ISAAC'S TIME

Newton, Leibniz, and the arrow of time

> Nature, and Nature's Laws lay hid in Night. God said, Let Newton be! and all was Light.
>
> – Alexander Pope

"Join me in singing the praises of Newton, who opens the treasure chest of hidden truth," the English astronomer Edmond Halley said in his preface to his colleague's masterwork, *Philosophiae Naturalis Principia Mathematica* (*Mathematical Principles of Natural Philosophy*). "No closer to the gods," Halley gushed, "can any mortal rise." It was well-deserved praise: with the *Principia*, Isaac Newton (1642-1727) laid out the mathematical framework that would serve as the foundation of physics for more than two hundred years.*

But the *Principia* almost never saw the light of day. Described in his youth as a "sober, silent, thinking lad," Newton lived an intensely private life. His greatest insights were scribbled by candlelight in his rooms at Cambridge; when an outbreak of the plague forced the university to shut down, he relished in the even deeper seclusion of his family's rural estate at Woolsthorpe in Lincolnshire. The latter period – an eighteen-month interval beginning in late 1665 – is sometimes called his *annus mirabilis*, or miracle year. "In those days I was in the prime of my age for invention," he later recalled, "and minded mathematics and philosophy more than at any time since." In 1667, with the plague in retreat, Newton returned to Cambridge; by now his most important ideas had already crystallized in his mind. He had developed a mathematical basis for Galileo's dynamics, which he encapsulated in his three laws of motion; he had worked out the rules for a new kind of mathematics involving infinitesimal quantities, which we now call "calculus"; he had begun to investigate light and color; and, in a stunning leap of the imagination, he had shown how a falling apple and a whirling planet or moon were simply responding to the same force, which he spelled out with mathematical precision in his law of universal gravitation. He was twenty-four years old.

Isaac Newton declared that “Absolute, true, and mathematical time … flows uniformly.” For Newton, events unfold against a fixed backdrop of absolute space and time. *(© Science Museum/Science & Society)*

The Road to Principia

Yet Newton kept nearly all of these ideas to himself. Men of learning from across Europe would write to him; often he did not write back, choosing “to decline correspondencies by Letters about Mathematical & Philosophical matters,” as he later recalled, finding they “tend to disputes and controversies.” What little he wrote on physics – mostly unfinished treatises – would collect dust in his study in Trinity College for more than twenty years, alongside his tracts on alchemy and theology. But his attitude changed after a visit from Halley in August of 1684. Halley, based in London, knew that other scholars were on the verge of publishing ideas similar to those that Newton had been working on. (Robert Hooke, for example, appears to have thought of the inverse-square law of gravitation at about the same time as Newton.) Newton realized that if he was to be recognized for his revolutionary contributions to science, he would have to work fast. Writing at a feverish pace, he began to set down everything he knew about the structure of the universe. In doing so, he briefly retreated even further from the outside world. Often he would forget to eat; when he did opt to join his colleagues in the dining hall, he would sometimes get lost on the short walk. (On leaving his chamber, he would sometimes turn left instead of right, his assistant later recalled; on realizing his mistake, he would turn back but then once more bypass the hall and return to his room. Occasionally he would "write on his Desk standing, without giving himself the Leasure to draw a Chair to sit down in.") The *Principia* was finally printed in 1687 – and was immediately hailed as the most important treatise on physics ever written (an honor many would say it still deserves).

Time lies at the very heart of Newton's description of the world. His goal was to describe motion mathematically – and motion, of course, is a change in position over time. Yet what he actually says about time in the *Principia* has long puzzled physicists and philosophers. "I do not define time, space, place, and motion, as being well known to all," he says in the opening pages of his magnum opus – and then proceeds to do just that. (No doubt he was influenced by his former teacher, the mathematician Isaac Barrow, who once remarked, "Because mathematicians frequently make use of time, they ought to have a distinct idea of the meaning of the word, otherwise they are quacks.") Why does Newton feel he has to define "time" if we all intuitively know what it is? He says that his aim is to distinguish "mathematical time" from the "common" notion of time that we all harbor, so as to eliminate "certain prejudices." And so we come to his famous definition:

> Absolute, true, and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly.

What, exactly, is Newton saying here? Motion, again, is change over time – but time measured *how*? In Newton's day, clocks that kept time to better than a few minutes per day were still a novelty; anyone interested in precision timekeeping looked to the heavens and the regular motions of the sun, moon, and stars. Yet even these motions – as Newton understood better than anyone – were variable and imperfect. The example he mentions in the *Principia* is the "equation of time," the technical term for the discrepancy between the sun's daily movement across the sky – this is "solar time" as read by a sundial – and the idealized *average* of that movement, today referred to as "mean solar time." The discrepancy is no small affair: the time shown by a sundial can be as much as twenty minutes ahead or behind mean solar time. So where do we turn for flawless timekeeping? Newton realized there simply isn't a perfect clock anywhere for us to rely on, either on Earth or in the sky; even the stars, obeying the same laws as terrestrial objects, must be imprecise timekeepers. Underpinning these imperfect physical clocks, Newton reasoned, there must be a true "universal" clock: a perfect cosmic chronometer whose precise movements real clocks can only approximate.

