Space, Time, and Spacetime

Prof. David Kaiser

This image is public domain.

Motion unit

Overarching questions:

Are the motions of objects subject to universal laws?
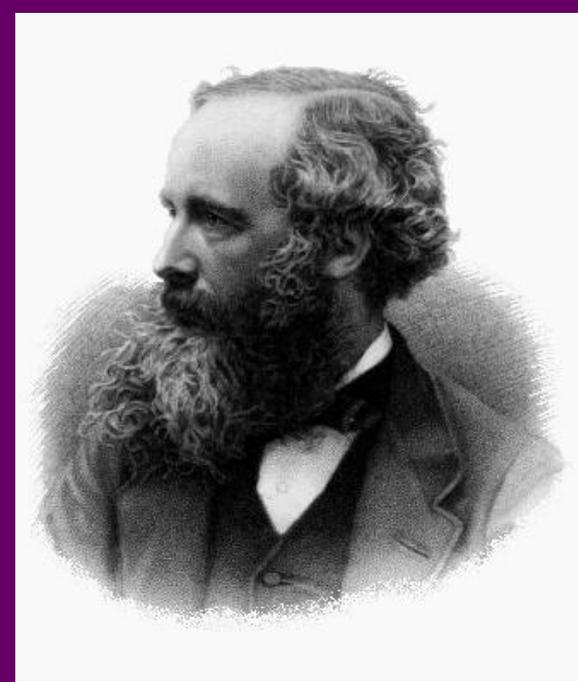Does science drive technology, or the other way around?

I. Motion through the Ether
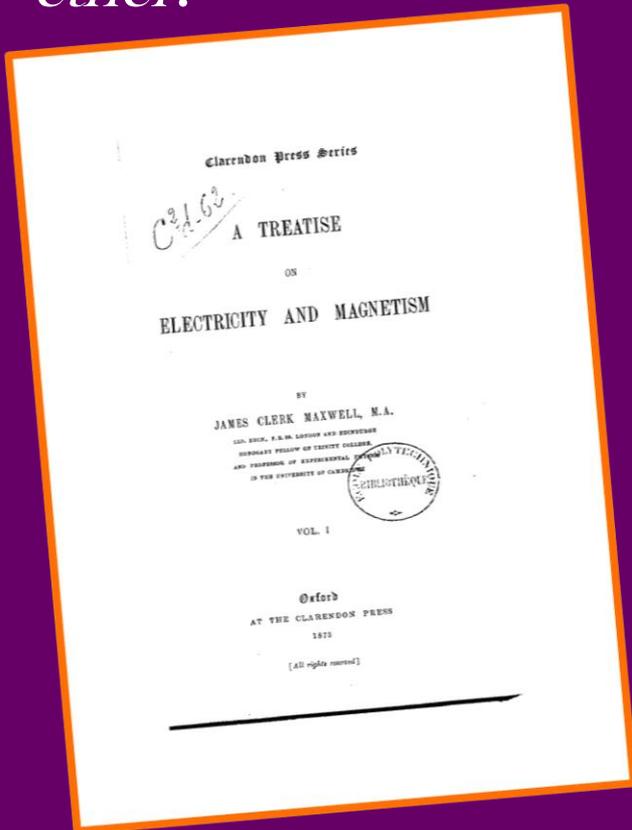
II. Patent Clerk, Third Class

III. Clock Coordination

Readings: Einstein, "On the Electrodynamics of Moving Bodies";
Eisenstaedt, *Curious History of Relativity,* 24-57.

Maxwell's Medium

Electrical actions are "effected, not by direct action at a distance, but by means of a distribution of stress in a medium extending continuously" throughout the universe: the *ether*.

James Clerk Maxwell (1831 – 1879)

Clarendon Press Series

A TREATISE

ON

ELECTRICITY AND MAGNETISM

BY

JAMES CLERK MAXWELL, M.A.

VOL. I

Oxford

AT THE CLARENDON PRESS

1873

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Wm. Thomson: "Stick your hand in a bowl of jelly, and see how it wiggles and vibrates as you move your hand around."

Maxwell's Waves

"The velocity of
transverse undulations in
our hypothetical medium
agrees so exactly with the
velocity of light calculated
from optical experiments
that we can scarcely avoid
the inference that light consists of the transverse
undulations of the same medium which is the cause of
electric and magnetic phenomena." (1864)

Graph of the changing amplitude of the electric and
magnetic fields of a light wave over distance removed
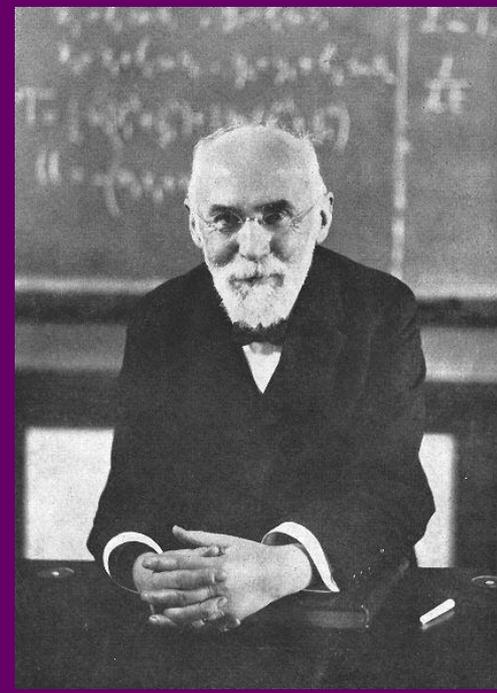due to copyright restrictions.

