

Chapter 6

What Φ Is and Is Not

A clock face tells you the hour but is hopeless at telling you the day. Three o'clock comes round again, whether you have spent the time working or looking for your glasses. Phase has the same limitation. It tells us where we are in a cycle. It does not tell us the whole journey.

Φ , pronounced phi, stands for our phase labels. Do not let its unfamiliar shape put you off. Different journeys can end at the same phase, just as a clock shows three on different days. To describe what happened, we need more than the final reading.

$$\Phi: X \rightarrow S^1$$

This labels members of X around the circle S^1 . It is a useful special case. The full foundations assign phase to comparisons, including journeys whose effects endpoint labels miss. Neither description has yet supplied physical space.

Before connecting phase with energy, let us keep three questions separate. Where are we in a cycle? How many times have we gone round? What changed along the way? One number need not answer all three. A clock face, a counter and a record do different jobs.

That last question matters to me. The past affects the next encounter when something from it remains. A signal is saved or a structure changes. Yesterday need not reach out mysteriously. We must find what it left behind and what that does now.

Which two phases are we actually comparing

A quarter turn is easy to picture. But a quarter turn between what? Two light contributions meeting now? A cycle and a nearby clock? Two readings taken an hour apart? The number is the same, while the questions are different.

An interferometer brings waves together so their phase difference changes the result. [1] For readings taken at different times, we must also keep the earlier information. Either way, something physical

makes the comparison possible. Writing the subtraction is easy. Building the instrument that gives it meaning is another matter.

Δ is the Greek letter delta. Here it means a difference, so $\Delta\Phi$ means a phase difference. That saves space on the page. We still have to say which phases we mean and how comparing them affects the experiment.

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

Subtract the first angle from the second to find their gap. Complete turns are left out unless we have counted them separately. Modulo 2π means keeping just the position around the circle. It is the clock face view, without a count of earlier turns.

This avoids a simple muddle. Comparing a phase with a laboratory clock is not automatically the same as comparing phases that help hold an object together. We must say which pair we mean. A correct subtraction can still answer the wrong question.

Phase strain means the demands on the proposed structure. They may depend on its connections, surroundings and changes left by earlier encounters. A phase angle gives part of the picture. It cannot keep the whole set of accounts alone.

Why the final reading can hide the journey

Imagine a wheel disappearing behind a screen and reappearing in exactly the same position. Did it stand still or complete ten turns? The wheel is giving nothing away. To tell the journeys apart, we need another piece of information.

A turn counter could keep that information. So could someone watching continuously. Figure 6.1 compares a reading that starts again every turn with one that keeps counting. One tells us where the wheel is. The other remembers how far it has turned.

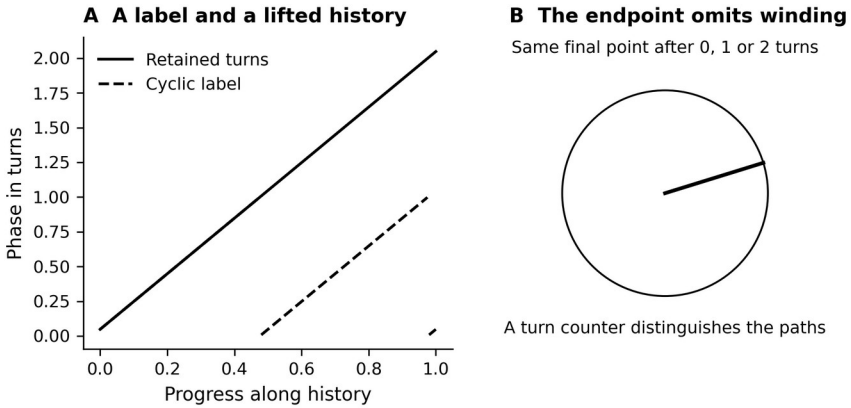


Figure 6.1 The dashed line starts again after each turn. The solid line keeps counting. The same final phase can follow different journeys. For the journey to affect what happens next, some part of the physical system must retain it.

If a burden builds up, I must show what carries it. The particle cannot consult my notebook. Something physical must retain a count or a lasting change. Otherwise I have put the history in the description without explaining how it affects anything.

Bend a paperclip back and forth, then return it to roughly its old shape. It may look much as it did while being closer to breaking. The earlier bending matters because it changed the metal. The past acts through what remains in the present.

That is what memory means here. An encounter leaves a change that survives and affects a later one. It need not involve a mind remembering anything. A paperclip has a history without having an opinion about it. A phase reading alone may miss that history's surviving effects.

