

Chapter 3

What Phase Is

Watch two children on neighbouring swings. Both may take the same time to swing out and back. Yet they need not move together. One can be going forwards while the other goes backwards. To describe their relationship, we need to know where each is in its swing, as well as how quickly it repeats.

That position within a repeating cycle is called phase. We compare it with a reference, such as the other swing. The same idea applies to a turning pointer or a repeating electrical signal. Each passes through a sequence of positions and comes round again.

Phase matters because cycles can affect one another. Two contributions can have the same size and repeat at the same rate, yet produce different results when combined. The difference comes from where each has reached in its cycle when they meet.

This is what interests me about phase. A relationship can change the result even when the separate sizes and rates stay the same. Before asking whether matter itself might depend on such relationships, we need to understand this simpler, well established effect.

Where we are in a cycle

Picture two pointers on a clock face. We can describe their positions as angles measured from twelve o'clock, or choose another starting point. Either choice leaves the gap between the pointers unchanged. Their relative phase is that gap, expressed as a part of a complete turn.

We use φ_1 and φ_2 for the two angles. The equation below subtracts the first from the second to give their phase difference, $\Delta\Phi$.

$$\Delta\Phi = \varphi_2 - \varphi_1$$

A full turn brings a pointer back to the same position. Mathematicians express a full turn as 2π radians. Saying that phase is measured modulo 2π simply means that complete turns are set aside when comparing the final positions. A separate counter would be needed to remember how many turns occurred.

Figure 3.1 draws two pointers a quarter turn apart. It also shows the waves made by plotting one component of each pointer's movement as it turns. The waves repeat at the same rate and have the same height. One is shifted along relative to the other because the pointers start at different angles.

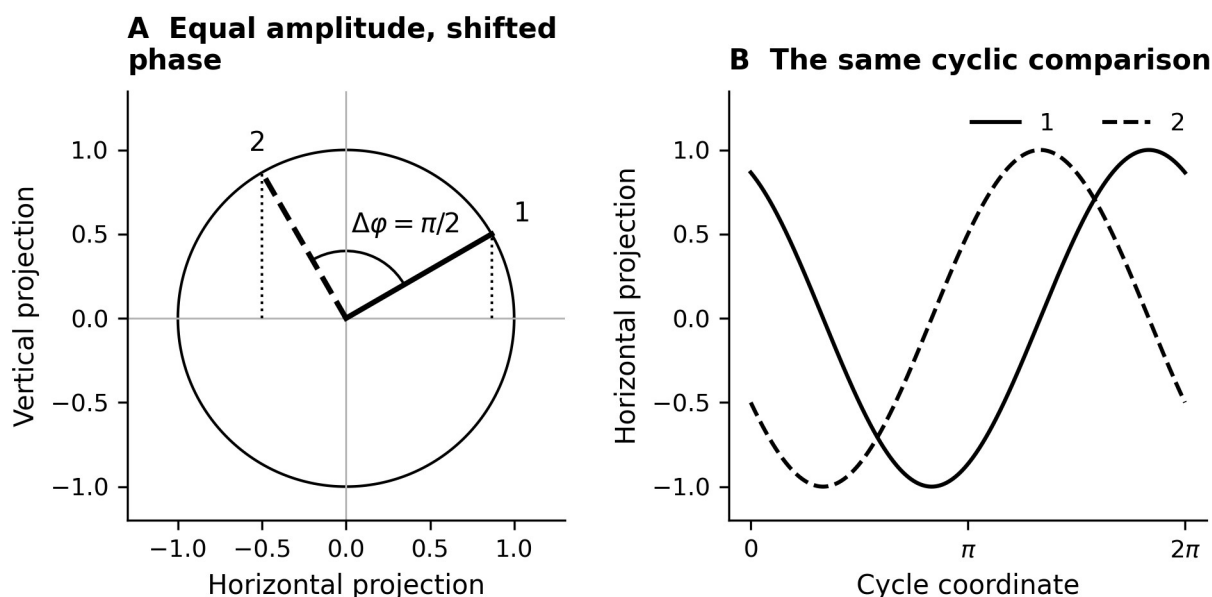


Figure 3.1 Two equal pointers are a quarter turn apart. Plotting their changing positions along one axis gives two waves with the same height and a steady offset. Turning both pointers by the same amount leaves the gap between them unchanged.