Luminiferous Ether

Lorentz: Sources in Motion

Lorentz, 1890s: What if the source or receiver of light is in *motion*?

Galileo-Newton:

$$x\square = x + vt$$

$$t\square = t$$

Hendrik Lorentz (1853 – 1928)

But then solutions to Maxwell's (transformed) wave equation are no longer sines and cosines – and yet we measure light to behave like sines and cosines all the time, on our moving earth.

Lorentz introduced "local time," a purely fictitious time variable: $t\square = f(x, t, v)$. The mathematical trick restored the form of Maxwell's wave equation.

Interferometer

Albert Michelson (1852 – 1931) tried to *measure* the earth's motion through the ether: look for "ether wind" effects on light.

Diagram of an interferometer removed due to copyright restrictions.

With his assistant (Edward Morley), Michelson searched for *years* to find evidence of the earth's motion through the ether.

"Second order": sensitive to $(v/c)^2$.

1883: Despite years of careful measurement, they found *no evidence* of the earth's motion through the ether.

Lorentz Contraction

Lorentz was concerned about Michelson's (null) result. He thus had a *physical* as well as a *mathematical* reason to change x' and t'.

$$L' = L / \gamma$$

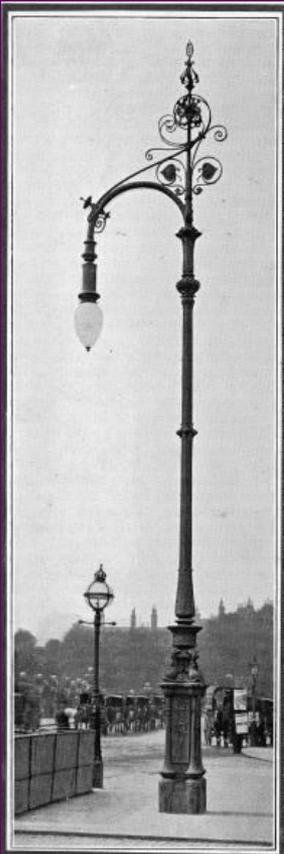Graph of the Lorentz Contraction removed due to copyright restrictions.

Picture of a distorted sphere removed due to copyright restrictions.

$$\gamma = \frac{1}{\sqrt{1 - (v/c)^2}}$$

Young Albert

Albert Einstein (1879 – 1955) was born in Ulm, Germany. He dreamed of joining his father's and uncle's business in electrical engineering.

He dropped out of high school, took the entrance exam for the ETH in Zürich in 1895 – and failed. He passed the second time.

He then proceeded to cut classes to read on his own: Maxwell, Boltzmann, etc.

Electric street lighting, ca. 1900

Elektrotechnische Fabrik

J. Einstein & Cie.

München.

Ausführung elektrischer Beleuchtungs-anlagen in jedem Umfange.

Ausführung elektrischer Kraftüber-tragungs-anlagen jeder Grösse.

Fabrikation von

Dynamo-Maschinen

für Beleuchtung, Kraftübertragung und Elektrolyse, Bogenlampen, Elektrizitätszählern, Mess- und Regulirapparaten.
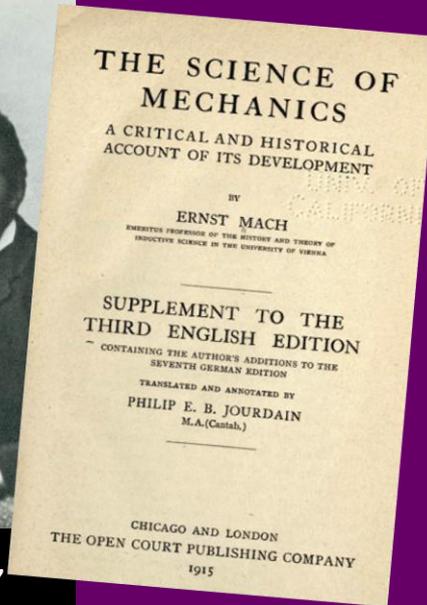
Patent Officer, 3rd Class

Einstein had so annoyed his professors that upon graduation he couldn't get a job. With help from his friend's father, he finally landed a position in the patent office in Bern, Switzerland.

Einstein at the Patent Office, 1905

THE SCIENCE OF MECHANICS

A CRITICAL AND HISTORICAL ACCOUNT OF ITS DEVELOPMENT

BY

ERNST MACH

EMERITUS PROFESSOR OF THE HISTORY AND THEORY OF INDUCTIVE SCIENCE IN THE UNIVERSITY OF VIENNA

SUPPLEMENT TO THE THIRD ENGLISH EDITION

CONTAINING THE AUTHOR'S ADDITIONS TO THE SEVENTH GERMAN EDITION

TRANSLATED AND ANNOTATED BY

PHILIP E. B. JOURDAIN
M.A.(Cantab.)