Newton's view of time built on – but also departed from – the recent work of Galileo and Descartes. Galileo had envisioned time geometrically, as a line marked off at regular intervals; Newton's predecessor, Barrow, shared that vision.* René Descartes (1596-1650) saw time as a measure of motion but considered the idea of duration as something subjective, "a mode of thinking." And although he developed a coordinate system for analyzing space geometrically, Descartes does not seem to have thought of time in geometrical terms. Newton went further by envisioning both time and space as geometrical structures that had a real existence. (As the philosopher Philip Turetzky points out, Newton may have been influenced by the growing prevalence of mechanical clocks, which, imperfect as they were, encouraged "the analogy of time with space" and reinforced "the priority of time over motion.") Newton's universal clock ticked away at a rate independent of stars and planets; independent of our perceptions. It was simply *there*. Should all the matter in the universe disappear, it would *still* be there. It was fundamental.

The Problem with "Absolute Time"

From Newton's framework we can derive all kinds of equations that let us predict how an object will move. Back in high school we learned several of the most useful ones. Suppose you have an object moving along at a steady speed. In that case, the distance that it covers will be given by the equation $d = v \times t$ ("distance equals velocity [speed] multiplied by time"). Similar (and only slightly more complicated) equations tell us how a body will move in response to a constant force, giving it an acceleration. Time enters into such equations as a *parameter* that describes how one quantity changes with respect to another. Newton needed a framework of uniform time and space in order to develop laws of this sort; it allowed him to treat time and space as abstractions. Indeed, his definition of absolute time is preceded by a definition of absolute space phrased in almost exactly the same words: "Absolute space, of its own nature, without reference to anything external, always remains homogeneous and immovable." For Newton, this abstracted version of space and time was essential. Without absolute time – if we decide, for example, that speeds and distances must be measured against some particular local clock – Newton's laws lose their universality.

A number of philosophers immediately objected to Newton's idea of absolute time. They argued instead for a "relational" view of time – the idea that time only makes sense in relation to the motion of physical bodies. Among Newton's contemporaries, the German mathematician and philosopher Gottfried Leibniz (1646-1716) was the most prominent supporter of the relational view. In the year before his death, Leibniz carried on an animated exchange of letters with a supporter of Newton named Samuel Clarke (1675-1729), an English theologian. Time, the relationists argued, is simply a way of comparing one event to another. In the relational view, time is *not* independent of the material objects that make up the universe. Just the opposite, in fact: the physical objects and their motions are what *define* the passage of time. One might argue that this more closely matches our experience of the world: We do not "see" time, just as we do not see space. What we perceive are *events* in time, and objects in space.

Physicist Lee Smolin of the Perimeter Institute in Waterloo, Ontario, offers a helpful analogy. Imagine an empty concert hall in which the only sound is the ticking of a metronome that someone has left behind. The metronome is Newton's imagined absolute time, ticking away independently of all else. Then the musicians – perhaps a string quartet or a jazz ensemble – enter the hall. Ignoring the metronome (perhaps they can't even hear it), they begin to play. The "time" that emerges in their music, Smolin explains, is now "a relational time based on the developing real relationships among the musical thoughts and phrases." The musicians listen only to one another, and "through their musical interchange, they make a time that is unique to their place and moment in the universe." For Newton, the time of the musicians "is a shadow of the true, absolute time of the metronome." For Leibniz, on the other hand, the metronome "is a fantasy that blinds us to what is really happening"; the only time we encounter in the hall is what the performers "weave together."

The German philosopher Gottfried Leibniz rejected Newton's "absolute" space and time. Instead he proposed a "relational" view, in which time can only be measured in relation to the motion of physical objects. *(George Bernard, Science Photo Library)*

It is not easy to work out a system of mechanical laws that encompass relational time; Leibniz certainly did not know how to do it. (Einstein did, as we will see in the next chapter.) And the relational view comes with its own difficulties: If time is motion, what happens when all motion ceases? Would time stop? A relationalist would have to say yes: no motion, no time. In Newton's scheme, time would march on, somehow, in the metaphysical background.

Newton vs. Leibniz

The battle between Newton and Leibniz was fought on theological grounds as well. This was an age of belief, and great thinkers like Newton and Leibniz had to do more than explain the physical world; they also had to show that it made sense for God to create the world the way he did. But Newton and Leibniz approached this issue quite differently. According to Leibniz, God does nothing on a whim; there must be a reason – a rational explanation – behind God's every action. This is called the "principle of sufficient reason." Leibniz believed that if time were absolute – continuing even when no change is observed – then time must have been passing even before God created the universe. In that case, God created the universe at some particular time. But why *that* particular time? Why not five minutes earlier or five minutes later? After all, in the Newtonian scheme, every moment is alike. (The best that Newton's ally Clarke could offer in reply was that sometimes God *did* do certain things on a whim. That did not satisfy Leibniz, who said such a notion "is plainly maintaining that God wills something, without any sufficient reason for his will.")*

In the relational picture, it isn't meaningful to speak of time in the absence of events, so time simply doesn't exist before the creation of the universe. In Leibniz's view, God didn't create the universe *in* time; rather, he created time *along with* the universe. (Mind you, Leibniz had his own troubles with time. Is time "real," if an instant has no duration? "For how can a thing exist," he asked, "whereof no part does ever exist? Nothing of time does ever exist, but instants; and an instant is not even itself a part of time.")