The wave's height at one moment is not the phase. Two swings can reach the same height while moving in opposite directions. We need to know where each is in the whole cycle, including which way it is moving. That is what the turning pointers help us picture.

Three useful words describe different features. Frequency tells us how often a cycle repeats. Amplitude tells us its size. Phase tells us where it has reached compared with a reference. A louder sound has a greater amplitude, but need not have a higher pitch. Two sounds with the same pitch need not arrive at the same phase.

Quantum theory uses phase when calculating how contributions combine. The pointers are an aid to understanding that comparison. They do not mean that a tiny clock hand is turning inside an electron. We judge the quantum phase by how it affects experimental results.

How phase changes what we see

When two light contributions can interfere, their phase difference affects the result. They can reinforce each other at an output, or cancel there if their sizes match. Cancellation does not make energy disappear from the whole experiment. Interference changes where the light appears. [1]

The dark output is particularly revealing. Each contribution, sent alone, could produce light there. Send both together with the right phase difference and the output becomes dark. Remove one and it can light up again. To explain that, we must include how the two contributions combine, not just add their separate brightnesses.

Their sizes still matter. A weak contribution cannot completely cancel a stronger one. Phase determines how they combine, while amplitude determines how much each contributes. Giving phase an important role does not remove the need to know these other properties.

Return to the swings. They can keep moving in opposite directions with a perfectly steady relationship. In the same way, light contributions half a cycle apart can remain coherent. Here,

coherence means that their phase relationship allows interference. It does not mean that their phases must match. A steady difference can give a steady pattern of bright and dark regions.

Now imagine taking several photographs of an interference pattern, shifting it slightly between photographs. Each image has clear stripes. Add the images together without aligning them and the stripes can blur away. A flat average does not tell us that every individual pattern was flat.

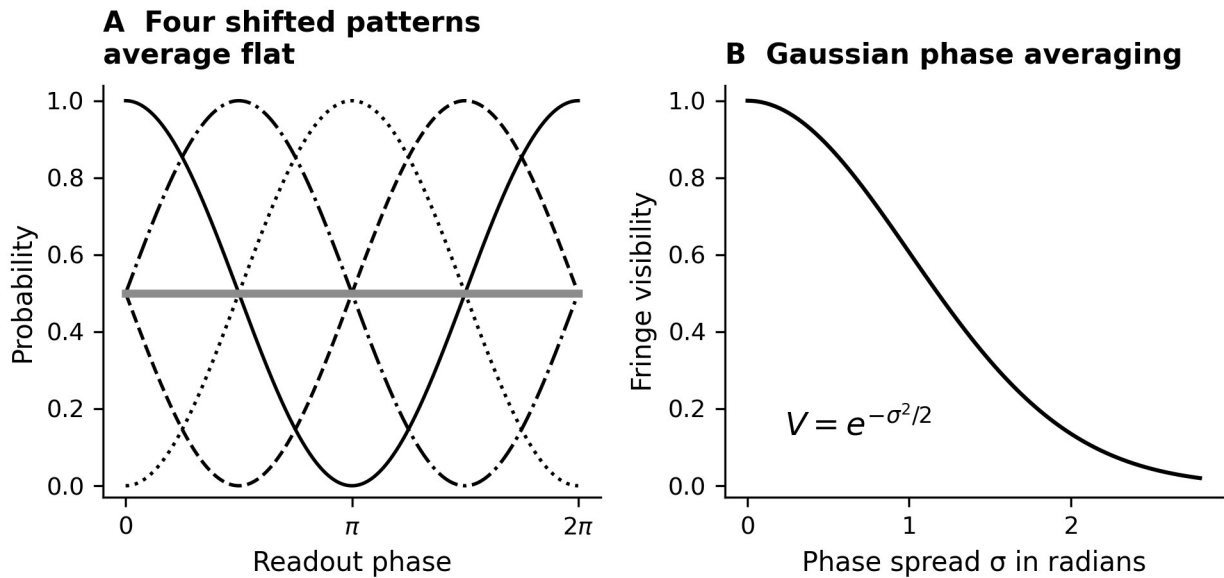


Figure 3.2 Four shifted patterns average to a flat line. The right panel gives an example of how random phase variation reduces the contrast between bright and dark stripes. A steady offset moves the stripes. Uncontrolled variation can wash them out. Neither change, by itself, selects one measurement result.