CHICAGO AND LONDON
THE OPEN COURT PUBLISHING COMPANY
1915

"Olympia Academy": Solovine, Habicht, Einstein, ca. 1905

Even for Einstein, it's not what you know, but whom you know...

Not a Bad Year...

While working at the patent office, Einstein submitted several papers to the *Annalen der Physik*.

March 1905: light quanta
May 1905: Brownian motion
June 1905: special relativity
September 1905: $E = mc^2$

In conclusion, let me note that my friend and colleague M. Besso steadfastly stood by me in my work on the problem discussed here, and that I am indebted to him for several valuable suggestions.

Annalen der Physik 17 [1905]: 891-921

"An Asymmetry in the Explanation"

When the magnet and coil were in relative motion, an electric current was produced.

Physicists had given two completely distinct explanations for the effect, depending on which item was moving.

Diagram of how electricity is generated using a coil and a magnet removed due to copyright restrictions.

See: http://www.gcse.com/energy/generation.htm

Einstein insisted that physicists had been too clever by half: there was only *one phenomenon*, so there should only be *one explanation*.

"Principle of Relativity"

"We will raise this conjecture (the purport of which will hereafter be called the "Principle of Relativity") to the status of a postulate, and also introduce another postulate which is only apparently irreconcilable with the former, namely that light is always propagated in empty space with a definite velocity c which is independent of the state of motion of the emitting body. These two postulates suffice for the attainment of a simple and consistent theory of the electrodynamics of moving bodies based on Maxwell's theory for stationary bodies. The introduction of the "luminiferous ether" will prove to be superfluous inasmuch as the view here to be developed will not require an "absolute stationary space" provided with special properties, nor assign a velocity vector to a point in space in which electromagnetic processes take place. "

On the Electodynamics of Moving Bodies, Albert Einstein

1. Laws of physics are valid in any inertial frame of reference
2. Speed of light is constant, independent of motion of source.

Kinematics First
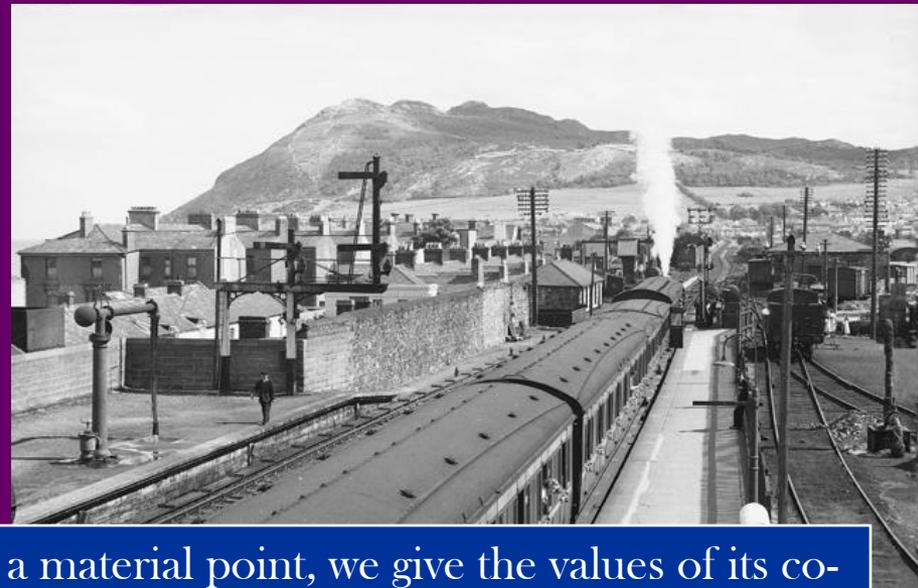
If we wish to describe the *motion* of a material point, we give the values of its co-ordinates as functions of the time. Now we must bear carefully in mind that a mathematical description of this kind has no physical meaning unless we are quite clear as to what we understand by "time." We have to take into account that all our judgments in which time plays a part are always judgments of *simultaneous events*. If, for instance, I say, "That train arrives here at 7 o'clock," I mean something like this: "The pointing of the small hand of my watch to 7 and the arrival of the train are simultaneous events."

On the Electrodynamics of Moving Bodies, Albert Einstein.

Inspired by Mach, Einstein *began* with kinematics, not dynamics.

Relativity of Simultaneity

If there is no absolute time, how can we compare times measured in different places? By sending *light signals*, since c = constant.

Diagram explaining relativity of simultaneity removed due to copyright restrictions.

See: http://upload.wikimedia.org/wikipedia/commons/9/96/Einstein_train_relativity_of_simultaneity.png

Thus we see that we cannot attach any *absolute* signification to the concept of simultaneity, but that two events which, viewed from a system of co-ordinates, are simultaneous, can no longer be looked upon as simultaneous events when envisaged from a system which is in motion relatively to that system. –Albert Einstein, *On the Electrodynamics of Moving Bodies*

Time Dilation

Diagram explaining Time Dilation removed due to copyright restrictions.

