

Chapter 2

The Measurement Problem Is Not a Detail

Leave a detector running in an empty laboratory overnight. It will still register arrivals. By morning, it may have stored a result, copied it and started another experiment. The night shift has managed perfectly well without us. Whatever makes a result happen is already at work before anyone comes in to read it.

A thermometer gives a simple example. Its liquid expands as it warms, whether or not we look at the scale. Reading it tells us about a change that has already occurred. Quantum instruments make the explanation more difficult, but I want to keep the same question in view. What did the instrument do before we read it?

Why the calculation still contains two possible readings

Imagine a detector with two lights, left and right. First send in something that should light up left, then something that should light up right. We are checking what the lights mean. Physicists call this calibration. I call it checking the instrument understands its job.

A quantum input combining both possibilities is called superposition. Like light waves strengthening or cancelling, the possibilities can work together. This differs from a coin hidden under a cup, its heads or tails answer already waiting. Interference lets us measure the difference.

The usual quantum equations link the left possibility to a left reading and the right possibility to a right reading. They include the detector too. So far, so sensible. But the answer still contains both pairings. We have followed the possibilities into the equipment without finding out why just one reading occurs. [7, 8]

The rule is manageable. Work out what happens to each contribution, then add the answers. Its mathematical name is linearity. You need not decode every symbol below. Both possibilities enter the calculation, and both are still there when we finish.

$$|\psi\rangle = \sum_i c_i |i\rangle \Rightarrow U|\psi\rangle = \sum_i c_i U|i\rangle$$

Here c_i gives each contribution its weight, and U is the rule for how it changes. The symbols make the point precise. Both contributions go through the rule. The rule does not pick a winner.

An ideal linear measuring interaction

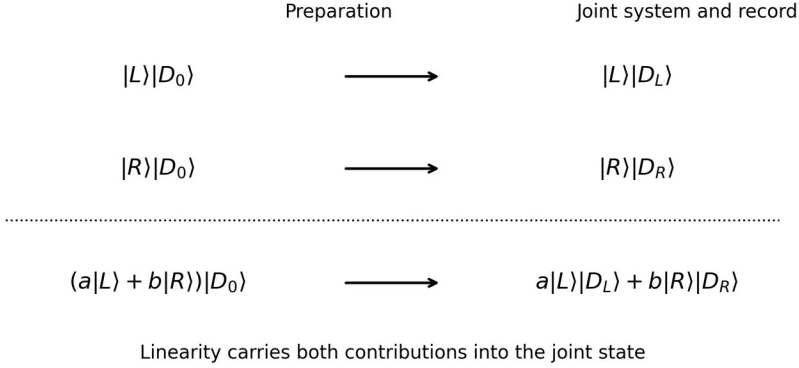


Figure 2.1 Read each arrow as what happens next. The first two rows test left and right separately. The bottom row combines them. Both possible readings remain in the calculation. The letters a and b say how much each contribution counts.

Adding more equipment does not, by itself, solve this. Include an amplifier and a memory in the calculation, and both become linked with the two possibilities. We have given the puzzle a bigger laboratory. We still have to explain why the instrument ends up with this particular reading.

Textbooks commonly add a rule for updating the description once a result occurs. This is called projection. We change the quantum state, the description used in our calculation, to match the result. The Born rule gives its probability. [3, 8] It works extremely well. I am still asking what turned the possible readings into the recorded one.

This is where I propose phase snap. The detector has a structure of its own. As it meets the incoming system, some possible endings may become impossible for the two together. Could that process explain the reading? PDT looks for the answer in the matter doing the detecting and recording.

How a tiny arrival leaves a lasting record

A tiny arrival must usually trigger something bigger before we can read it. It might release an electrical charge, which starts a larger response and leaves a signal in memory. Think of a doorbell. Your fingertip

presses the button, but the electrical supply powers the chime. The detector can likewise supply much of the energy needed for its record.

Follow the signal and we find a chain of physical changes. Charge affects an amplifier. The amplifier changes a memory. We later read the memory. There is no obvious point where the equipment stops obeying physics and begins to act simply because somebody wants to know the answer.

How we set up the detector matters. One arrangement lets the light paths interfere. Another records information that tells them apart. Those instruments do different things to the arriving system. Changing the equipment changes the encounter, not just the question in our notebook.

We can choose which experiment to build. We cannot then request our favourite result from the next arrival. The detector is not taking orders from a menu. Its response must follow the physical rules of the encounter.

Suppose a left reading opens one shutter and a right reading opens another. Light passes through the open shutter to the next experiment. The first result has now changed what the next instrument receives. This is what I mean by one history. What happened becomes part of the conditions for what happens next.

Erasing the original memory will not close a shutter that has already opened. Nor will it recall a signal sent elsewhere. A record can disappear from one place while its effects remain in others. This is how a small event can matter long after its original trace has gone.