Newton was aware of Leibniz's objections, but he nonetheless considered his own theory to be a testament to the glory of God. Indeed, Newton's conception of absolute space and time may have been anchored to his belief in an eternal, omnipresent deity. In his published writings, that connection is seen most clearly in the "General Scholium" – a brief appendix added to the second edition of the *Principia* in 1713:**

> He is eternal and infinite, omnipotent and omniscient, that is, he endures from eternity to eternity, and he is present from infinity to infinity … He is not eternity

> and infinity, but eternal and infinite; he is not duration and space, but he endures always and is present everywhere, and by existing always and everywhere he constitutes duration and space.

As historian of science Stephen Snobelen writes, “This God of dominion is the God of Newton’s faith *and* his natural philosophy. This is also the God of Newton’s absolute space and time … God comes first, and hence absolute space and time are predicates of God’s infinite extension and eternal duration.”

Newton also embraces the ancient “argument from design,” the idea that evidence for a Creator can be seen in the natural world. He declares in the General Scholium, “This most beautiful system of the sun, planets, and comets, could only proceed from the counsel and dominion of an intelligent and powerful Being.”

Interestingly, Newton would come to be seen as the father of the “clockwork universe,” a cosmos that may have been set in motion by God at the beginning of time but that no longer needs divine meddling.* Newton’s view, however, was just the opposite: he believed in a Creator who was constantly active, sustaining the laws of nature and intervening when necessary. For Newton, the universe and its workings were utterly contingent on the existence of God. Here, again, Leibniz disagreed: How could God – the embodiment of perfection – be so clumsy as to build a universe that needs regular maintenance?

The Flow That Wasn’t There

Let’s turn again to Newton’s definition: “Absolute, true, and mathematical time … flows uniformly,” he tells us. But what, exactly, is flowing? The so-called flow of time is one of the most argued-about phenomena in all of philosophy. Usually when we say something flows, we mean that it flows at some particular rate with respect to something else. A river, for example, flows at some rate with respect to its banks, and we could measure that rate in liters per second or similar units. But what does time flow with respect to? And at what rate? To say that time flows by at “one second per second” tells us nothing at all. If time is a “thing” whose passage we can measure, then we must be measuring it with respect to some deeper “hypertime.” In the 1960s, the philosopher Jack Smart gave a clear account of the problem:

> If time flows … this would be a motion with respect to a hypertime … If motion in space is feet per second, at what speed is the flow of time? Seconds per what? Moreover, if passage is of the essence of time, it is presumably the essence of hypertime, too, which would lead us to postulate a hyper-hypertime and so on ad infinitum.

As the philosopher Huw Price points out, just as we can’t meaningfully speak of the rate at which time flows, we also cannot meaningfully speak of the *direction* in which it flows. Saying it flows “from past to future” does not get us very far, as this is how past and future are defined.

After mentioning the flow of time in his famous definition, Newton never brings it up again. In fact, his laws of motion do not even help us distinguish past from future. All of his equations are *time-symmetric*, which means that they are equally valid as descriptions of natural phenomena no matter which way time “goes.”

When we think of the power of Newton’s laws, we usually think of how they help us predict future events, from the path of a projectile to the orbits of the planets. Perhaps the quintessential example is the predicted return of Halley’s Comet. Halley used observations of earlier comet sightings, along with Newton’s equations, to predict that a bright comet seen in 1682 would return in 1759. (Which it did, though Halley, who died in 1742, did not live to see his prediction borne out. He was eventually honored, of course, in having the comet named after him.) A book on my shelf tabulates upcoming solar and lunar eclipses for the next decade, timed to the nearest minute, and the tables could continue for the next thousand years if the author had so desired. When NASA publishes its data for the next few years worth of eclipses, the figures are given to the nearest second, and some parameters are given to the nearest tenth of a second.

Such predictions take advantage of the *deterministic* nature of Newton’s laws: if you know the state of a system at some particular moment, you can, in principle, predict the state of the system at some arbitrary time in the future. The French mathematician and astronomer Pierre-Simon Laplace (1749-1827) enthusiastically embraced the deterministic world view when he declared:

> We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.

Notice the phrase “the future just like the past”: Laplace recognized that Newton’s formulas work just as well in reverse; one can use them to make predictions in either direction of time. After tracking some particular astronomical body, for example, astronomers can work out its orbital parameters and then proceed to “predict” (we might say “retrodict”) where it would have been at some arbitrary time in the past. (This technique is of immense value to archeo-astronomers and historians, who can date ancient texts by working out the dates of any astronomical events that may be mentioned, such as eclipses or planetary alignments.)