See: http://en.wikipedia.org/wiki/Minkowski_diagram

$$\Delta t' = \gamma \, \Delta t$$
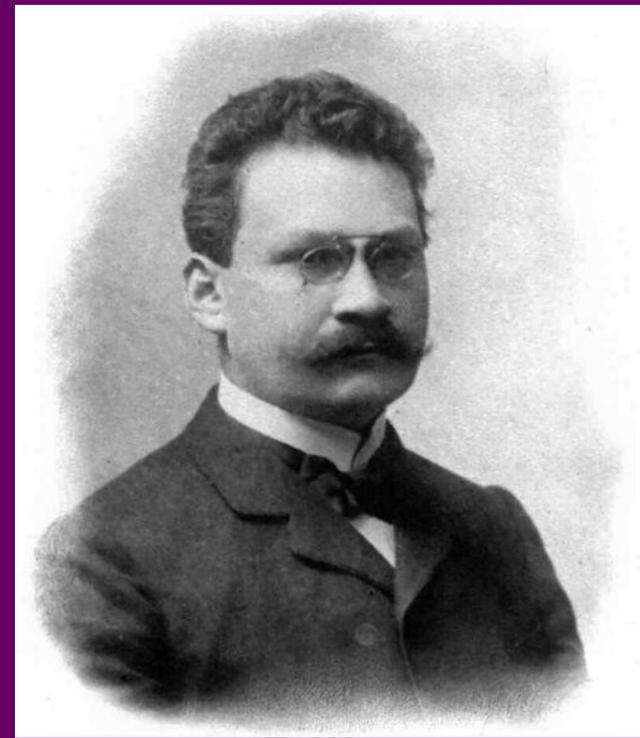
A moving clock appears to run *slowly*.

Mass and Energy
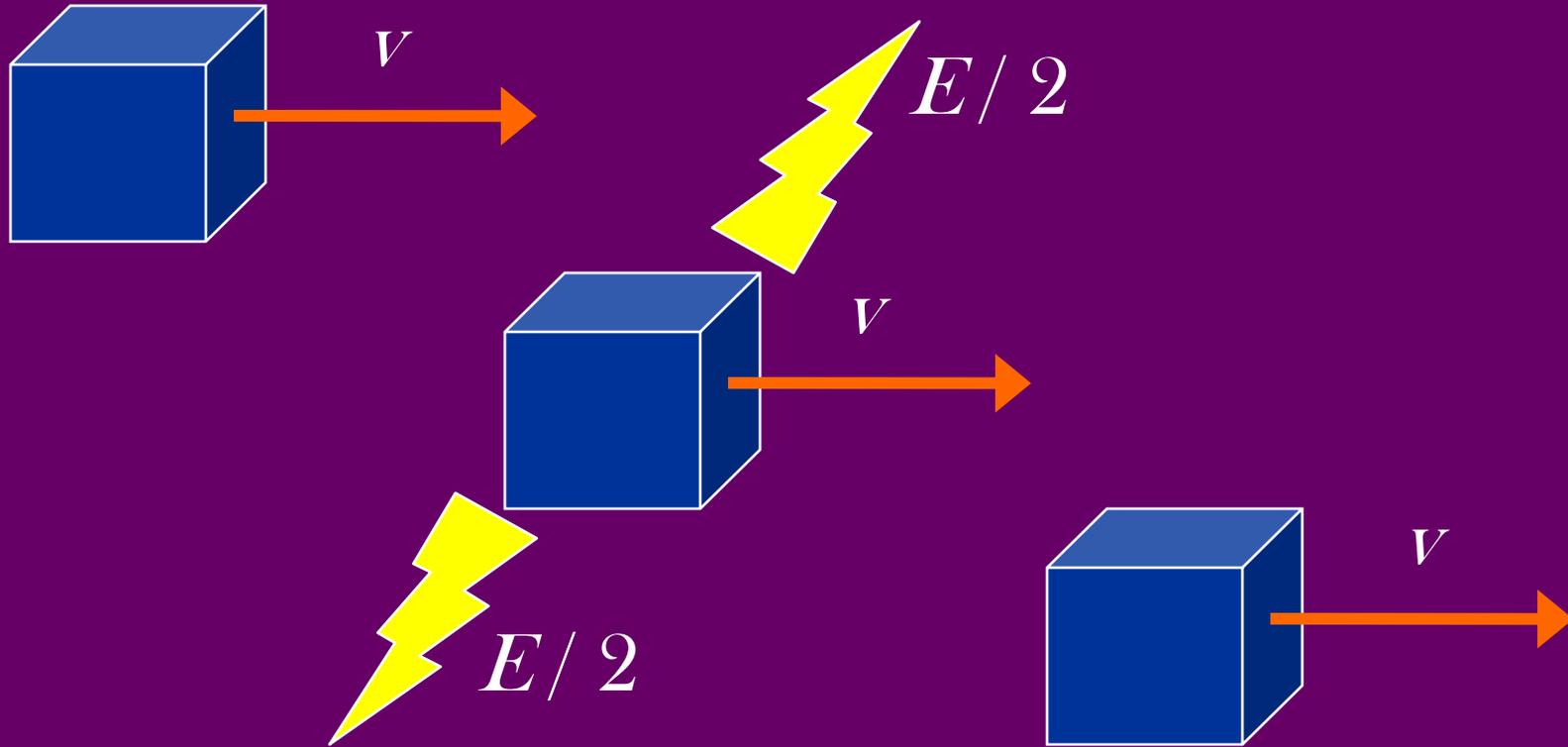
$$\Delta\text{KE} = \frac{1}{2}\left(\frac{E}{c^2}\right) v^2 + ..., \text{ or} \qquad E = \Delta m\, c^2$$

