

Chapter 3

What Phase Is

Watch two children on neighbouring swings. Both may take the same time to swing out and back. One goes forwards while the other comes back. Ask them to move together and you will quickly discover that having the same speed is not the whole story. We also need to know where each has reached in the swing.

Phase is where something has reached in a repeating cycle. On the swing, are you at the front, the back or between them? We usually compare that position with another cycle. Turning pointers and repeating electrical signals can be compared in the same way.

Phase matters when cycles meet. Two waves can have the same height and repeat at the same rate, yet give different results together. It depends on whether, for example, their peaks arrive together or a peak meets a trough.

This is what caught my attention. Keep the waves' sizes and rates the same, change how they line up, and the result changes. The relationship does real work. Before asking it to help explain matter, I want us comfortable with this simpler, well tested effect.

Phase tells us where a cycle has reached

Picture two pointers on a clock face. Measure both from twelve o'clock, or choose another starting mark. The gap between them stays the same. Relative phase is simply this gap around the cycle. Moving the numbers on the clock will not move the hands.

ϕ_2 names the second angle and ϕ_1 the first. Subtract the first from the second to find their gap. That phase difference is written $\Delta\Phi$. The symbols simply record the comparison.

$$\Delta\Phi = \phi_2 - \phi_1$$

A full turn brings a pointer back to its starting place. Mathematicians write that turn as 2π radians. Modulo 2π means ignoring complete turns

and comparing the final positions. It is the clock face view. We know where the hands are, but not how many laps they have done.

Figure 3.1 starts with two pointers a quarter turn apart. The waves beside them track part of their movement as they turn. Both waves have the same height and repeat at the same rate. One is shifted along because one pointer starts ahead of the other.

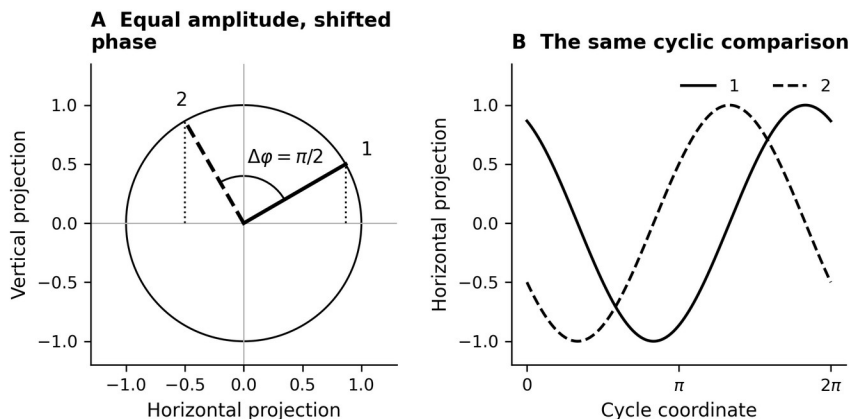


Figure 3.1 The pointers are a quarter turn apart. Their movement makes equal waves with a steady gap between the peaks. Turn both pointers by the same amount and the gap stays the same.

Height alone will not tell us the phase. Two swings can be equally high while moving in opposite directions. One is going out and the other coming back. We need to know which part of the cycle each has reached. Our turning pointers show that.

Three familiar questions help. How often does it repeat? That is frequency. How big is it? That is amplitude. Where has it reached? That is phase. Turn up the radio and the singer gets louder without changing the note or jumping to the chorus. Size, rate and position in a cycle tell us different things.

Quantum theory uses phase to calculate how contributions combine. Our pointers help us picture the comparison. There is no need to imagine an electron wearing a tiny wristwatch. What matters is how the phase difference changes results we can measure.

How two light waves can make darkness

Bring two parts of a light wave together and their phase difference helps decide what we see. They may strengthen one another at an exit or, if equally strong, cancel there. We have not made the energy disappear. The interference changes where the light goes in the experiment. [1]

The dark exit surprises us. Either contribution alone can light it; both together, with the right phase difference, make it dark. Remove one and it lights again. More input can mean less output there. Adding brightnesses misses how the waves meet.

Wave sizes still matter. A small wave cannot completely cancel a bigger one. Phase tells us how they meet. Amplitude tells us how much each brings. I am giving phase an important job, but not every job in the laboratory.

The swings can move in opposite directions while keeping a steady gap in their cycles. Light waves can likewise stay half a cycle apart and interfere. We call that coherence. Everything need not march in step. A steady difference can work perfectly well. The dependable relationship matters.

Imagine taking several photographs of a striped pattern, nudging it sideways between each photograph. Every photo has clear stripes. Lay the pictures over one another without lining them up and the stripes may blur away. The blurred result does not mean the original pictures had no stripes.

