

Chapter 4

The Argument That Froze Physics

Put two physicists beside the same experiment and they may agree on every number, then disagree about what happened. Einstein and Bohr managed this on a grand scale. I find that rather reassuring. If the calculation leaves you wanting a clearer picture, you are in distinguished company. Their argument concerned the reality producing those successful answers.

Einstein wanted to know more than the odds of what we would find. Bohr insisted that how we set up the experiment mattered to what we could say. Neither concern is difficult to understand. Putting them together is where things become interesting.

Physics did not literally freeze. It was very busy discovering things. The title refers to the question that remained unsettled beneath that progress. How do the possibilities in a calculation become the particular events we record? We could build extraordinary technology while still disagreeing about the answer.

I return to the argument because both concerns matter to PDT. I want to understand a world that exists whether or not we look at it. But looking involves equipment that interacts with that world. An explanation must take the equipment seriously too.

Does a correct prediction tell the whole story

In 1935, Einstein, Podolsky and Rosen asked whether quantum theory gave a complete account. They considered systems that had interacted and then separated. A measurement of one could let us predict something about the other. They thought this exposed something missing in the description. [1] Later work challenged their assumptions. But the question is still worth asking. Have we described everything relevant, or only what we can predict?

I share that curiosity. The odds tell me what to expect when I look. I also want to know what is going on. An explanation could deepen our

understanding even without improving our next prediction. For me, that would be worth having.

A deeper explanation need not look like everyday machinery. Quantum relationships may be quite unlike those between familiar objects. We can ask for an explanation we can follow without demanding that nature behave like the things in our kitchen.

As an engineer, I want to look inside for a mechanism. Show me something troublesome and I ask what it is doing. But that instinct has limits. Nature has not promised a smaller machine inside every particle. The evidence must decide how far my familiar picture can take us.

How the measuring equipment shapes the experiment

Bohr asked us to include the whole experiment. What we can learn depends on how we prepare and measure the system. Different setups show different features. Some cannot be shown together in the same setup. He called this complementarity. [3] The name sounds grander than the starting point. One arrangement cannot answer every kind of question.

An instrument does something to the system it measures. Equipment that lets light paths interfere works differently from equipment that records which path was taken. Changing the equipment changes the encounter. We must understand that change before deciding what the result tells us.

That makes immediate sense to me. If relationships matter, the particle's relationship with its detector matters too. Imagine explaining a dent while leaving out what struck the surface. Removing the equipment may remove the encounter we are trying to understand.

I want to take that thought further. Could the changing phase relationships in the whole experiment help explain how its result forms? PDT asks whether the detector's part in the encounter helps explain why this particular event happens.

Prepare a detector one way and it can distinguish one feature. Prepare it differently and it makes another comparison. The result belongs to the encounter we actually arranged. We should not automatically assume that every answer was already complete inside the arriving object.

How possible endings could fall away until one remains

Was the result fixed in advance, or did chance choose it? Before answering, I want to examine the encounter. As it develops, the conditions change. PDT asks whether some ways it could proceed become impossible because the arrangement can no longer support them.

Figure 4.1 gives us four possible endings, A, B, C and D. Each has a burden score. Read that as how hard it is to keep that ending possible. In this invented example, an ending drops out when its score crosses the limit. Follow the lines and count the options left.

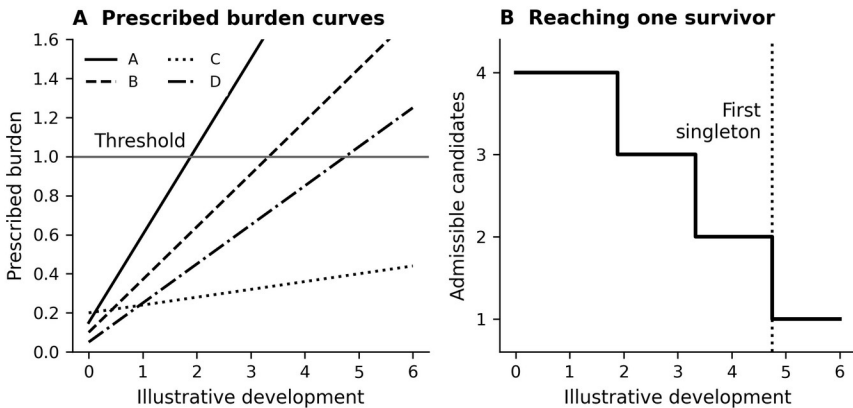


Figure 4.1 A crosses the limit first, then B and D. C remains below it. The steps on the right count the possibilities left. These invented curves illustrate a rule for narrowing the options. They are not measurements or a proved law of nature.

After A drops out, three options remain. After B, there are two. Only when D goes does C stand alone. PDT then assumes that this remaining possibility becomes the actual event. I call that the realisation principle. It names the step from what can still happen to what does happen.

For a real experiment, I must say what that burden is, how it grows and what sets the limit. I must also justify the final step. All four endings might remain, or all four might go. The drawing invites us to investigate. It cannot slip the answer in for us.

This suggests a possibility worth exploring. An incoming particle need not carry an independent answer to every measurement we might choose. The result could take shape through its encounter with the

apparatus. That would give us a physical process to investigate, even if we could not predict each result ourselves.

