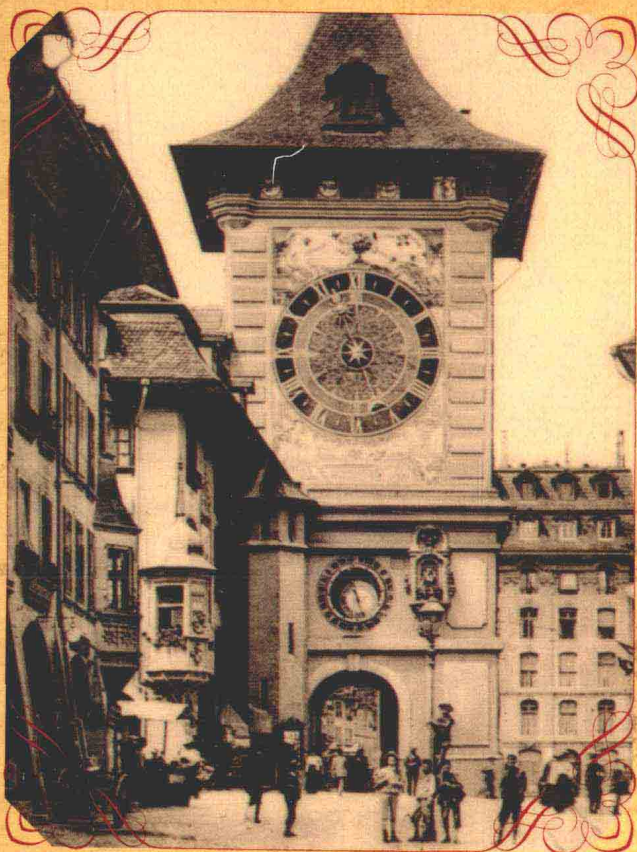


Einstein's CLOCKS, Poincaré's MAPS

EMPIRES OF TIME



PETER GALISON

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CLOCKS,
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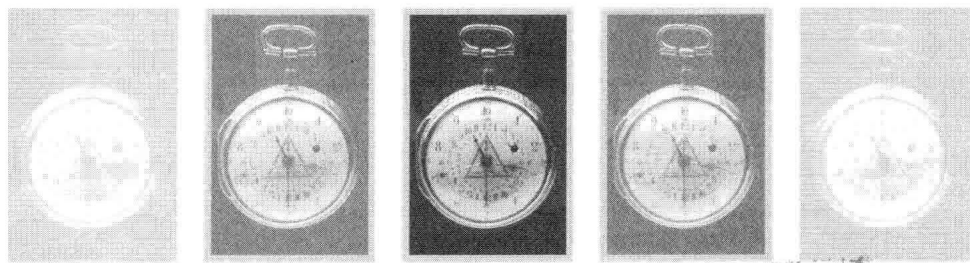
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EINSTEIN'S CLOCKS, POINCARÉ'S MAPS

Empires of Time



Peter Galison



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*For Sam and Sarah,
who have taught me the right use of time*

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EINSTEIN'S
CLOCKS,
POINCARÉ'S
MAPS

SYNCHRONY

TRUE TIME WOULD never be revealed by mere clocks—of this Newton was sure. Even a master clockmaker’s finest work would offer only pale reflections of the higher, absolute time that belonged not to our human world, but to the “sensorium of God.” Tides, planets, moons—everything in the Universe that moved or changed—did so, Newton believed, against the universal background of a single, constantly flowing river of time. In Einstein’s electrotechnical world, there was no place for such a “universally audible tick-tock” that we can call time, no way to define time meaningfully except in reference to a definite system of linked clocks. Time flows at different rates for one clock-system in motion with respect to another: two events simultaneous for a clock observer at rest are not simultaneous for one in motion. “Times” replace “time.” With that shock, the sure foundation of Newtonian physics cracked; Einstein knew it. Late in life, he interrupted his autobiographical notes to apostrophize Sir Isaac with intense intimacy, as if the intervening centuries had vanished; reflecting on the absolutes of space and time that his theory of relativity had shattered, Einstein wrote: “Newton, forgive me [‘Newton, verzeih’ mir’]; you found the only way which, in your age, was just about possible for a man of highest thought—and creative power.”¹

At the heart of this radical upheaval in the conception of time lay an extraordinary yet easily stated idea that has remained dead-center in physics, philosophy, and technology ever since: *To talk about time, about simultaneity at a distance, you have to synchronize your clocks. And if you want to synchronize two clocks, you have to start*

with one, flash a signal to the other, and adjust for the time that the flash takes to arrive. What could be simpler? Yet with this procedural definition of time, the last piece of the relativity puzzle fell into place, changing physics forever.

