it furthest apart from classical physics and our everyday view of the world, is that in its mathematics there are often **several simultaneously existing versions of reality** (as opposed to the single version we perceive). It is this peculiarity that lies at the heart of almost all the problems in understanding quantum mechanics.

The half-silvered mirror experiment.

We will illustrate this splitting into several simultaneously existing versions of reality by a relatively simple experiment using light and a half-silvered mirror. (This will be converted into the better-known Schrödinger's cat experiment in Ch. 7.) We have a light source that shines a beam of light at a mirror placed at an angle of 45 degrees, as in Fig. 6-1.

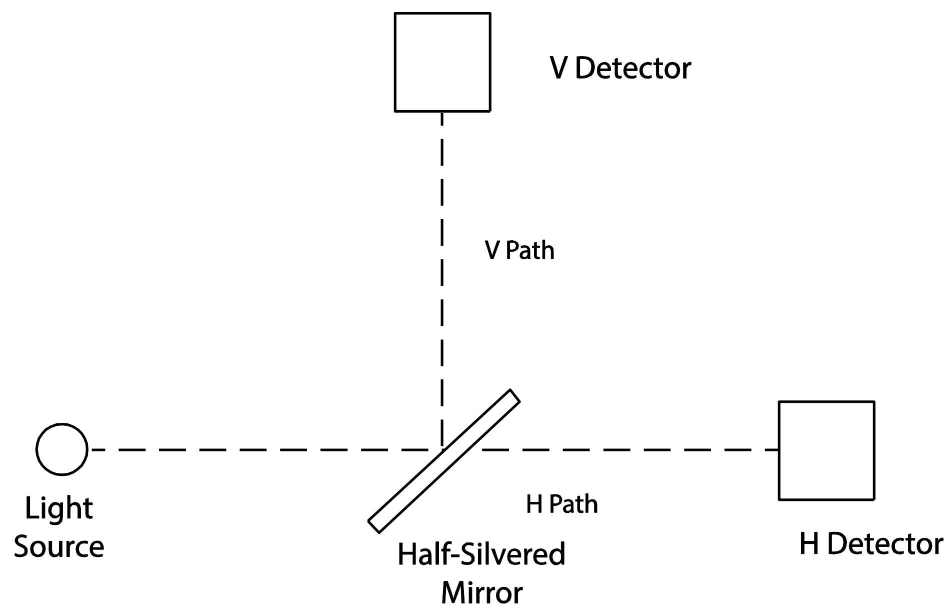

Fig. 6-1

Figure 6-1. Diagram of the half-silvered mirror experiment.

The front surface of the mirror is coated with a thin layer of silver so that half the light goes through the mirror as a horizontal beam, and half is reflected at 90 degrees to give a vertical beam. A dark filter is placed in front of the light source so the beam that hits the mirror is very weak. In addition, to further limit the amount of light, there is a fast shutter which opens, lets light through, and closes again in about 1 nanosecond. The detector of the light is a light-sensing element similar to that used in a digital camera.

One detector, labeled H, is placed at the end of the H path and another, labeled V, at the end of the V path, with the two being the same distance, about a meter, from the mirror.

The experiment is then run several times, with the shutter opening and closing once on each run, and with the read-out from each detector recorded on each run. The question is what the read-out will be. If we think conventionally, half the beam of light hits detector H and, at the same time, half the beam hits detector V. If we were to use our usual, non-quantum mechanical way of thinking about how things work, we would guess first that, because 50% of the light goes in each direction, the readings on the two detectors on each run would be equal. And because the light source is so weak (due to the filter and shutter), we would guess that the response of the detectors would be very weak. But that is not what happens.

Versions of reality.

The first step in understanding the outcome is to note, as we said in Ch. 5, that the light beam is not continuous; instead, it comes in packets. We will assume that, because of the filter and shutter, at most just one packet gets through on each repetition of the experiment. Each packet corresponds to the wave function of a single photon, the minimal "piece" of light. Usually, the photon is thought of as a particle with an associated wave function, but for now it corresponds to just the wave function of the minimal piece of light.

At the mirror, this single packet gets divided into two parts. One part goes through the mirror and continues on a horizontal path towards a detector of light. The other part gets reflected by the mirror and continues on a vertical path towards another detector. To show this, we write the **state** of the single photon as the sum of two wave functions

$$
\begin{aligned}
|\text{state of single photon}\rangle = &\ |\text{part 1 of wave function on the H path}\rangle \\
&\oplus \\
&\ |\text{part 2 of wave function on the V path}\rangle
\end{aligned} \qquad (1)
$$

The "state" is a description of the general properties of the system at hand. In quantum mechanics, it is generally put inside the peculiar 'ket' bra*ket*s, |…⟩ (see A1.1, A6.2,).