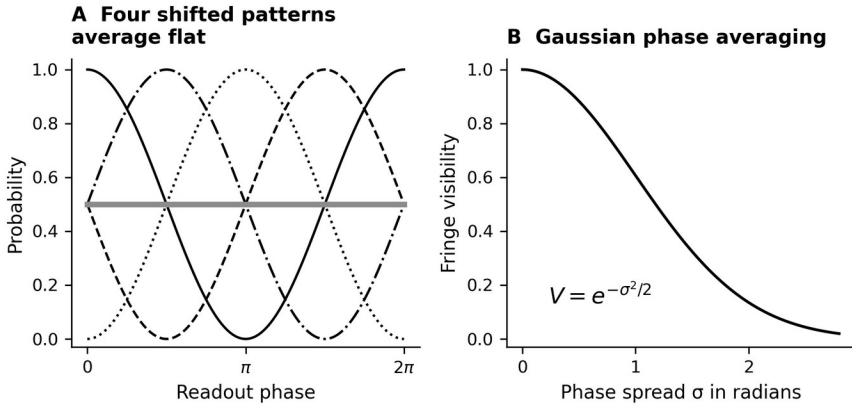


Figure 3.2 Shifted patterns can average to a flat line. The right curve shows how uncontrolled phase changes can make stripes harder to see. A steady shift moves the stripes. A varying shift can wash them out. Neither, by itself, explains one particular measurement result.

Missing stripes can have different causes. Perhaps we mixed together patterns that had shifted by different amounts. Or perhaps the surroundings took away the interference our instrument could reveal. That is the decoherence we met in Chapter 2. [2] A flat result alone does not tell us which happened, or why one particular quantum result occurred.

Why the gap between cycles matters

Which pointer owns the gap between them? It would be an awkward argument to referee. The gap belongs to the comparison. Relative phase works in the same way. Describe each contribution but leave out their relationship, and you may lose what you need to predict the result.

The relationship is not an extra little object sitting between them. It describes something they can do together. In the light experiment, its effect is as concrete as an output becoming bright or dark.

Nor does it depend on somebody thinking about the comparison. The instrument responds whether we watch it or leave it running alone. We choose the labels, but the physical result is not chosen by our attention.

This is where I start asking the more awkward question. Could the objects themselves depend on phase relationships holding together? Usually we begin with objects, then describe what they do together. I

want to try turning that around. Perhaps those relationships help explain why there is a lasting object in the first place.

Interference does not prove that proposal. It shows us a case where relationships matter to what happens. I am exploring whether a wider organisation of such relationships could account for matter. Chapter 5 will look more closely at what it means for an object to remain the same thing.

An object could contain many such relationships. Some might change while others last. Nudge a chair and you expect it to remain a chair. Losing an interference effect inside it need not destroy the whole structure. A change in one pattern is different from losing what holds the object together.

This leaves room for different kinds of matter. The same kind of phase relationship could be organised in different ways, producing different responses. A common starting idea need not make everything behave alike.

When phase differences put a structure under strain

Differential means we are looking at differences. A large phase difference is not automatically bad news. How are the parts connected? Moving half a cycle apart might suit one pair and be hard for another to maintain. The gap tells only part of the story.

Think of pushing a swing. A push at the right moment helps its motion. The same push at the wrong moment can work against it. Timing matters because of the way the push meets the swing. Likewise, linked cycles may favour moving together or in opposition. The link determines what works.

Change the link between the cycles and their behaviour may change even if they start at the same angles as before. Or keep the link unchanged and alter their starting separation. Both the phase difference and the way the cycles affect one another matter to the response.

Phase strain is my name for the demands on the relationships holding something together. Can they adjust and keep going? The angle helps describe the situation, but it is not a damage meter. Half a turn apart does not mean halfway to breaking.

An arrangement may adjust to a disturbance and settle again. Its important relationships can survive despite the change. PDT needs to explain that ordinary resilience as well as sudden events. Most of the objects around us withstand many small disturbances without becoming something else.

A limit makes one continuation impossible. In my phase snap proposal, possibilities fall away until one remains and happens. That final step remains an assumption: knowing the phase does not guarantee one surviving ending.

How a pattern stays steady while its parts move

Why circles? A cycle returns to an equivalent phase after one turn. A straight line that keeps rising would lose that feature. The circle reminds us what repeats.

Two swings can keep the same phase difference while moving. Their steady relationship illustrates the active stability I have in mind for matter.

We should now leave the swings in the playground. Quantum phase need not be something swinging inside a particle. It enters calculations and affects results; PDT proposes a deeper role. Our picture helps us ask the question without pretending we have filmed the answer.

Returning to the same phase need not restore everything. A counter may remember several completed turns. Chapter 6 separates final position from the journey.

We now have a picture of phase and an experiment showing its effects. Does that tell us what the world is doing? Two great physicists disagreed.

Bridge to Chapter 4

Phase should now feel familiar enough to follow the next argument. Einstein and Bohr agreed on much of the calculation, but not on what it meant. Chapter 4, *The Argument That Froze Physics*, asks why that disagreement still matters. I want to learn from both sides while keeping our question in view. What turns the possibilities into an event?

References and further reading

- [1] Feynman, R. P., Leighton, R. B., and Sands, M. (1965). *The Feynman Lectures on Physics*, Volume III, Chapter 1, Quantum Behavior. Addison-Wesley. https://www.feynmanlectures.caltech.edu/III_01.html
- [2] 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>
- [3] Bell, J. S. (1964). On the Einstein Podolsky Rosen paradox. *Physics Physique Fizika*, 1, 195–200. <https://doi.org/10.1103/PhysicsPhysiqueFizika.1.195>