This book is about that clock-coordinating procedure. Simple as it seems, our subject, the coordination of clocks, is at once lofty abstraction and industrial concreteness. The materialization of simultaneity suffused a turn-of-the-century world very different from ours. It was a world where the highest reaches of theoretical physics stood hard by a fierce modern ambition to lay time-bearing cables over the whole of the planet to choreograph trains and complete maps. It was a world where engineers, philosophers, and physicists rubbed shoulders; where the mayor of New York City discoursed on the conventionality of time, where the Emperor of Brazil waited by the ocean's edge for the telegraphic arrival of European time; and where two of the century's leading scientists, Albert Einstein and Henri Poincaré, put simultaneity at the crossroads of physics, philosophy, and technology.

Einstein's Times

For its enduring echoes, Einstein's 1905 article on special relativity, "On the Electrodynamics of Moving Bodies," became the best-known physics paper of the twentieth century, and his dismantling of absolute time is its crowning feature. Einstein's argument, as usually understood, departs so radically from the older, "practical" world of classical mechanics that the paper has become a model of revolutionary thought, seen as fundamentally detached from a material, intuitive relation to the world. Part philosophy and part physics, Einstein's rethinking of simultaneity has come to stand for the irresolvable break between modern physics and all earlier framings of time and space.

Einstein began his relativity paper with the claim that there was an asymmetry in the then-current interpretation of electrody-

ics, an asymmetry not present in the phenomena of nature. Almost all physicists around 1905 accepted the idea that light waves—like water waves or sound waves—must be waves *in* something. In the case of light waves (or the oscillating electric and magnetic fields that constituted light), that something was the all-pervasive *ether*. Most late-nineteenth-century physicists considered the ether to be one of the great ideas of their era, and they hoped that once properly understood, intuited, and mathematized, the ether would lead science to a unified picture of phenomena from heat and light to magnetism and electricity. Yet it was the ether that gave rise to the asymmetry that Einstein rejected.²

In physicists' usual interpretation, Einstein wrote, a moving magnet approaching a coil at rest in the ether produces a current indistinguishable from the current generated when a moving coil approaches a magnet at rest in the ether. But the ether itself could not be observed, so in Einstein's view there was but a single observable phenomenon: coil and magnet approach, producing a current in the coil (as evidenced by the lighting of a lamp). But in its then-current interpretation, electrodynamics (the theory that included Maxwell's equations—describing the behavior of electric and magnetic fields—and a force law that predicted how a charged particle would move in these fields) gave two different explanations of what was happening. Everything depended on whether the coil or the magnet was in motion with respect to the ether. If the coil moved and the magnet remained still in the ether, Maxwell's equations indicated that the electricity in the coil experienced a force as the electricity traversed the magnetic field. That force drove the electricity around the coil lighting the lamp. If the magnet moved (and coil stayed still), the explanation changed. As the magnet approached the coil, the magnetic field near the coil grew stronger. This changing magnetic field (according to Maxwell's equations) produced an electric field that drove the electricity around the stationary coil and lit the lamp. So the standard account gave *two*

explanations depending on whether one viewed the scene from the point of view of the magnet or the point of view of the coil.

As Einstein reframed the problem there was *one* single phenomenon: coil and magnet approached each other, lighting the lamp. As far as he was concerned, *one* observable phenomenon demanded *one* explanation. Einstein's goal was to produce that single account, one that did not refer to the ether at all, but instead depicted the two frames of reference, one moving with the coil and one with the magnet, as offering no more than two perspectives on the same phenomenon. At stake, according to Einstein, was a founding principle of physics: relativity.

Almost three hundred years earlier, Galileo had similarly questioned frames of reference. Picturing an observer in a closed ship's cabin, borne smoothly across the seas, Galileo reasoned that no mechanical experiment conducted in a below-deck laboratory would reveal the motion of the ship: fish would swim in a bowl just as they would were the bowl back on land; drops would not deviate from their straight drip to the floor. There simply was no way to use any part of mechanics to tell whether a room was "really" at rest or "really" moving. This, Galileo insisted, was a basic feature of the mechanics of falling bodies that he had helped create.

Building on this traditional use of the relativity principle in mechanics, Einstein in his 1905 paper raised relativity to a principle, asserting that physical processes are independent of the uniformly moving frame of reference in which they take place. Einstein wanted the relativity principle to include not only the mechanics of drops dripping, balls bouncing, and springs springing but also the myriad effects of electricity, magnetism, and light.

This relativity postulate ("no way to tell which unaccelerated reference frame was 'truly' at rest") gave rise to an additional assumption that proved even more surprising. Einstein noted that experiments did not show light traveling at any speed other than 300,000 kilometers per second. He then *postulated* that this was