Some more instructive quotes

Nobel Prize 2011 for the discovery of quasicrystals:

"It shook the foundations of solid-state science. The discovery has actually left us knowing less than we knew before the discovery."

Schrödinger:
We never experiment with just one electron or atom or (small) molecule. In thought-experiments we sometimes assume that we do; this invariably entails ridiculous consequences...

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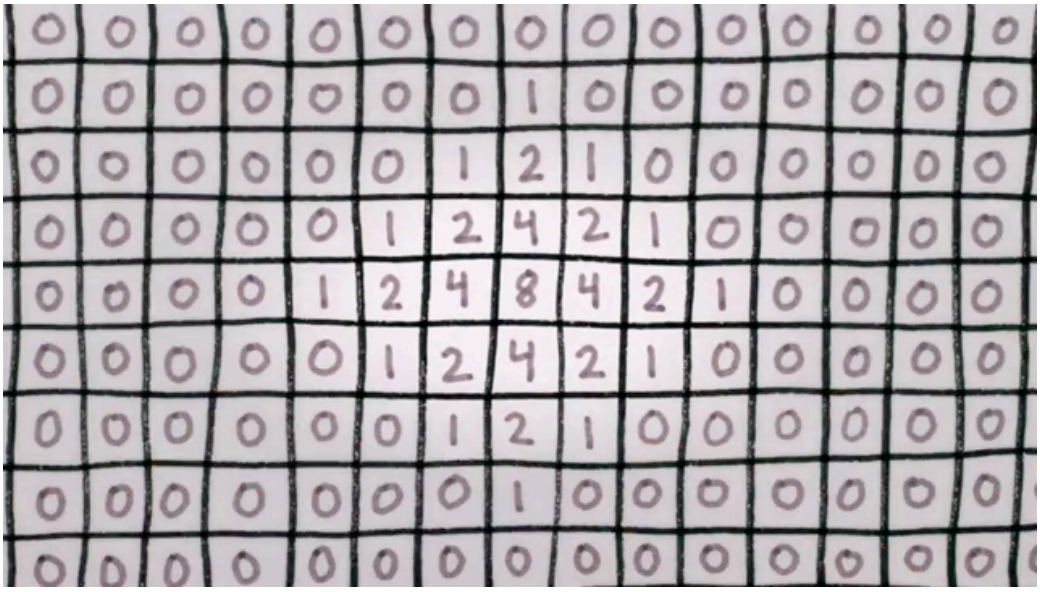
What is the meaning of the E field?

(a) It tells us about the position of a photon
(b) It tells us about the energy of the photon
(c) It tells us the force a charged particle would feel at any given position
(d) It tells us about the probability of finding a particle at any given position
(e) It tells us about the charge present at any given position

Telekinesis



http://www.youtube.com/watch?v=NMgcX8UNIGY

How can the field be both "the probability amplitude for finding a photon" and "the force a particle would feel"?

ANSWER: in the modern view, all forces arise by "exchanging" particles. The Earth is surrounded by a field of "gravitons" and if I stand somewhere near the Earth, it's those gravitons that collide with me and pull me down ("locally").

There are only 4 forces (gravity, electromagnetism, and two nuclear forces) -- all non-gravitational forces you're used to (your hand holding a coffee cup, the floor keeping you from falling to the center of the Earth) are electromagnetic!
And all electromagnetic forces have to do with exchanging photons!

How does particle exchange explain forces?