Missing stripes can therefore have different causes. We may have mixed together patterns with different shifts. Or interactions with the surroundings may have removed the interference available to our instrument, through decoherence. [2] Looking at a flat result does not tell us which happened. It also does not explain why one particular quantum outcome occurred.

I will use coherence with this distinction in mind. Matching phases, a steady difference and an uncontrolled changing difference are not the same thing. The useful question is what phase relationship remains, and whether the experiment can still reveal it through interference.

Why the relationship matters

Which pointer owns the gap between them? Neither does on its own. We can label each position, but the gap comes from comparing the two. Relative phase works this way. If we describe each contribution and forget their relationship, we can lose information needed to predict what they do together.

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.

PDT takes a further step. I ask whether the things we call objects might themselves depend on phase relationships holding together. Usually we start with objects and describe their relationships afterwards. I want to investigate whether those relationships help explain why there are lasting objects 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 organised structure need not make all its parts move alike. The two swings can maintain a steady opposition. In PDT, differences between phases may be part of what makes an arrangement stable. Matching every phase would be one possible arrangement, rather than a goal all matter must approach.

A complex object can also contain many different phase comparisons. Some may change while others remain. Touching a chair does not have to destroy its identity simply because the touch affects an interference effect somewhere within it. Whether an object survives and whether a particular experiment shows interference are different questions.

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 a difference puts an arrangement under strain

Differential means that we are concerned with differences. But a large phase difference does not automatically mean that something is under strain. We also need to know how the parts interact. The same difference may be easy to maintain in one arrangement and difficult in another.

Two linked cycles might naturally settle into step, while another pair settles into opposition. Moving either pair away from its preferred relationship may require work. The interaction determines what it prefers and how strongly it responds. The angle alone cannot tell us that.

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.

This is what I mean by phase strain. An interaction puts demands on the relationships that sustain an arrangement. The phase angle helps describe them, but is not a damage meter. Two cycles half a turn apart are not automatically halfway towards breaking down.

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 is reached when an interaction makes a particular way forward impossible. In the phase snap proposal, possibilities are ruled out until one remains and becomes actual. The final step still needs the additional principle stated earlier. Phase helps specify the relationships involved, but does not prove that step on its own.

The useful connection is that survival and change can be studied together. We ask how the same relationships respond to different disturbances. A gentle encounter may let an arrangement continue. A different encounter may force a lasting change.

Stability while things move

Why use a circle to describe these relationships? Because a cycle returns. Unlike a number increasing along an endless straight line, phase comes back to an equivalent position after a full turn. Interference already depends on this repeating comparison.

That offers a way for something active to stay organised. Two swings need not stop to keep the same phase difference. The relationship can remain steady while each swing keeps moving. This is the kind of stability I have in mind when thinking about matter.

The comparison has limits. Quantum phase is not necessarily the position of something we could film moving back and forth. It is part of the mathematics, and its relative value affects measurable results. PDT proposes a deeper physical role for it. It does not place an unseen mechanical swing inside each particle.

Coming back to the same phase also need not put everything back as it was. A wheel may have completed several turns, and a counter may remember them. Chapter 6 will separate the final position from the journey that led to it.

For now, keep one point in view. Two contributions can produce a different result when their phase relationship changes, even if their separate sizes and rates do not. PDT asks whether lasting matter might also depend on an organisation of these relationships.

The swings helped us picture phase. The light experiment showed why it matters physically. We are now ready to ask how much such a successful description tells us about the world behind it. That question takes us to Einstein and Bohr.

Bridge to Chapter 4

Einstein and Bohr understood phase. They disagreed about what quantum theory allowed us to say about reality. The next chapter looks at that disagreement and asks where PDT's proposed account of events might fit. Knowing what phase means helps us frame the question. It does not settle their argument.

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>