Next we look at the system after the two wave functions have hit their respective detectors. The first peculiarity is that the two parts of the wave functions of the photon 'annihilate'—go out of existence—after they hit their respective detectors. The second peculiarity is that even though the wave function of a photon is very small, with very little energy, when it hits a detector, it always changes its reading (if the detector is 100% efficient) from no (no detection) to yes (yes, detection). But if it doesn't hit a detector, it cannot, of course, change its reading. Thus part 1 of the photon changes the H detector but not the V detector and vice versa for part 2. This means that the state of the system—the photon (which is now annihilated) and the two detectors, is now

$$
\begin{aligned}
|\text{state of the system}\rangle = &\ |\text{H detector reads yes}\rangle|\text{V detector reads no}\rangle \\
&\oplus \\
&\ |\text{H detector reads no}\rangle\ |\text{V detector reads yes}\rangle
\end{aligned} \qquad (2)
$$

Thus in effect **the whole physical universe has divided into two versions of reality**! In one version, the detectors read yes,no and in the other they read no,yes. We will show in Ch. 10 that these two versions of reality correspond to separate, non-interacting, non-communicating universes.

It is of considerable interest that **there are no longer single-version 'objects'** in quantum mechanics; instead there are **multiple versions** of each 'object.' In Eq. (1), there are two versions of the photon, corresponding to part 1 and part 2, with each version capable of triggering a detector (Ch. 13). And in Eq. (2), there are two versions of each detector. Each version corresponds to a full-blown version of reality, not to a partial reality.

Diagrams of the states.

It is often helpful to have diagrams corresponding to states such as those in Eq. (1) and (2). Typically the diagram corresponding to Eq. (2), before the photon wave functions annihilate, is drawn as in Fig. 6-2.

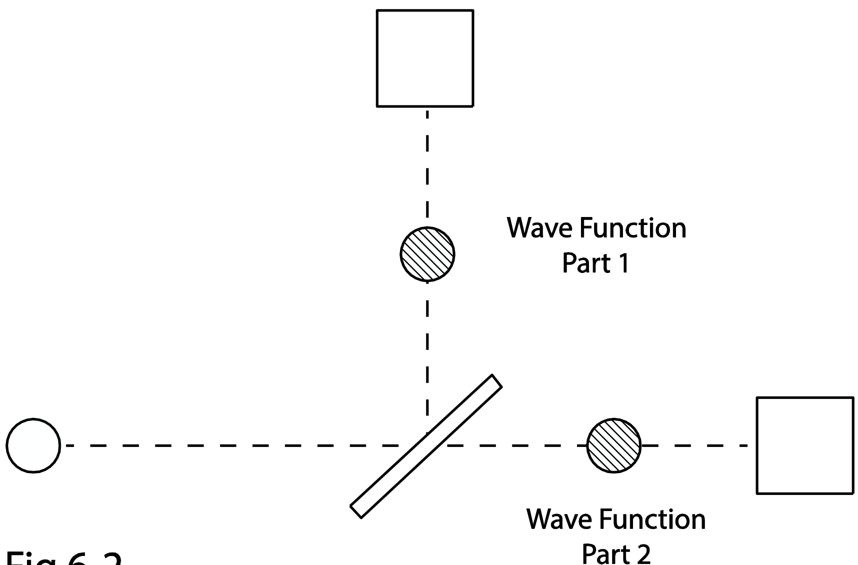

Fig 6-2

Figure 6-2. Two parts of a single photon, denoted by the open circle, simultaneously existing. The dashed lines indicate the path each version of the photon took. This diagram does not properly convey the meaning of Eq. (2).

But this diagram does not convey the import of Eq. (2). Instead the proper diagram is the 'sum' of two diagrams, as in Fig. 6-3.