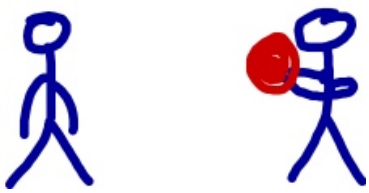
http://particleadventure.org/unseen.html

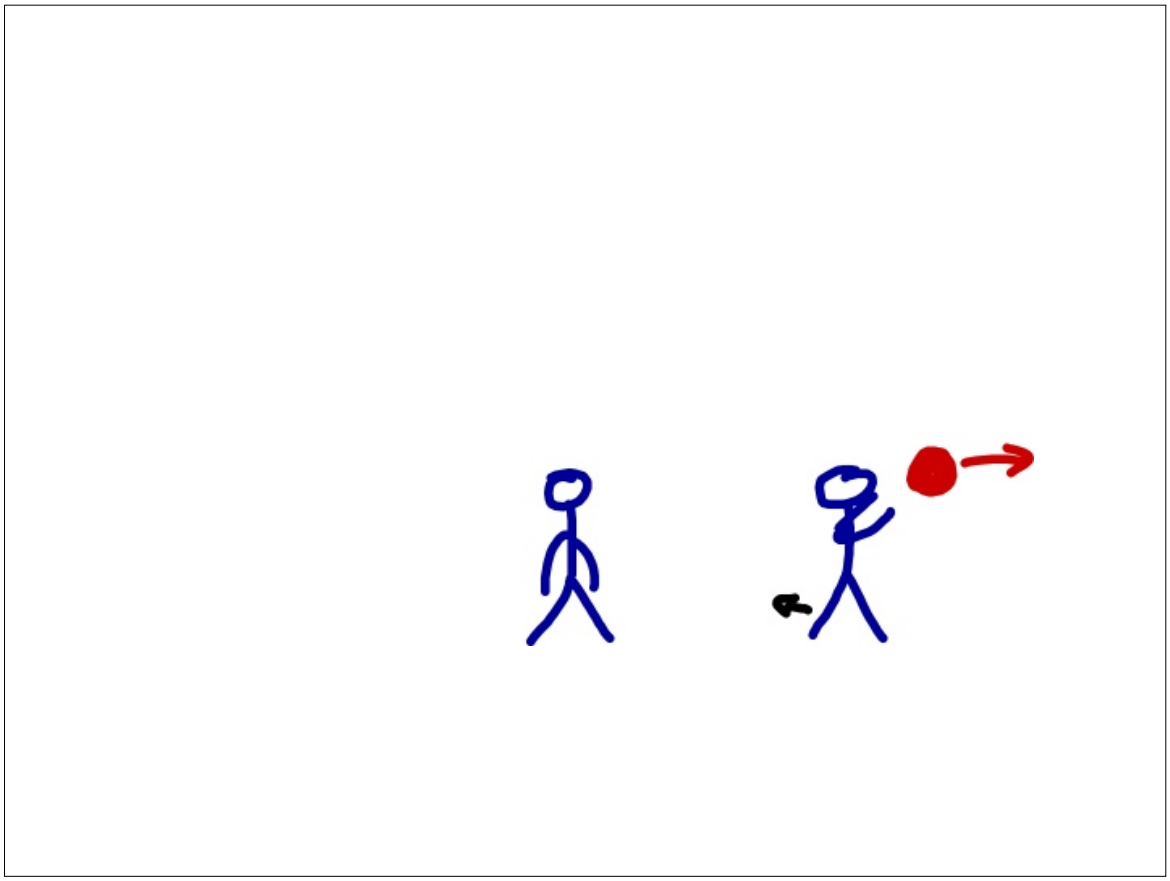
How does particle exchange explain forces?