Spacetime

To Minkowski, (x, t) and (x', t') were merely *projections* of events onto arbitrary axes. Yet a combination of those coordinates was *invariant*.

$$s^2 = c^2 (\Delta t)^2 - (\Delta x)^2 = c^2 (\Delta t')^2 - (\Delta x')^2$$

Hermann Minkowski (1864 – 1909)

"Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve independence." (1908)

A Minkowski diagram removed due to copyright restrictions.

Einstein and Experiment

For a long time, physicists, philosophers, and historians read Einstein's relativity as a direct response to the Michelson-Morley experiment.

Image of "Thematic Origins of Scientific Thought Kepler to Einstein," Gerald Holton, removed due to copyright restrictions.

Yet it's not clear whether Einstein even *knew* about the results at the time. Either way, they don't seem to have played much role in his thinking.

Examples of this sort, together with the unsuccessful attempts to discover any motion of the earth relatively to the "light medium," suggest that the phenomena of electrodynamics as well as of mechanics possess no properties corresponding to the idea of absolute rest. They suggest rather that, as has already been shown to the first order of small quantities, the same laws of electrodynamics and optics will be valid for all frames of reference for which the equations of mechanics hold good.

On the Electrodynamics of Moving Bodies, Albert Einstein.

Does that mean that Einstein was uninterested in experiments?

Train Time

Until the late 19th century, there were no coordinated time zones. Each town kept local time, based on a clock in its town square.
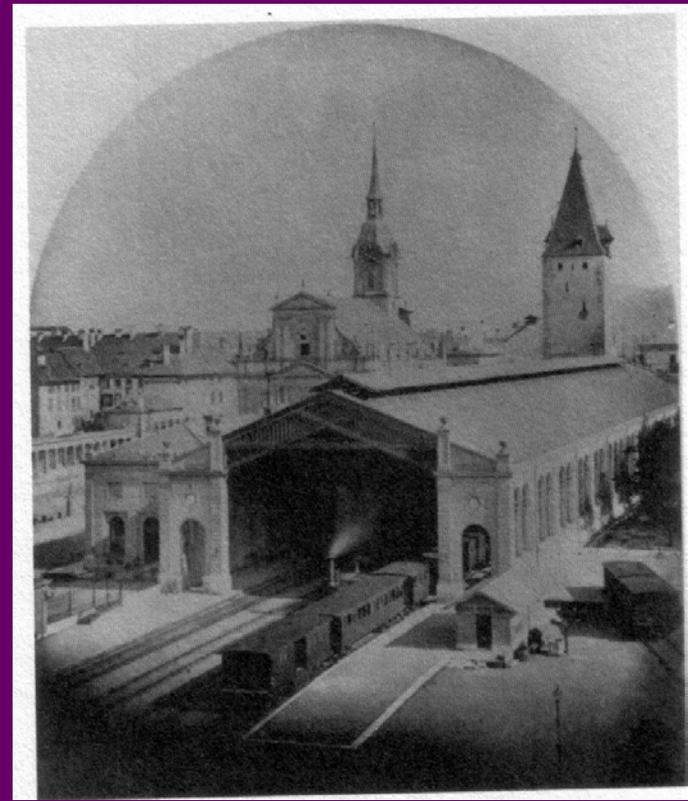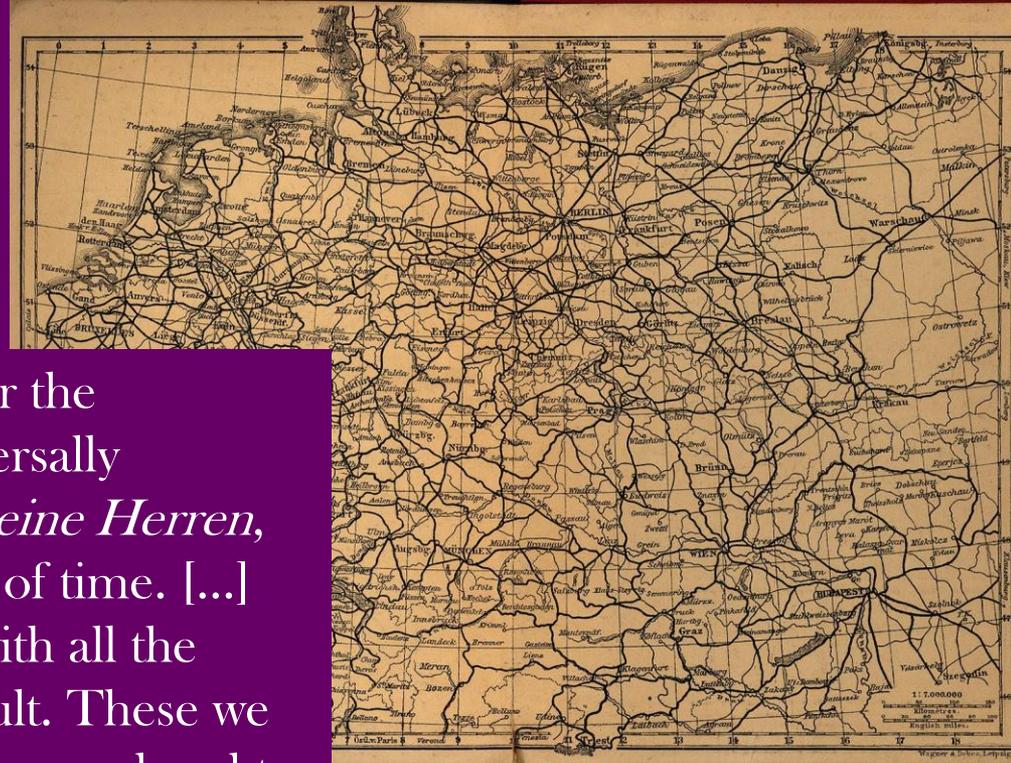