Ordinary physics describes memory too. Saying the past mattered does not make PDT an explanation. I must identify what kept the information, how it survived and what it changed. The paperclip shows the sort of clear answer to look for.

Returning to a position therefore need not reset everything. The wheel returns, but its counter advances. Reset the counter too, and perhaps it already sent a reading elsewhere. Whether we have erased a record depends on how far we follow its effects.

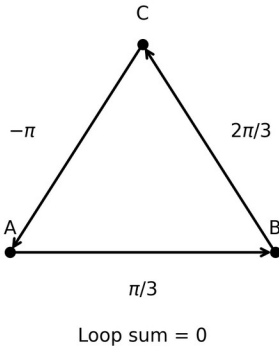
How the route can change a phase comparison

Suppose three clocks sit in different places. How shall we compare them? We could send signals between them or carry one clock to another. Those journeys may affect the comparison. The numbers on the faces do not tell us everything about how we brought them together.

If we only subtract fixed phase labels around a triangle, the differences cancel. We go from A to B, B to C and C back to A. Every label is added once and subtracted once. We end where we started, allowing for complete turns.

Now carry a reference around that route. The journey itself may change it. On returning, we may find a difference that the original labels could not tell us about. Figure 6.2 separates these two cases. Look for the extra change on the right.

A Differences of vertex labels



B Added transport information

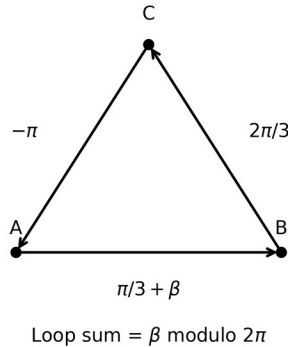


Figure 6.2 On the left, the three label differences cancel around the triangle. On the right, a journey adds an extra change, β . It remains when we finish the loop. A rule for what happens along the route supplies information that the endpoint labels alone lack.

Mathematicians call a rule for comparisons along a route a connection. Keep the idea without worrying about the name. Labels describe the ends. Another rule tells us what happens between them. If the journey changes the comparison, endpoint labels cannot do the job alone.

For me, making the comparison belongs inside the physical story. A signal has to travel, or a reference has to be carried. Something on the way may affect it. Drawing a tidy line between two points is useful on paper. Nature still has to make the journey.

Space and gravity will need that route information. The foundations allow phase on comparisons along a journey. Endpoint labels are useful examples, but cannot describe every route. Chapter 8 makes the rule explicit.

Why a clock needs to count its cycles

Count ticks while a kettle boils to compare two changes and measure the wait. PDT seeks time through these comparisons and event order. Cycles provide the beat; records distinguish this event from the one before.

Clocks are physical things too. Their journeys and the way we compare them matter, including the effects described by relativity. I am not imagining a master clock outside the universe, issuing instructions. Each clock keeps time through what happens within it.

On this view, we measure a duration by comparing changes. The duration is real and can be measured precisely. Calling time a relationship does not make a late train arrive any sooner. It tells us what we are comparing and what PDT hopes to explain.

A clock must distinguish successive turns and connect readings to events. Phase gives position within a cycle; a count tracks its returns. The clock combines them.

A stopped clock may be right twice a day. Its display keeps a record, but the hands no longer move with surrounding events. It has lost the process that measured passing time.

When a jump is only in the labels

Phase labels can jump when they reset, like seconds rolling from 59 to 00. Nothing physical need jump. A phase snap must change what can happen, not merely restart our numbering.

In Hahn's spin echo experiment, spins—tiny magnetic features of particles—got out of step and the signal faded. Timed control brought it back. [2] Like performers rejoining the beat, some information had survived. The loss was not total or permanent.

PDT must allow recovery. A snap claims more: alternatives become physically impossible and the remaining possibility becomes the event. Losing sight of a signal cannot establish that.

Φ describes a position in a repeating cycle. It is no magic explanation of energy, encounters and memory, nor is it phase space, the different mathematical picture of positions and motion together.

Bridge to Chapter 7

Our clock has done enough work. Let us give the idea a more physical test. In Chapter 7, The Phase Differential Equation, we take hold of a loaded shopping trolley and ask why it resists a change in motion. If phase relationships help matter hold together, could they also explain that resistance? The next equation has to connect with something we can feel in a push.

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] Hahn, E. L. (1950). Spin Echoes. Physical Review, 80, 580–594. <https://doi.org/10.1103/PhysRev.80.580>