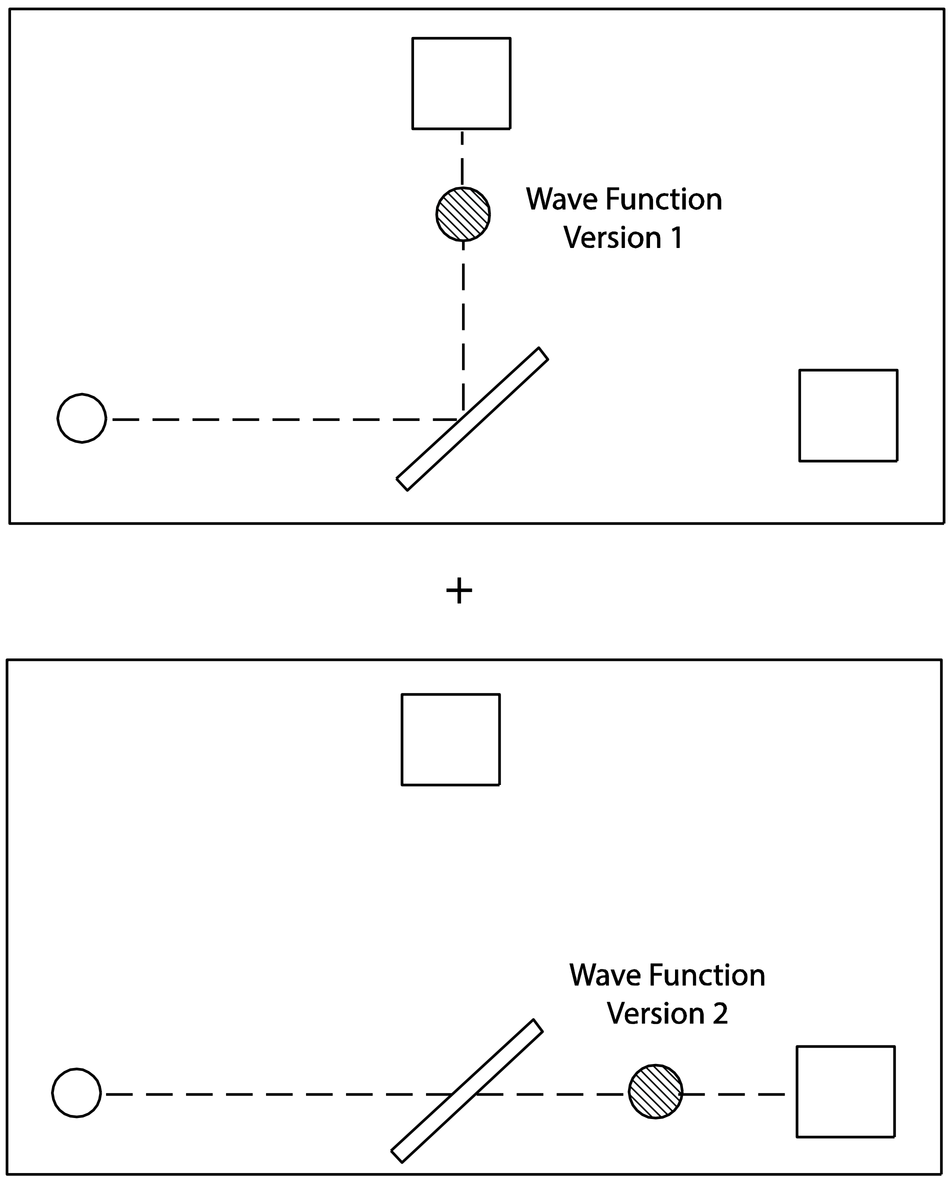

Fig. 6-3

Figure 6-3. The two simultaneously existing versions of the photon of Eq. (2) are drawn in separate diagrams.

And the proper diagram for Eq. (2) is again the sum of two diagrams, as in Fig. 6-4, with the sum put in because the states the two diagrams represent are added together in basic linear quantum mechanics.