Bern train station, ca. 1860

French train wreck, 1895

Passengers riding from Boston to New York City had to change their watches by 37 minutes after their trip.

Time Zones

German railway system, 1910

"That unity of time is indispensible for the satisfactory operating of railways is universally recognized, and is not disputed. But, *meine Herren*, we have in Germany five different units of time. [...] We have thus in Germany five zones, with all the drawbacks and disadvantages which result. These we have in our own fatherland, besides those we dread to meet at the French and Russian boundaries. This is, I may say, a ruin which has remained standing out of the once splintered condition of Germany, but which, since we have become an empire, it is proper should be done away with."

Count von Moltke, 1891

Especially relevant after 1870 war with France, and 1871 unification of Germany.

All during Einstein's childhood.

Coordinating Clocks at a Distance

Main idea: install massive "mother clocks" in central train stations, connected to other clocks via telegraph or radio signals.
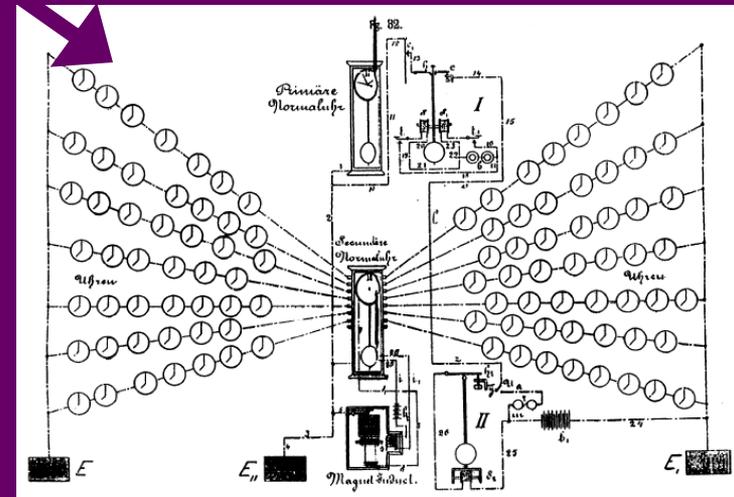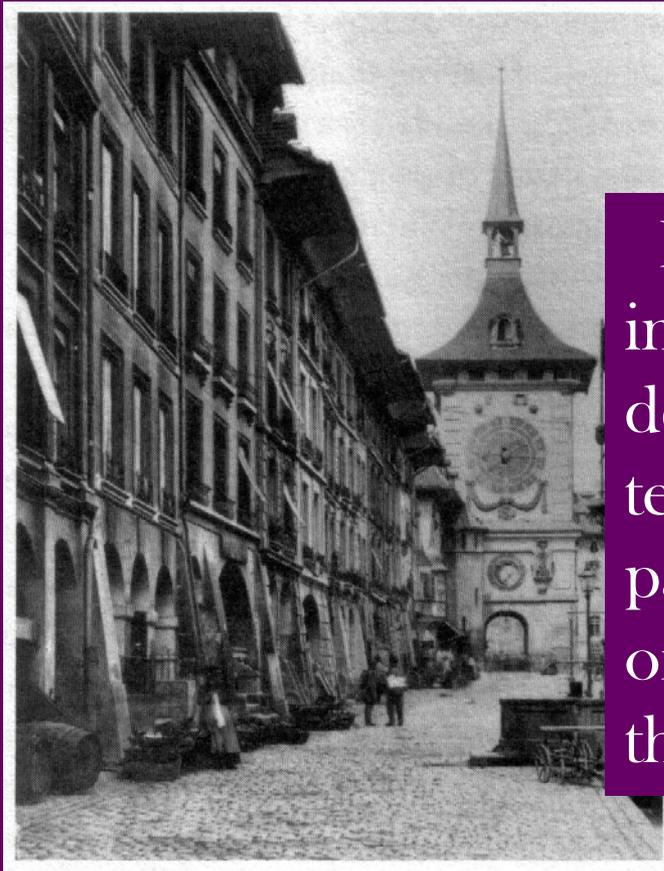
Image of "Einstein's Clocks, Poincare's Maps: Empires of Time," Peter Galison, removed due to copyright restrictions.
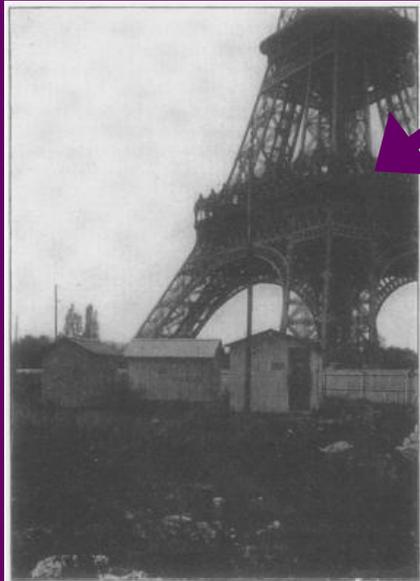
Eiffel Tower radio station, ca. 1910
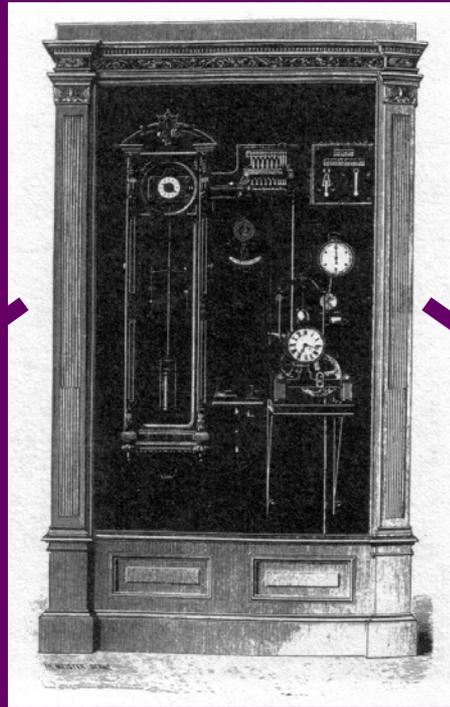
"Mother clock" in Neuchatel, Switzerland, ca. 1920