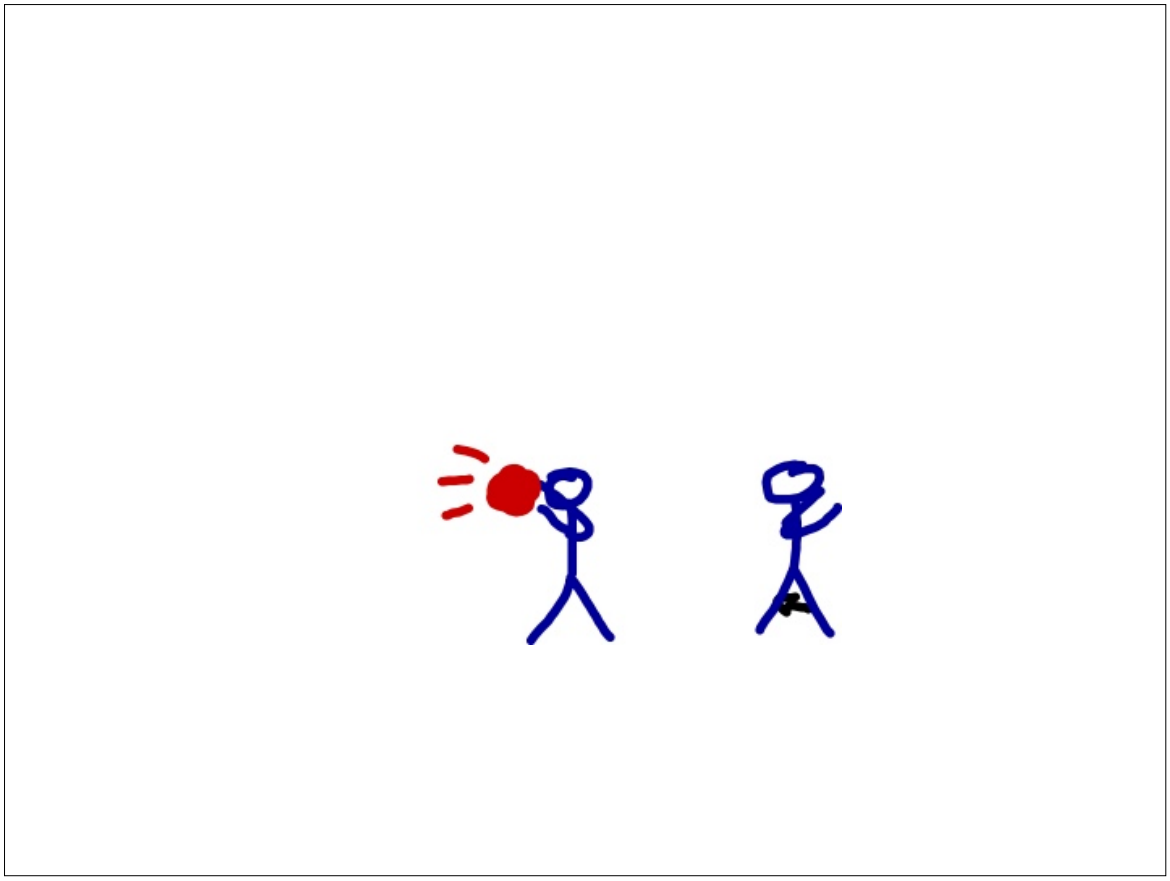
Question: what about *attractive* forces?

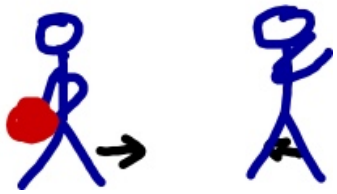
QM is really weird.
Heisenberg uncertainty principle: if you know something's momentum (velocity), you can't know its position.

If I "toss" a photon to the right, we know it's moving to the right, but we don't actually know where it is...
you can "catch" this photon even if you're on my left.









