

Time Flows Toward Order

By Julian Barbour · Nautilus · 12 min

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Revisiting the gospel of the second law of thermodynamics.



The one law of physics that virtually all scientists believe will never be found to be wrong is the second law of thermodynamics. Despite this exalted status, it has long been associated with a great mystery and a bleak implication. The mystery is that all the known laws of nature except one do not distinguish a temporal direction. The second law, however, asserts the existence of an all-powerful unidirectionality in the way all events throughout the universe unfold. According to standard accounts, the second law says that entropy, described as a measure of disorder, will always (with at most small fluctuations) increase. That's the rub: Time has an arrow that points to heat death.

Surprisingly, evidence that a more nuanced account is needed is hiding in plain sight: the universe itself. Very soon after the Big Bang, the universe was in an extremely uniform state, which since then has become ever more varied and structured. Even if uniformity equates to order, that initial state was surely bland and dull. And who can see disorder in the fabulously structured galaxies or the colors and shapes of the trees in the fall? In fact, the sequence in which two of the greatest discoveries in science were made resolves the paradox: The second law was discovered eight decades before the expansion of the universe.



ES NOW: Two people walking down opposite sides of Mount Fuji would see the terrain change in much the same way. In our world, the hikers' perceptions offers an apt analogy for how beings on either side of what he calls a "Janus Point" in the universe would experience moving orderly in time.

The time lag is critical for one simple reason. The laws of thermodynamics, discovered in 1850 by William Thomson (later ennobled to Lord Kelvin) and Rudolf Clausius, emerged from a brilliant study that Sadi Carnot (son of Napoleon's greatest general) published in 1824. In a slim booklet that laid out all but one of the foundational principles of thermodynamics, he sought to establish the maximum efficiency steam engines could achieve. Steam engines can only function if their working medium is confined in a cylinder. This led all early work on thermodynamics to be based on systems in a conceptual box. Clausius's discovery and definition of entropy—one of the wonders of science—relied totally on infinitesimal changes from one equilibrium state of a confined system to another. The pioneers of statistical mechanics, the theoretical framework created above all by Clausius, James Clerk Maxwell, and Ludwig Boltzmann to provide a microscopic atomistic explanation of phenomenological thermodynamics, invariably considered models of gas molecules trapped in a box and forced to bounce off its walls and each other.

A rich conceptual framework, completely valid and immensely fruitful for confined systems, developed out of this simple model, and reached its definitive form in the work of J. Willard Gibbs. The model proved the existence of atoms and molecules, established their sizes, determined the incredible number of them in a grain of sand, and struck the death knell of Newtonian classical physics. That was when Planck discovered the first quantum effect in 1900. What's more, both the first and second law appeared to be founded

on a rock-solid principle: the impossibility of creating perpetual motion machines.

I don't deny the arrow of time. But the "box mentality" has led us to misunderstand what is happening in the universe.

It's therefore not surprising that few, if any, scientists have disagreed with the great astrophysicist Arthur Eddington's warning, "If your theory is found to be against the second law of thermodynamics I can give you no hope; there is nothing for it but to collapse in deepest humiliation." Einstein, surely a greater scientist than Eddington, was more cautious. A few years before his death, Einstein said of thermodynamics, "It is the only physical theory of universal content which I am convinced that, within the framework of applicability of its basic concepts, will never be overthrown." The caveat is all important: Do conditions in an expanding universe remain within the framework of applicability?

That is what I question. I don't suggest we can ever alter the facts that Thomson and Clausius first brought to light. Neither you nor I are going to get younger or see a shattered cup miraculously reassemble itself and jump back onto the table. There is a pervasive unidirectionality, an arrow of time, about the way things happen in the universe. Kelvin, the first to recognize its significance, called it

“a universal tendency in nature to the dissipation of mechanical energy.” I don’t deny the existence of the arrow, but I do suggest that the “box mentality” has led us to misunderstand what is happening in the universe and even blinded us to the beauty that it is creating. A one-way street need not lead to a scrap yard; it might bring us to a finely landscaped park.