Preparation matters, and so does the later experiment. Preparing the system sets up relationships that affect what follows. The apparatus introduces new encounters. An explanation must follow both stages. We cannot simply give the whole job to either the arriving particle or the detector.

Would knowing every detail let us predict the result? That depends on the physical rules, which the drawing has not supplied. Even a process with a definite outcome may be too complicated for us to predict. The example shows an idea to investigate. It cannot decide the question by itself.

Why particles cannot simply carry local answer sheets

Bell found a way to test a tempting explanation. Suppose separated particles carry shared instructions from their past and respond only to conditions nearby. Suppose, too, that those instructions do not determine which tests the experimenters choose. Bell showed that their results could agree only up to a certain limit. Quantum theory predicts stronger patterns. [2] Those private local answer sheets cannot give the full quantum result.

Writing PDT on the cover does not get me past that test. My explanation has to account for those patterns too. Figure 4.2 gives their agreement a score. The quantum curve can go above the local limit. Yet this stronger connection still cannot be used to send an instant message. We have to explain both facts.

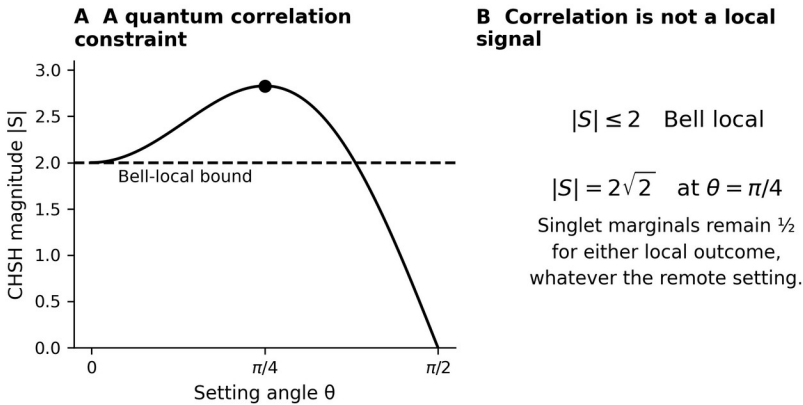


Figure 4.2 Think of CHSH as a score calculated from paired results at different settings. Local answer sheets cannot score above 2 under Bell's assumptions. The quantum prediction can reach about 2.83, or $2\sqrt{2}$. Yet neither observer can choose the other's result. The pattern emerges when they compare records.

Picture two experimenters comparing their lists. Together, the lists reveal a striking pattern. But neither person can choose the next entry on the other's list. An instant messaging service would need that control. A surprising pattern alone cannot deliver a chosen message.

Distance therefore does not always let us tell two separate stories. How the systems were prepared can matter to their later combined results. We can describe each instrument on its own, yet still miss information needed to predict how the two lists will compare.

Bell brings relationships into focus for me. What can we describe about one object alone, and what needs the wider picture? Two separate things need not each carry a complete instruction manual. Their connection may contain something we need to know.

Bell demands a hidden mechanism that produces the right pattern of results. Some familiar ideas cannot. Nature need not choose the explanation easiest for us to draw.

Explaining both a lasting record and a single result

Decoherence has brought progress since Einstein and Bohr: contact with surroundings helps explain stable, familiar records. [4] More of the experiment enters the explanation. Why it leaves one particular result remains the difficulty.

The world beneath quantum theory may resist pictures. I still want clear reasoning: which interaction matters, how does it act, and why does it produce the observed pattern?

A quantum state is a successful calculating description. What does it describe? PDT asks whether relationships explain what lets something exist, giving us a basis for explaining its state.

Perhaps those relationships can continue only under certain conditions. An encounter changes them, closing possible endings. PDT adds a starting rule for the final step to one event. The state would still serve calculation, alongside an account of the event.

This gives me a direction, not a settled argument: combine a real physical world with the importance of the whole experiment, then explain its one definite result.

Bridge to Chapter 5

We have spent four chapters asking what happens when objects meet. Now I want to be slightly more troublesome. Why start with objects at all? Chapter 5, *The Misplaced Primitive*, asks whether relationships could explain why the objects exist. We begin with a house and a heap of the same bricks. Only one is much use when it rains. The difference may help us choose a better starting point.

References and further reading

- [1] Einstein, A., Podolsky, B., and Rosen, N. (1935). Can Quantum-Mechanical Description of Physical Reality Be Considered Complete? *Physical Review*, 47, 777–780. <https://doi.org/10.1103/PhysRev.47.777>
- [2] Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika*, 1, 195–200. <https://doi.org/10.1103/PhysicsPhysiqueFizika.1.195>
- [3] Bohr, N. (1935). Can Quantum-Mechanical Description of Physical Reality be Considered Complete? *Physical Review*, 48, 696–702. <https://doi.org/10.1103/PhysRev.48.696>
- [4] Zurek, W. H. (2003). Decoherence, einselection, and the quantum origins of the classical. *Reviews of Modern Physics*, 75, 715–775. <https://doi.org/10.1103/RevModPhys.75.715>