But can complicated objects like people and animals “go” backward? Here we have a dilemma, because common sense says they cannot; most phenomena we observe in nature are clearly *irreversible*. And yet it is not Newton’s equations that forbid such reversals; as we’ve seen, his equations are symmetric with respect to time. This mathematical symmetry between past and future, embodied in Newton’s laws, was noted by Lord Kelvin in the journal *Nature* in 1874:

> If the motion of every particle of matter in the universe were precisely reversed at any instant, the course of nature would be simply reversed for ever after. The bursting bubble of foam at the foot of a waterfall would reunite and descend into the water; the thermal motions would reconcentrate their energy, and throw the mass up the fall in drops reforming in a close column of ascending water … living creatures would grow backwards, with conscious knowledge of the future, but no memory of the past, and would become again unborn.

Of course, we don't actually see the fanciful events described by Kelvin. Broken teacups do not spontaneously reassemble, scrambled eggs do not unscramble, and recorded music played backward sounds very little like "music" at all (notwithstanding the alleged tribute to "my sweet Satan" in Led Zeppelin's "Stairway to Heaven" and hints that "Paul is dead" in certain Beatles songs). Instead, time – in spite of the mathematical symmetry in Newton's laws – seems to have a definite direction.

In Search of Time's Arrow

Think of a ball rolling along the surface of a billiards table. If we imagine that the surface is frictionless and the collisions with the rubber cushions perfectly elastic, the ball will roll around forever, bouncing off the cushions every few seconds, its speed remaining constant. If we film a few minutes worth of this admittedly dull scenario, we end up with a movie that plays just as well forward as backward. Upon seeing the film, the viewer has no way of knowing in which of the two possible directions the frames of the film were recorded. (The same applies on larger scales, so long as the motions are simple enough: a film of the earth revolving around the sun also looks perfectly plausible in reverse.) In accordance with Newton's laws, the behavior of the billiard balls is time-symmetric. If we add a second ball, again the motions look the same forward and backward. They're more complicated now, because in addition to hitting the cushions, the balls sometimes hit each other. But as before, the film looks just as plausible forward as backward. If we have ten balls bouncing around the table, still there is no obvious "direction" in time – so long as they start off randomly scattered on the table.

But suppose now that we impose some order on the array of balls, by racking them up using the plastic triangle provided for just this purpose. We put the cue ball in position, take aim, and "break" the carefully ordered array of balls. From order we now have disarray. A few clumps of balls may remain, but as the next player shoots, the disorder – the randomness – increases again. Physicists use the term *entropy* to quantify the amount of disorder of a system – so we could say the entropy increases as each player takes his turn.

Now the events most definitely are *not* time-symmetric. A film shown in reverse would be immediately identified as such. We know from experience that a random array of billiard balls will not spontaneously arrange itself into a neat and compact triangular pattern. We don't see such decreases in entropy in nature.

We can see a similar pattern whether the objects involved are macroscopic, like billiard balls, or microscopic, like molecules of gas. Imagine that we have a container with two compartments, separated from each other by a valve. Suppose one compartment is filled with nitrogen gas, the other with oxygen. Now we open the valve. What happens? Immediately some of the nitrogen molecules enter the oxygen chamber, and vice versa. After a few minutes they are thoroughly mixed. The molecules keep on bouncing around – just like the billiard balls – but they will never again take on their original configuration. The first chamber will never again be pure nitrogen, the second chamber never again pure oxygen. If the molecules were somehow colored – or if we were talking about milk and coffee instead of nitrogen and oxygen – the film would plainly show that mixing. And again the film makes sense in only one direction: the two components would never "unmix."

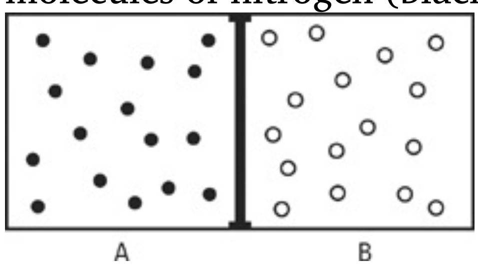
The principle at work in these examples has come to be known as the *second law of thermodynamics*. The second law says that the amount of disorder in a closed system – the amount of entropy – can never decrease.* It must always increase, or at best remain the same, over time.

We should take particular note of two aspects of the second law. First of all, it is statistical in nature; it doesn't apply to lone billiard balls, but it does let us characterize the motion of an array of many such balls. Secondly, it reveals a kind of built-in asymmetry to processes that involve large numbers of particles or bodies. That asymmetry is often thought of as indicating the flow of time. In 1927, the British astronomer Arthur Eddington (1882-1944) used the phrase "the arrow of time" to describe this asymmetry, and the vivid metaphor is still with us. (For Eddington, the second law held "the supreme position among the laws of nature.")