Compare two situations. First, the molecules in their box. If, every now and then, you open it to look at them, you can be sure to find them filling the box uniformly and going through their habitual routine—bumping into each other with random outcomes. Nothing of interest develops. This, nevertheless, was the model used to interpret mundane measurements of pressure and temperature. It led to all those marvelous discoveries and much of the technology on which today we so depend. No wonder it inspired confidence.

But now picture the box in space with its walls suddenly removed. What will the molecules do? The answer’s in Siegfried Sassoon’s poem “Everyone Sang”:

As prisoned birds must find in freedom, Winging wildly across the
white
Orchards and dark-green fields; on – on – and out of sight.

In mathematical rather than poetic terms, the molecules soon cease to interact and fly apart, maintaining forever their release velocities and getting ever further from each other. In fact, a simple calculation may surprise you: The speed with which the molecules move apart approximates ever better the law of galactic recession

that Hubble announced in 1929. This simple Big Bang model does not look like disorder on the increase.

There is a greater mismatch between entropic disorder and reality in the very heart of Newton's theory of universal gravitation. He achieved fame by explaining not only Kepler's laws of planetary motion but also the fall of an apple. However, the problem of three bodies—he had in mind the earth, sun, and moon moving in their mutual gravitational fields—gave him headaches. Although a famously difficult problem, in 1772 the great mathematician Joseph-Louis Lagrange made some progress, including a significant discovery about the behavior of a “three-body universe” that was later shown to be true for any number of bodies. It concerns what is now called the center-of-mass moment of inertia, I . This measures the extent of the system—for bees it would be about the diameter of a swarm—and behaves in a characteristic universal way if a single condition is satisfied: The total energy of the system is not negative.

The beauty is in the ratios, and they persist forever even in the expanding universe.

To understand what the behavior is, assume with Newton that time flows forever forward from past to future. Then what Lagrange found is that I decreases from infinity in the distant past, passes through a unique minimum, and grows to infinity in the distant

future. I call this unique minimum a Janus Point. The Roman divinity can be invoked because he looks simultaneously in two opposite directions of time at once. What he sees is striking. In the region around the threshold on which he traditionally stands, the distribution of the particles (especially when there are many) is more uniform than anywhere else on the timeline of the universe. Then, in both directions, the particles cluster, taking on a shape that is more ordered and forming “galaxies.” From his vantage point, Janus can see this, but if you, being a mere mortal, were in such a universe you would necessarily be on one or the other side of the Janus point and could not “see through it” to the other side. You would find that the laws of nature around you do not distinguish a direction of time but that your universe gets ever more clumpy in one direction.

There is a precise, mathematically significant quantity that may be called complexity and increases (with small fluctuations) in both directions from Janus. The big difference from what entropy does is that growth of complexity reflects an increase of order, not disorder. The effects in confined and unconfined systems are the exact opposites of each other. Moreover, the increase of complexity in unconfined systems follows directly from the governing dynamical law whereas entropy increases in confined systems for statistical reasons.

Traditional arguments assume that somehow, for an as yet unfathomable reason, the universe gets in a special state of low entropy and correspondingly high order that is then remorselessly

destroyed. A model often given is molecules confined to a little box in the corner of a big box. That's the special initial condition. Now lift the lid of the little box; the laws of dynamics allow two quite different outcomes. It's conceivable, but barely so, that the molecules will collect in the corner of the little box and then be in an even more special state. But it is statistically more likely that the molecules will spread out into the large box and eventually fill it uniformly. This is a statistical explanation of the entropic arrow. Applied to the whole universe, a special initial condition of this kind has been dubbed the "Past Hypothesis" by the philosopher of science David Albert. The difficulty is that nothing in the known laws of nature explains the special initial condition.

Let's now think about the Janus point. It's unique and a special point. It isn't there for some inexplicable reason. Newton's laws say it must be there. Even if the weak condition on the energy is relaxed, something very like it in the form of a "Janus region" will almost always be present. The complexity will increase in both directions from it. The increase in order has a dynamical explanation and is what puts the direction into time. Moreover, beings on either side of the Janus point would think they are going forward in time and would have typically the same kind of experiences, just as two people walking down opposite sides of Mount Fuji in Japan would find the terrain and vegetation change in much the same way.