Time synchronization scheme, 1890

Patents and Pathways

Patents on clock coordination components, 1903–1905

Einstein was immersed in these devices: at the electro-technical desk at the patent office, and even on his stroll to get to the patent office.

Coordinated clock on Einstein's block, 1905
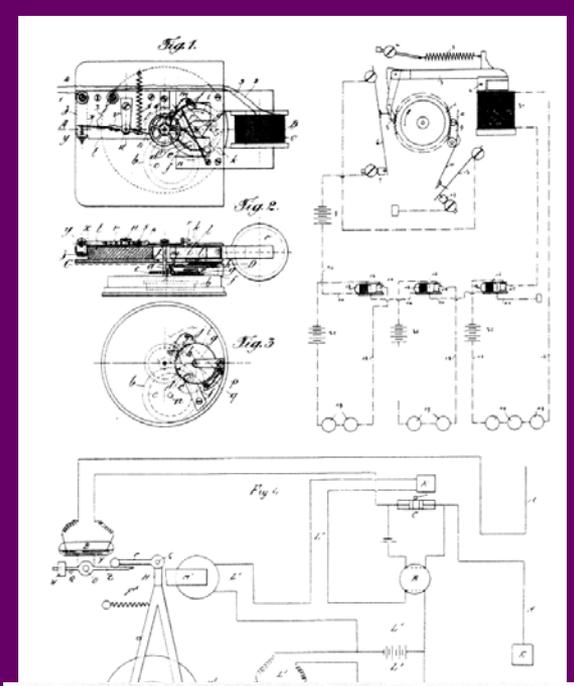
Coordinated clock network throughout Bern, 1905