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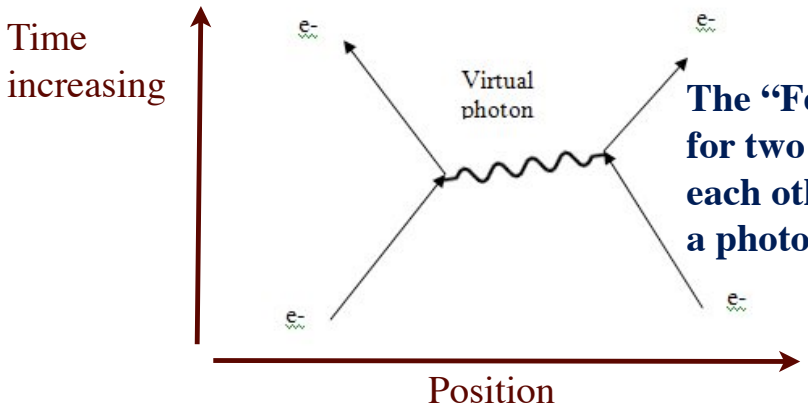
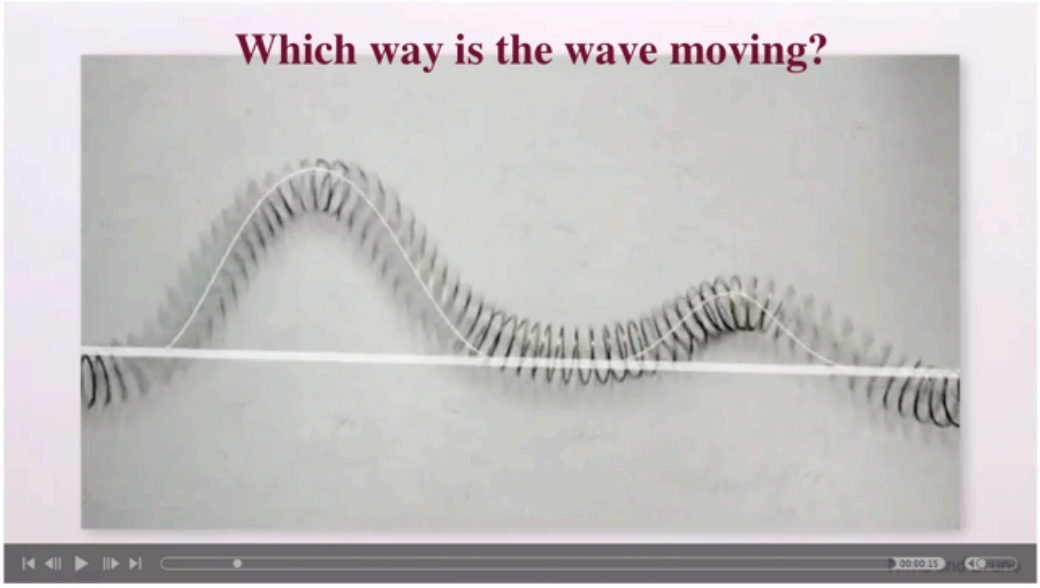
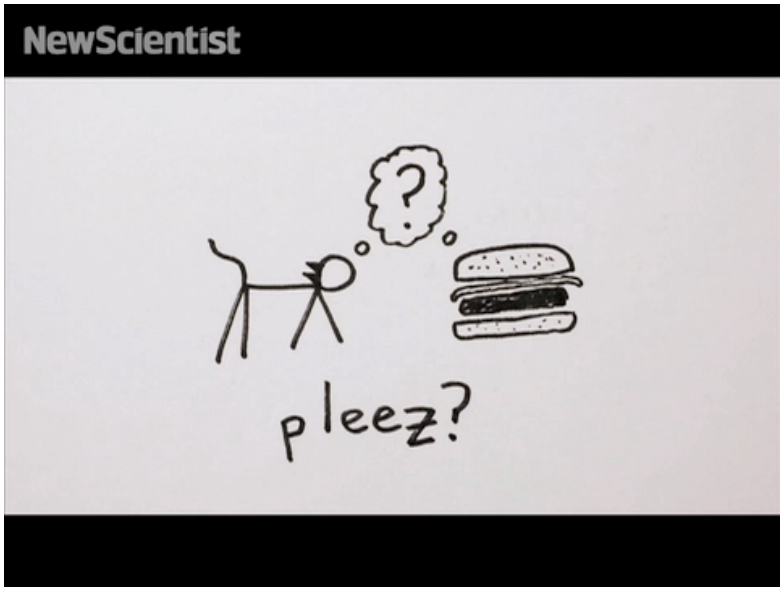


The "Feynman diagram" for two electrons repelling each other by exchanging a photon