Doubts about the repeatedly claimed growth of disorder in the universe get greater when we consider what happens when, as the particles emerge from the melee at the Janus point—they are there

typically going in all possible directions—some of them come together as “Kepler pairs.” Except for encounters with other particles, which become exceptionally rare as the model universe expands and the typical distances between the particles become greater and greater, such pairs bond forever, settling down into ever more perfect elliptical motion about their common center of mass. They form exquisitely accurate rods, compasses, and clocks all in one. Their major axis defines an astronomical unit of length and a fixed compass direction (true north), while the period of their motion defines a unit of time. Does that look like disorder?

The Janus Point resolves the mismatch between a law that does not distinguish a direction of time and solutions that do.

William Blake hated Newton’s clockwork universe, as it came to be known. The poet thought it was reductive, but that was based on the appearance of the solar system, which does resemble clockwork. In fact, Newton was so amazed by its beauty and order he could not believe his laws could explain its existence—God must have set it up that way and keep a careful watch on it to see the order does not get disturbed. In fact, Kepler pairs are miniature solar systems and Newton’s laws create them out of chaos. His universe first makes clocks and then allows them to tell the time.

In the 19th century nobody had the remotest idea that the universe could be expanding, though the possibility might have been recognized when Lagrange made his discovery. The significance of the expanding universe is that it creates room for things to happen. William Thomson may have inadvertently set people thinking in the wrong way when he spoke about universal dissipation of mechanical energy. Among multiple talents, he was a brilliant engineer and, like Carnot with his study of steam engines, was always looking for ways to improve the human lot. A negative connotation attaches to “dissipation”; had Thomson used the neutral word “spreading,” positive as well as negative possibilities might have been seen.

There is a beautiful effect I often go to watch on afternoon walks near my home. A tree hangs above a brook where the water flows smoothly over a ford. If it has rained, drops of water fall from the tree onto the water, creating circular waves that spread out over the flowing water. You can watch the effect for far too long if you need to get on with work. The waves created by drops that hit the water at different points meet and pass through each other, each emerging intact. If the brook had no banks and the water no viscosity, that would create the condition that radiation finds in the vast voids of our expanding universe, and the patterns would remain as beautiful forever. That’s the difference between an open and a closed system.

Before the banks have their effect in the brook, mechanical energy is first entirely within each falling drop but is then spread out in the circular waves. Except at or near equilibrium, Clausius’s entropy is a quantity difficult to define and measure; Thomson’s dissipation is a

qualitative effect that is both universal and easy to recognize. He mentioned the heat created by friction as an example of dissipation; the illustration has been endlessly repeated. But Thomson loved the river Kelvin in Glasgow and took his baronial name from it. He must have often seen water drops falling onto the river. If in the title of his 1852 paper, which was so influential, he had changed “dissipation” into “spreading”—it would have been a better characterization—who can say how that might have changed the interpretation of the second law, especially after Hubble’s monumental discovery?

The circle is the most perfect geometrical figure and pi, which relates its circumference to its radius, bids fair to be the most perfect number. “Ah,” you say, “a thing of beauty may have been born, but it decays as the waves get shallower and shallower.” To which I answer that you forget the lessons of *Gulliver’s Travels* and the relativity of size. It is only ratios that have physical meaning. The beauty is in the ratios, and they persist forever even in the expanding universe.

I will end by saying that the notion of the Janus point, which resolves the mismatch between a law that does not distinguish a direction of time and solutions that do, might turn out to be less significant than how expansion of the universe can change the way we interpret the second law and look at the universe. I say this because the scenario I have described assumes that the size of the universe remains finite at the Janus point. But it can actually become zero in Newtonian theory and does so typically in Einstein’s

general theory of relativity. That opens up extremely interesting possibilities that just might lead to a truly new theory of time.

Julian Barbour is an independent theoretical physicist and past visiting professor in physics at the University of Oxford. His new book, The Janus Point: A New Theory of Time, is available from Basic Books.

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