How information escapes into the surroundings

The detector meets the wider world. Light scatters from it and heat leaves it. Information about its possible readings spreads out too. Our instrument can then lose the interference between those readings. This is decoherence. [9] Behind the awkward name is a useful idea. Information has spread beyond the part of the experiment we can follow.

Once that information has spread widely, gathering it all back and undoing the process becomes extraordinarily difficult. It is rather like trying to collect a rumour after it has gone round the village. Decoherence helps explain why the detector's possible records become stable and look familiar to us.

Here is the distinction I do not want us to lose. Making interference disappear is one job. Explaining one result is another. Follow Figure 2.2. In the middle, interference has faded, but both readings remain possible. Only the last panel shows a known left result. The pictures explain it without an exam in the numbers.

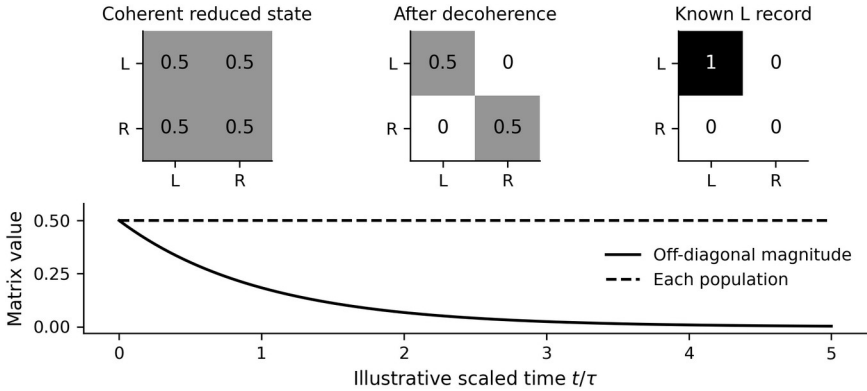


Figure 2.2 First, the alternatives can interfere. In the middle, that interference is no longer accessible, but both readings remain. On the right, a left result is known. Below, the falling curve tracks the fading interference. Fading is not itself a choice of one result.

Decoherence explains an important part of the story. By itself, it does not establish one result for the whole experiment. I want PDT to tackle the remaining question. Can the encounter make some endings physically impossible, rather than simply stop us seeing the interference between them?

By ruled out, I mean that the physical rules no longer permit that ending. Merely hiding its interference is not enough. PDT also assumes that, when exactly one possibility survives, it becomes the event. Both steps need explaining. Neither follows just from giving the process a name.

How one recorded result changes what happens next

Return to the shutters. Before the reading, either might open. Afterwards, light passes through the one that did open and reaches the next experiment. That experiment starts from an actual physical arrangement. Its input depends on the earlier result, not just on the probabilities that existed before it.

PDT proposes that, as particle and detector affect each other, some endings become impossible. The arrangement can no longer sustain them. Phase snap is my name for the proposed final step, when one possibility remains and happens. That result can then open the shutter or trigger the next instrument.

I am not imagining tiny finished readings waiting inside the detector like prizes in sealed envelopes. Before a snap, the alternatives may still interfere. Removing an alternative physically would therefore mean more than opening an envelope and discovering an answer that was there all along.

Many interactions need not cause a snap. We can change a phase, compare it later and sometimes undo the change. Several possibilities may stay open. PDT must allow that. A theory that snapped at every encounter would destroy the interference it is supposed to explain.

One result also leaves room for uncertainty later. Once a shutter opens, its light can enter another experiment with several possible outcomes. The first event supplies the starting conditions for that experiment. It does not have to settle the entire future.

We built this chain to make it easy to follow. Nature needs no laboratory to have events: an encounter in a gas cloud can affect later encounters too. Measurement illustrates a process I propose also occurs without a human record.

Different explanations for the same quantum results

Physicists tell this story differently. Everett keeps multiple branches. Collapse theories change the equations to produce definite results. Bohr emphasised preparation and measurement. [2, 4, 5] You need not choose a camp. Agreement on a calculation need not mean agreement on what it describes.

PDT starts with my commitment to one actual history. I can imagine the other shutter opening, but take the opening that occurred as a physical fact. The example illustrates this starting point; it does not prove it.

PDT must reproduce quantum mechanics' successful odds and satisfy Bell's test, which we meet in Chapter 4. [1] A pleasing shutter story must survive the difficult experiments.

The measurement problem takes us from alternatives that can interfere to one particular reading. PDT asks how that whole journey happens. That small click carries a surprisingly large question.

Back in the empty laboratory, the result may already have changed another experiment. Reading its record joins a story already under way.

Bridge to Chapter 3

We have followed a click far enough to see why it matters. Now phase deserves a proper introduction. Chapter 3, What Phase Is, takes us from the laboratory to a playground. Two swings will get us started. Then we will see how adding light can make an exit go dark. That is where the ordinary picture becomes rather surprising.

References and further reading

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