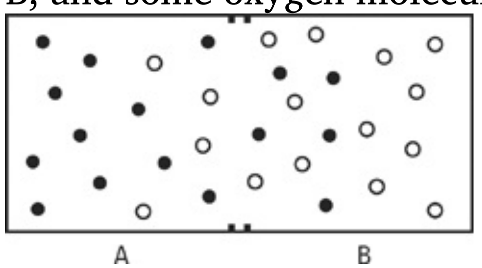
The statistical nature of the second law helps us understand why complex systems evolve in one direction only. There are billions of ways to arrange ten billiard balls randomly on a table – but there are by comparison only a few ways to arrange them in a compact triangle (the arrangement they had before the break). As the balls move randomly

The Second Law of Thermodynamics

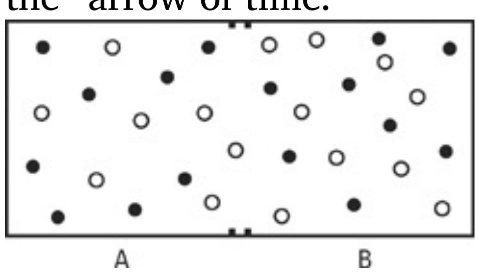
a) A barrier separates two compartments.The first (A) contains molecules of nitrogen (black), the other (B) contains oxygen (white).



b) With the barrier removed, some nitrogen molecules are now found in B, and some oxygen molecules in A.



c) Soon the two kinds of molecules are thoroughly mixed. The sequence is irreversible: the two gases will never “unmix.” Such processes, guided by the second law of thermodynamics, seem to be linked to the “arrow of time.”



over the course of time, we can see why it is staggeringly unlikely for the balls to take on that original arrangement. The same argument can be applied to the molecules of gas in the container. Or, to take another example, to a shattered teacup. There are many ways for a teacup to smash, but only one way to piece it back together again. A shattered teacup *could,* in theory, spontaneously reassemble – it is not forbidden by Newton's laws – but it is astronomically improbable, thanks to the second law of thermodynamics. In practice, it is so unlikely that we would harbor no expectation of ever witnessing such an event. In all of these examples – and in any complex system – the arrow of time reveals itself as a change in the amount of disorder in a system, a change that always proceeds from lower to higher entropy.

The second law of thermodynamics can feel a little depressing. It suggests, perhaps, that "order" is fleeting – that no matter how often we clean the basement, for example, entropy will have the final victory. Our bodies will inevitably yield to it; perhaps, in the end, so too will our civilization. The Oxford chemist Peter Atkins captured this pessimism when he wrote:

> We have looked through the window on to the world provided by the Second Law, and have seen the purposelessness of nature … All change, and time's arrow, point in the direction of corruption. The experience of time is the gearing of the electrochemical processes in our brains to the purposeless drift into chaos as we sink into equilibrium and the grave.

The second law of thermodynamics certainly seems to be telling us something about the arrow of time – but perhaps the connection isn't as straightforward as it appears. Have we really explained the distinction between past and future? Consider again a low-entropy situation such as the billiard balls occupying a tight configuration on one side of the table. It is certainly true that, projecting forward in time, we expect to see a higher-entropy situation – a more disordered array of balls. But remember, the laws that we're using to predict the motions of the balls are perfectly symmetric. If we start with the same configuration and try to guess what the most likely arrangement was in the past – if we try to "predict" how a film-played-backward of the last few minutes would appear – then once again we would predict higher entropy. In other words, starting from some particular low-entropy state, the statistical argument that we've been using tells us that entropy increases not only into the future, but into the *past* as well. This is a subtle but profoundly important point: the same analysis that we used to predict that a low-entropy system will evolve into a high-entropy system in the future could be used to "predict" that a low-entropy system *was probably preceded by a high-entropy system.** But we would almost always be wrong. Most tight arrays of billiard balls were in fact preceded by somebody racking them up, not by balls randomly rolling into that arrangement; most un broken teacups were preceded by someone pouring tea into a cup, not by scattered shards of china spontaneously coming together. Our analysis is clearly incomplete.

The second law of thermodynamics says that if you currently have a low-entropy system, you can expect to have a high-entropy system in the future. But it doesn't say *why* you might expect to have a low-entropy system right now. Perhaps we need to look further back in time. What events have transpired in the past that would lead to the low-entropy universe we find ourselves in today? Perhaps the roots of the second law of thermodynamics can only be understood in the broader context of cosmology – that is, in terms of the origin and evolution of the universe. Maybe the universe started off in a state of very low entropy, and that explains why our observations today show entropy on the rise. This idea comes with its own difficulties, and we will return to it in Chapter 11. At the very least, though, we have learned to be cautious in stating that the second law of thermodynamics "explains" the arrow of time.

Philosophical Interlude, Part One

Philosophers, not surprisingly, have been wrestling with time's many puzzles even longer than physicists have. (Of course, in the era of Newton and Leibniz, "philosophy" encompassed just about everything; what we now call science was embraced by the study of "natural philosophy.") Many of the main themes have endured over the centuries, and some of today's arguments can be traced back to ancient times. The Greeks tied themselves into knots over the problem of motion: How can an object change and still be the same object? Is "time" just another word for "change"? For many Greek thinkers, time was indeed a secondary concept to the more central ideas of change and motion. Heraclitus – we met him in Chapter 4 – was one such thinker. For Heraclitus, change was paramount; everything was seen as being in flux. He famously proclaimed that "a man can't step into the same river twice": it is not the same man and it is not the same river. Parmenides disagreed. In fact, he came to the remarkable conclusion that time doesn't exist. Parmenides' argument goes like this: Anything that we can conceive of must have a permanent existence. Anything that we can speak of, or think of, "is without creation or destruction; whole, unique, unmoved and perfect." For Parmenides, this line of reasoning ruled out change: whatever is, simply *is*; change must be an illusion.