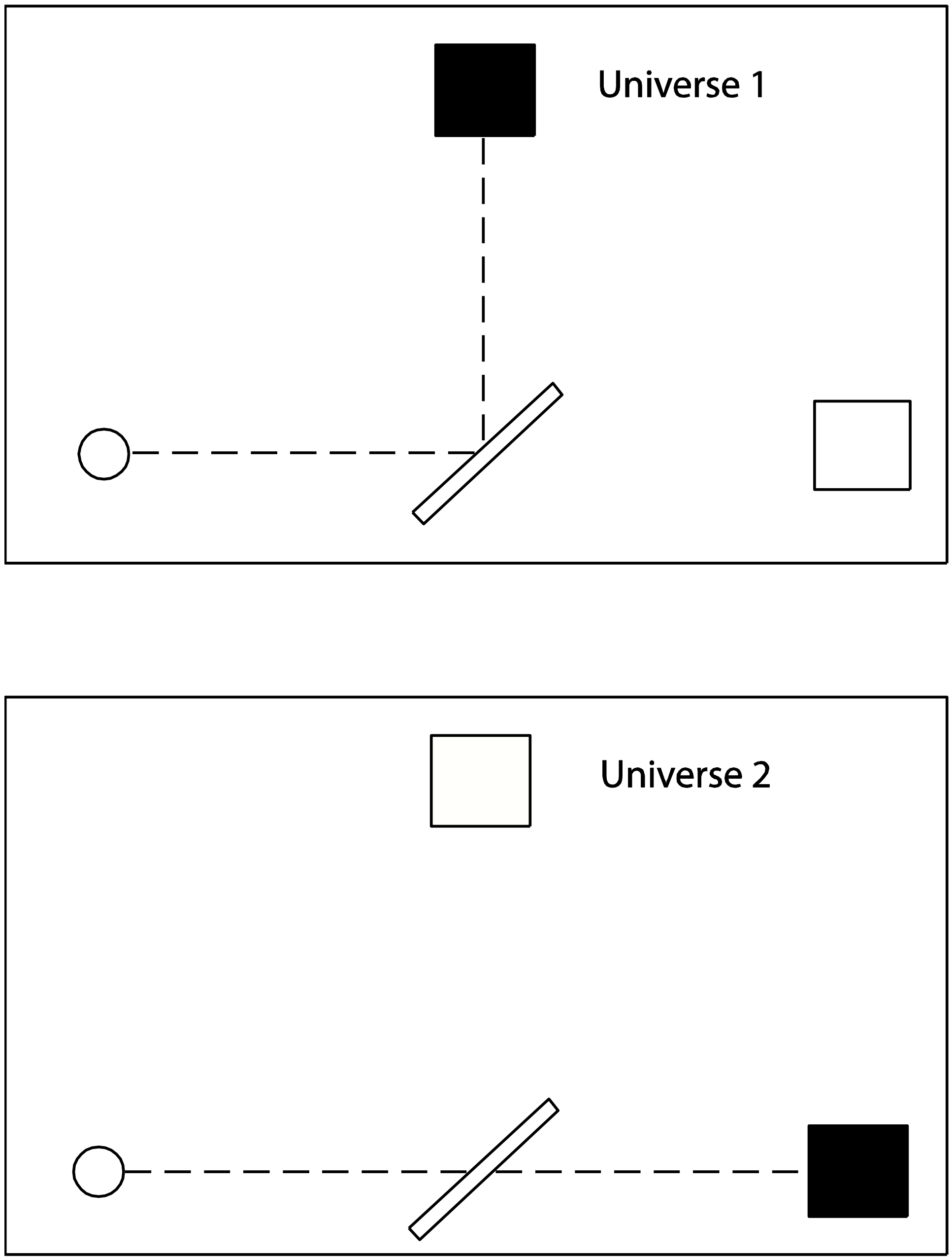

Fig. 6-4

Figure 6-4. The two versions of reality in the half-silvered mirror experiment. A solid detector symbol represents a “yes, detection” state of the detector and an open detector symbol, a “no detection” detector. The two rectangular boxes enclosing the two results indicate that the two processes are simultaneously occurring in *separate universes*.

Versions of the observer.

There is one more important point. Not only are there versions of the objects, there are also versions of the observer. Suppose you are the observer. Then the state of the two detectors plus you, the observer, at the end of the experiment is

$$|\text{state of the two detectors plus 'you'}\rangle =$$

$$\begin{array}{c} |\text{H detector reads yes}\rangle|\text{V detector reads no}\rangle\ |\text{version 1 of 'you' sees yes,no}\rangle \\ \oplus \\ |\text{H detector reads no}\rangle\ |\text{V detector reads yes}\rangle\ |\text{version 2 of 'you' sees no,yes}\rangle \end{array} \quad (3)$$

There is, in the mathematics of quantum mechanics, no single version of you, no 'objective' you; instead there are (in many circumstances) **several versions of you**!

Evaluation.

The splitting of the wave function into different versions of reality in the linear mathematics of quantum mechanics is, beyond doubt, absolutely correct. The equations and figures used to illustrate them here are also, beyond doubt, correct. This splitting is at the heart of the Schrödinger's cat paradox, proposed by the founder of quantum mechanics in 1935, where its primary feature—that the wave function in basic quantum mechanics often splits into two or more versions of reality—has never been challenged.

The question is what to do about it. The most common proposal is that the wave function (and thus reality) *collapses* to just one version (where collapse is *not* included in the basic mathematics of quantum mechanics). But as we will discuss in Part III, there is no evidence for collapse. In addition, it is not quite so imperative to do something about this splitting as it might seem; for as we will show in Part II, quantum mechanics prohibits the *perception* of more than one version of reality.