On the Nature of Time
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Despite our ever-deepening understanding of the physical universe, we have yet to reach a consensus on the nature of time: does it flow like a river, carrying us along, or does it flow past us? What is the meaning of "now", the ever-shifting boundary between the future and the past? Did time have a beginning and will it have an end? Can it be stretched and squeezed, or even reversed? Some even believe that time is an illusion - a trick of our senses. According to the most fundamental ideas in physics, time might even be an emerging concept from something more fundamental, like quantum entanglement.

This lecture is divided into five ‘chapters’ summarised below.

Chapter 1: The Problems of Time

Disagreements over the nature of time go back at least two and a half millennia. Two Greek philosophers, Parmenides of Elea and Heraclitus of Ephesus, exemplify a debate that has been raging ever since: is the flow of time real with everything constantly in flux, or is all change just a trick of our senses? The problems of time are divided here into two categories:

The philosophical problems of time:

- Why do we perceive time to ‘flow’ when this concept is entirely absent in our physical theories and equations?
- Why is the past so different from the future, each sitting on either side of ‘now’, when there is nothing special about the present moment in physics?

The physical problems of time:

- How do we reconcile coordinate time in the dynamical equations of physics with time as a dimension in relativistic spacetime?
- How do we reconcile our time symmetric laws of physics with the irreversibility of thermodynamics and other processes that give us an arrow of time?

Chapter 2: Manifest Time

This term refers to the time we perceive, or ‘psychological’ time. It is manifest time that gives us the strong impression of a ‘flow’, of time passing continuously, turning our future into our past. But nowhere in physics do we see any evidence of flowing time. Another strong sense we have is of a present moment, a ‘now’ that divides our future from the past. But again, there is nothing in our understanding of the physical universe that picks out an objective, special moment we call the present. What then *is* the difference between the past and the future beyond our subjective experience.

Chapter 3: Physical Time

Far more interesting are the problems of physical time. They appear because there is no single way of thinking about what time actually is. In all the dynamical equations of physics, such as Newton's equations of motion or Schrödinger's equation of quantum mechanics, time appears as a simple parameter, a number to plug into the equation to find out the state of a system at that moment. This 'coordinate' time is in stark contrast to the way time appears in Einstein's theories of relativity, which is as a dimension, a direction in 4D spacetime along which all times coexist just as all points in space exist. Then, in thermodynamics we find a third definition of time, not a number or a dimension, but an arrow pointing in the direction of increasing entropy.

Chapter 4: The Arrow of Time

Known as Loschmidt's paradox, a problem that has puzzled physicists and philosophers since the mid-19th century is how time seems irreversible to us – and is certainly what is predicted by the second law of thermodynamics – and yet all the fundamental dynamical equations of physics are time symmetric: they work equally well both forwards and backwards in time. In this lecture a solution to this problem will be provided by arguing that we have had it the wrong way round all along. It is not a question of how irreversibility emerges from an underlying time symmetry, but rather that the irreversibility of time's arrow is baked into reality from the start and the so-called time reversal invariance is an idealisation that only applies to unrealistic isolated systems.

Chapter 5: The Beginning and End of Time

In this final chapter we will look at what modern physics has to say about whether it began at the big bang or has existed forever, while at the other extreme, will time ever come to an end? And how is this tied to the fate of the universe?

Finally, some conclusions will be drawn to see how far we have come in addressing the various problems of time.

References and Further Reading

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