The idea that much of what we perceive is illusion is echoed in the work of Plato. However, Plato did not simply dismiss our flawed perceptions but struggled to see how they relate to the deeper truth of the world that surrounds us. For Plato, time could not be rejected as an illusion, and, with great effort, he integrated time into his cosmology – his picture of the universe – which we looked at briefly in Chapter 4.

Aristotle, as we've seen, believed that time requires change – a view that would surface again with Leibniz two thousand years later. Aristotle also struggled with the concept of "now." He saw the passage of time as a succession of "nows" – a succession of instants – and yet he did not see time as *composed* of such instants. He believed time could no more be composed of "nows" than a line could be composed of points. (No two points can ever touch, he reasoned, because no matter how close they are, we can always insert another point in between.) But Aristotle seems to stumble on the question of what these “nows” actually do. Are they static? Is every instant just like every other instant? Or does “now” somehow flow through, or with, time? Once again the question of time’s apparent flow defeats even the most careful thinkers.

Is the Future “Real”?

Aristotle also wrestled with the distinction between past and future. Is the future “real”? It certainly *seems* less real than the present or the past. The future appears indeterminate; future events cannot be spoken of with the same certainty as present or past events. The future is like a mirage: while the past seems etched in stone, and the present is right in front of us, the future looms like a fog of infinite possibility. Aristotle thought very carefully about statements such as “There will be a sea-battle tomorrow.” It seemed that the truth of such a statement was undefined; it was contingent on whether the generals would indeed choose to do battle the next day. He reasoned that statements about future events are neither true nor false. One proposition may be deemed more likely than another, but that is as definite as we can be. The future, for Aristotle, has only *potential* existence.

Christian theology embraced many aspects of Aristotle’s world view, but also adapted them to its own needs. Augustine, in his *Confessions*, tells of his struggles with philosophy in parallel with his spiritual quest, one that would lead to his adoption of Christianity. Augustine considers the Judeo-Christian view of the creation of the world – and then immediately realizes that it raises difficult questions about time and eternity. Did God create the world “in time”? If so, what was God doing beforehand? As we’ve seen, this is the same dilemma that would grip Leibniz more than thirteen centuries later, and Augustine reaches the same conclusion: God, he reasons, must have created time *along with* the universe.

Augustine goes on to ponder the distinction between past, present, and future, and puzzles over the apparent “flow” of time. In the end he appears to grant “now” a special status: it is more real, somehow, than the past or future. Indeed, he argues that past and future are, in a sense, embedded in "now," for the present contains our memories of the past as well as our expectations of the future. The extreme version of this stance – the rejection of past and future – is sometimes called *presentism*. Whatever we make of Augustine's line of reasoning, his linking of time to human consciousness is a profound notion; we have already encountered it briefly with Descartes, and it will recur often in our story.

Two Kinds of Time

Anyone who has thought carefully about time will have noticed that we speak of time in two distinct ways. When we talk about what has already happened, what's happening now, and what may yet happen, we build up a mental picture of these events relative to the moment we're currently experiencing. We introduce the terms "past" and "future" to describe how those events relate to the present moment, and the verbs that we use to describe some particular action take on the appropriate "tense" as needed: "I cooked some pasta"; "I'm eating dinner"; "I will wash the dishes." These statements are all relative; the phrase "I'm eating dinner" stops being true once I finish eating. It describes events relative to "now," and "now" keeps shifting.

But when we imagine time as a line – as Galileo and Newton did – then we use a different approach. We attach labels to various events to indicate where they occur on that timeline. It is a much more static view, and we use language differently when we describe events from such a perspective. (Actually, even using the word "static" is a little misleading; it suggests that some kind of meta-time lurks in the background. Instead we must imagine a *timeless* array of events.) When we say "The Declaration of Independence was signed on July 4, 1776," we don't need to say that this was in the past relative to the present moment; when we say "There will be an eclipse in 2017," we similarly don't need to say that this is in the future relative to now. Rather, these seem to be unchanging facts about the world.

The British philosopher John McTaggart (1866-1925) spelled out this distinction in his influential essay "The Unreality of Time" in 1908. He called the two ways of thinking about time the "A series" and the "B series." The A series is simply the everyday notion of time in terms of past, present, and future; it is sometimes called the "tensed" view of time. Any event can be located in time with respect to the A series when the speaker states how long ago the event happened – or how long we must wait until it happens. The B series, in contrast, refers to fixed labels that we attach to specific moments in time – 5:00 p.m. GMT on March 30, 2010, for example. (This is sometimes called the "tenseless" view of time.) Events described in terms of the B series can be marked "earlier than" or "later than" each other – but "now" never enters into it.