Re-Reading Einstein
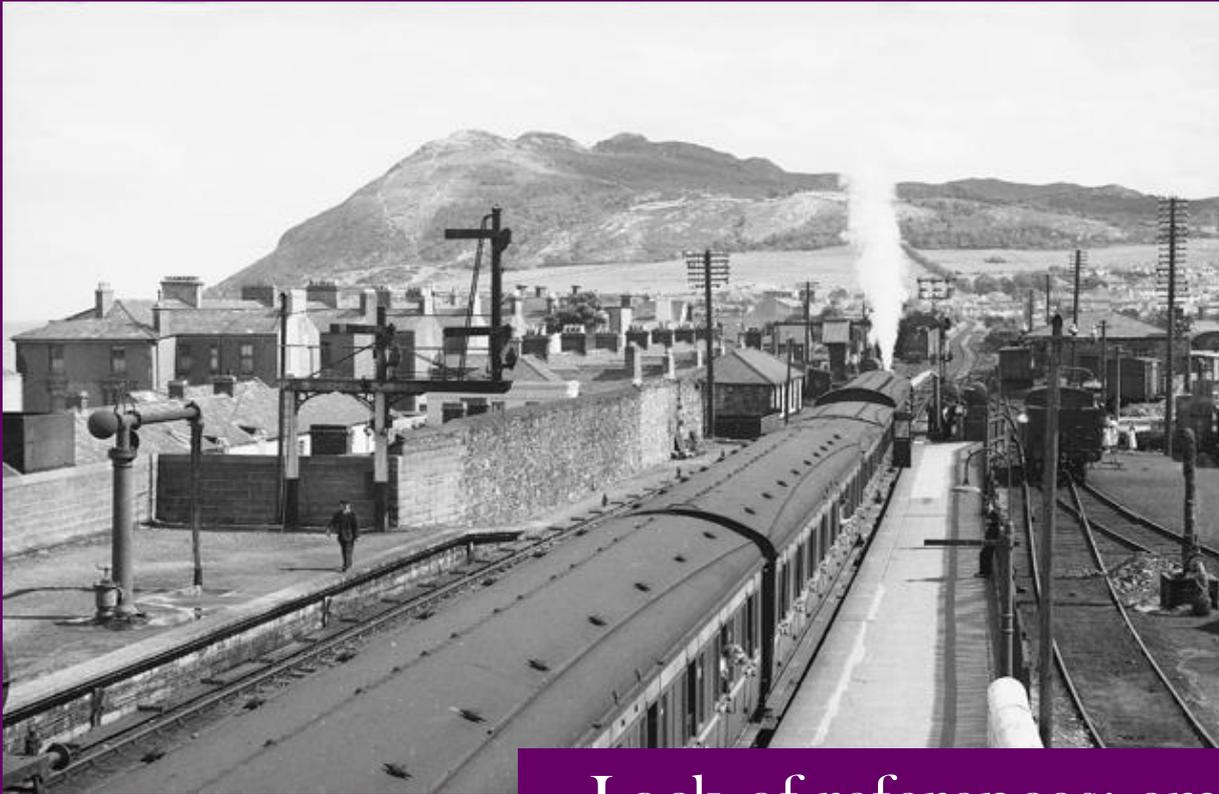
Lack of references: emphasize priority, downplay precedents;

Focus on operational details of measuring space, time, and simultaneity.
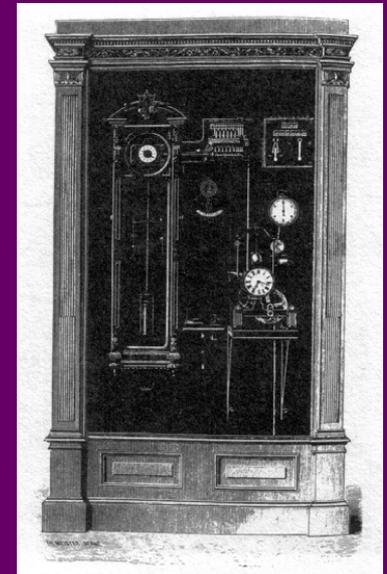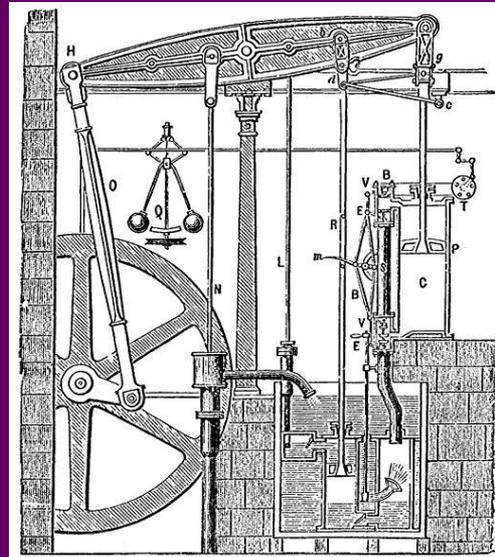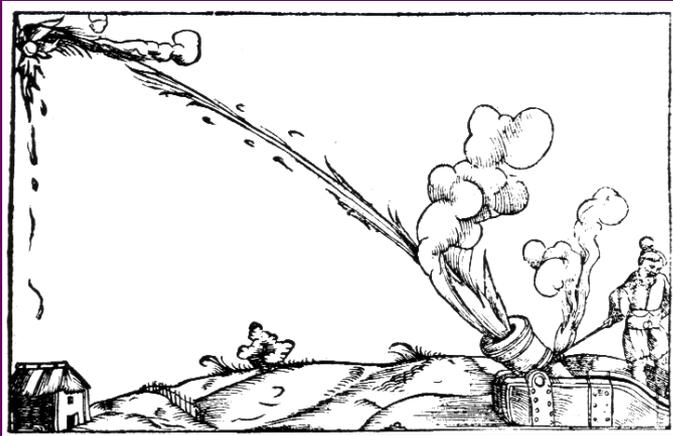
Looks like a patent application...

The Science of Motion

Universal laws vs. regularities or tendencies.

Move from observable motions (Aristotle, Galileo, Newton); to the effects of invisible motions (Joule, Thomson, Clausius); to extreme motions (Einstein).

Constant interplay between science and technology.

STS.003 The Rise of Modern Science
Fall 2010