When we describe events in terms of the A series, our statements seem to be contingent: the phrase "I had eggs for breakfast yesterday" is true if I say it the day after having the eggs, but it may or may not be true if I say it on some other day. Statements described in terms of the B series have a different feel: sentences like "The Declaration of Independence was signed more than a year after the battles of Lexington and Concord" or "The eclipse of 2017 will happen five years after the London Olympics of 2012" seem to have a more permanent truth; they appear to describe unchanging attributes of world history. I have used tenses in the usual way in those sentences, but one could, with a little practice, develop the habit of omitting past and future tenses when using the B series perspective, and just making do with the present tense. One could say, for example: "The Declaration of Independence is signed more than a year after the battles of Lexington and Concord." One can also capture the essence of past and future – absorbing the A series into the B series, so to speak – by eliminating any references to "now": instead of "The eclipse will happen nine years from now," say, "The eclipse occurs nine years after this utterance." It is not our natural way of speaking, to be sure, but philosophers would argue that it conveys the same information.

The world imagined according to the B series can seem quite strange at first. The B series grants no special status to "now"; every point along the timeline is on an equal footing. The word "now" becomes like the word "here" – it means something relative to the person saying it, but it has no absolute meaning. When events are strung out according to the B series picture, we end up with something like a block of time; indeed, the picture is often referred to as the "block universe." It is a short step from adopting the block view of time to the conclusion that the flow of time – and perhaps even free will – are illusions. In the B series view, one could argue that future events – the accession of the next pope, for example – are already “fixed” in time. Are future happenings then simply inevitable? Are they laid out in front of us, with no room for choice? McTaggart, in fact, went even further. As the title of his essay suggests, he eventually concluded – as Parmenides had – that time itself is an illusion. He reasons as follows: logically, past, present, and future are incompatible properties – an event can only be “in” one of them. And yet every event *does* seem to take on all three: the death of Queen Anne (to use McTaggart’s example) was once future, then present, and is now past. And so he rejects the “tensed” view of time. But since he believes the tensed view is the only way to address time’s apparent flow, he concludes that time is not a meaningful entity.

McTaggart’s argument has been debated endlessly in the century since its publication. Many philosophers, even if they don’t share McTaggart’s ultimate conclusion, have been deeply influenced by the “block time” picture suggested by the B series. In fact, while the A series description seems closer to our intuition, the “timeless” view embodied in the B series probably represents the majority view among physicists and philosophers today – especially in light of Einstein’s new picture of space and time, which we will come to shortly.

The Sage of South Newington

One of the strongest supporters of the “timeless” picture is English physicist Julian Barbour. Now in his mid-seventies, Barbour earned his Ph.D. on the foundations of Einstein’s theory of gravity, known as general relativity, from the University of Cologne in 1968. Since then he has worked as a freelance theoretical physicist, with no academic affiliation; he supports his family in part by translating Russian scientific journals. In his book *The End of Time: The Next Revolution in Physics* (1999), Barbour argues that time – along with motion and change – is nothing more than an illusion.

There are echoes of Parmenides and McTaggart in his argument, but Barbour has an enormous advantage over his predecessors: he has a deep understanding of modern physics, having worked extensively on both general relativity and quantum theory (both of which we will examine more closely in the next chapter).

I met with Barbour at his home, a 350-year-old thatched-roof farmhouse in the bucolic village of South Newington, in the north of Oxfordshire. He invites me into the garden, where we sip tea and begin to talk about space and time, motion and change, Mach and Minkowski. He strikes me as part savant, part English country gentleman.

It is late spring, the sun is shining brightly by British standards, and the scent of wisteria fills the air. Next door is a Norman church dating from 1150; as one of the caretakers, Barbour has his own key. He often escorts visitors through the chapel as they take in its many treasures, including a graphic fourteenth-century depiction of the murder of Thomas Becket by agents of King Henry II in 1170. (More visitors come to see the historic church than to discuss time, Barbour assures me.) When one too many airplanes has flown overhead – just about the only reminder that we are in the England of the second Elizabeth rather than the first – we move inside.

Orion Books

Independent physicist Julian Barbour.

We pause briefly for a dinner of asparagus, bread and butter, cheese, and fresh strawberries. Then we relax on Barbour’s living-room sofa. He leans back, and speaks in a careful, measured voice – a mix of solemn scholarly wisdom and disarming English charm.

Part of the problem with “time,” he explains, is that our two best theories – general relativity and quantum theory – treat it very differently. “It’s like two children sort of quarreling over a toy they want,” he says. “But the trouble is, each wants something different.” He believes the only solution is to remove the toy. We have to abandon the notion of time.

The heart of his argument is easy enough to follow. Barbour imagines every “now” as a complete, self-contained universe – a universe in which time is notably absent. If we imagine the history of the universe as frames in a movie, each frame must be considered equally “real.” (He refers to the total collection of all “nows” as Platonia, in honor of Plato and his vision of eternal, changeless forms.)

And what of the past and the future? For Barbour, they are every bit as slippery – and unnecessary – as time itself. We have no actual evidence of the past other than our memory of it (and the various artifacts that record those memories, whether natural, like fossils, or artificial, like newspapers). Similarly, we have no evidence of the future other than our belief in it. It is all an illusion.

“From the physicist’s point of view, there isn’t any sort of ‘flowing’ of time, and there isn’t any sort of ‘now’ creeping up through the world,” Barbour says. “The idea of a ‘flowing time’ is some sort of illusion that’s created, somehow, by our consciousness.”

So why do we imagine time as a steady progression, with a relentless “moving now”? Presumably because of the way our minds – and in particular our memories – work. What newspapers and fossils do for history at large, Barbour explains, the human brain does for personal memory. Each of these can be thought of as “time capsules” – physical systems arranged in a very precise way, enabling them to “preserve” the past within them. He calls this “the single most remarkable fact about the world as we experience it.” In a certain sense, Barbour is obviously at least partially right: if neuroscience progresses to the point where the brain’s neural activity can be “read” in precise detail, one could deduce a friend’s life history by studying his brain as it is now; the past would be present, so to speak.

“And, if you think about it, this is exactly what modern geology and modern cosmology are doing at the moment,” Barbour adds.

Cosmologists infer the universe's past by examining the sky as it is now; geologists do the same for the earth's past. It's all essentially "one snapshot," he says.

Among the ramifications of treating every "now" as equally real is a certain kind of immortality. It's not the sort of life after death that most of us would probably prefer; instead, it's something like life alongside death. Since time does not pass, we do not age. "The instant can't age – the instant is what it is," Barbour says. "So to this extent, there is a Julian at seventy – which I now am – but there's a Julian at sixty, who is just as real as the Julian at seventy. You don't have any sense in which yesterday is any less real than today."

What, then, of time?

"It's a mistake the mind has made," he says. "I would say of time what Laplace said to Napoleon about God: 'I have no need of that hypothesis.'"

On the train ride back to Oxford, the conductor calls out the stations. The platforms all have digital clocks, and the stops (at least in theory) are scheduled to the minute. Time certainly *seems* real. I'm as confused about time as I was before (there I go again, using words like "before"). It's hard to imagine time not being real when we can barely construct a sentence without invoking it in one way or another; the illusion of time – if that's what it is – seems to shape our every thought, and certainly permeates our language. I'm not alone in my confusion. The philosopher Simon Saunders, reviewing Barbour's book for the *New York Times*, called it "gold," adding that, as pedagogy and analysis, it is "a masterpiece" – but he also issued "a philosophical health warning," admitting that he was not sure "if it really makes sense."

Perhaps some future (whoops!) writer will find a clearer way of illuminating the illusion of time. After all, those who came after Newton were often much better at explaining his mechanics than he was. (Undergraduate physics students use a variety of textbooks today; the only one they would *never* use is the one Newton wrote.) Besides, Newton – like all of us – was partly a product of his time. A twenty-firstcentury presentation of his physics would involve, first of all, stripping away the theological overtones. (Through his idea of absolute time and space, Barbour told me, “Newton had thought that he had seen the anatomy of God. I think he felt that he had almost made the invisible God visible.”) Perhaps we, too, are so heavily burdened with preconceived notions of time that we cannot readily shed our biases.

In the meantime, I vow to reread *The End of Time*. It could be worse – at least I’m not trying to plow my way through the *Principia*. I’m reminded of a story – probably apocryphal – about a student who is said to have watched Newton pass by in his carriage. He supposedly quipped, “There goes the man that writ a book that neither he nor anybody else understands.”

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* A brief account of Newton’s life and work – along with an overview of the Scientific Revolution – can be found in Chapter 3 of my earlier book, *Universe on a T-Shirt*.

* In fact, Barrow spoke of time in language very similar to that which Newton would later use: “Time does not imply motion, so far as its absolute and intrinsic nature is concerned; not any more than it implies rest; whether things move or are still, whether we sleep or wake, Time pursues the even tenour of its way.”

* The debate continues. Philosopher J.R. Lucas, for example, suggests that God could have “chosen to set off the big bang” when he did because, ultimately, he “must at some time decide to get going.” He likens it to some of his undergraduate students, who may not have wanted to get up out of bed but, “eventually, for no particular reason, they finally did decide to get up.”

** Newton’s voluminous theological writings, many of them unpublished, have only recently seen the light of scholarly inquiry; they show Newton every bit as obsessed with theological matters as with science, perhaps more so. Though he was a devout Christian – he owned thirty bibles at the time of his death – his religious views were wildly unorthodox. He denied the Holy Trinity, which he felt smacked of polytheism. This was a criminal offense in Newton’s day; had his views been made public during his Cambridge years, he would at the very least have been expelled from Trinity College.

* Although often associated with Newton, the clockwork metaphor is actually much older. It can be traced back to at least the thirteenth century, with the work of such thinkers as Nicolas Oresme and Johannes de Sacrobosco; later supporters include Descartes and chemist Robert Boyle (1627-91). Some philosophers would actually consider Newton an “anti-mechanical” thinker because his concept of gravity allowed for “action at a distance.”

* A “closed system” is one which is isolated from outside influences. The billiards table, in fact, is *not* such a system; after all, the players keep striking the cue ball, and they cause a *decrease* in entropy, first by racking up the balls and later by sinking them. To better picture the second law of thermodynamics in action, we could imagine isolating the table immediately after the cue ball is struck for the first time. If the table were frictionless and had no pockets, entropy would gradually increase over time, until the balls were randomly scattered across the table.

* This is sometimes called “Loschmidt’s paradox,” after Austrian scientist Josef Loschmidt (1821-95).