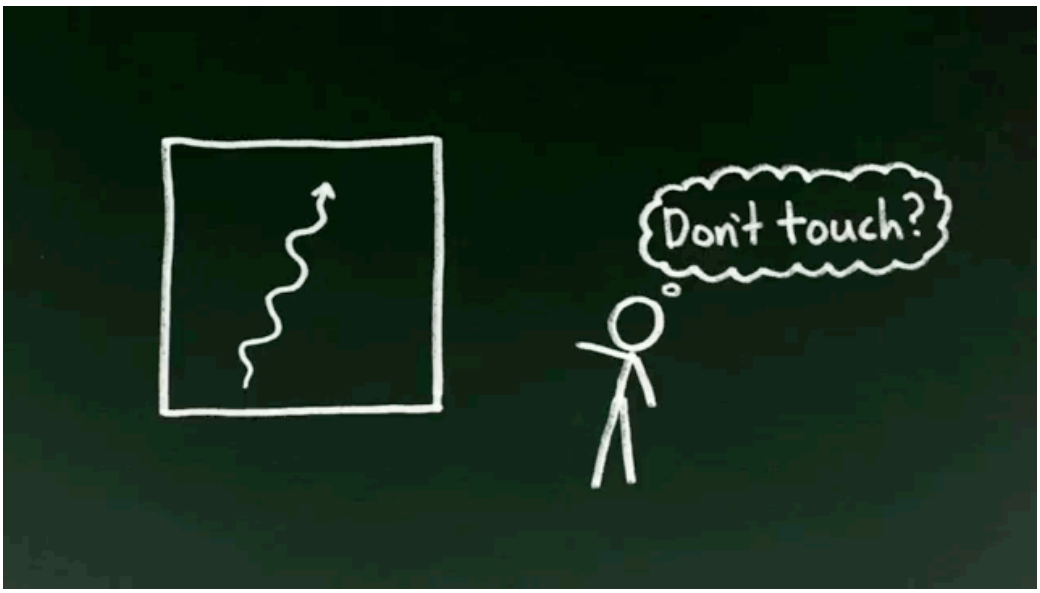
Recall superposition



Schrödinger's Cat



Haroche's Nobel-Prize-winning work



Physics = fortune-telling

	Description of the "state"	Rules for inferring the future state	Interpretation of this state
Classical mechanics	X, V (for all objects) → $X_1,V_1; X_2,V_2; X_3,V_3; \ldots$	$X \to X + Vt$ $V \to V + at$ a from $F=ma$ F from X (Newton's laws)	pretty self-explanatory
Weather	temperature (everywhere) wind speed (") humidity (") etc	fluid mech. + thermodynamics + atmos. chemistry etc	idem
Quantum mechanics of an electron	Probability amplitude that the particle is at any given x → $\psi(x)$	"Schrödinger's Eq." $i\hbar\frac{\partial\psi(x,t)}{\partial t} = \frac{-\hbar^2}{2m}\frac{\partial^2\psi(x,t)}{\partial x^2} + U(x)\psi(x,t)$ ⇓ Feynman's Rules (see QED)	PROBABILITY $P(x) = \lvert\psi(x)\rvert^2$
Quantum mechanics of cats et cetera	ψ(any possible classical state) → $\psi(x_1, x_2, x_3, \ldots\ldots\infty\ldots)$ "Prob. amplitude that the cat is dead, the photon takes slit one, the bomb is working, you passed the midterm, and Sarah Palin is running for president"		One probability for every possible state of everything in the universe!

The meaning of quantum states ("state vectors" or "wave functions")

Probability amplitude that the particle is at any given x
$\rightarrow \psi(x)$

"Schrödinger's Eq."

$$i\hbar \frac{\partial \psi(x,t)}{\partial t} = \frac{-\hbar^2}{2m} \frac{\partial^2 \psi(x,t)}{\partial x^2} + U(x)\psi(x,t)$$

$\Downarrow$

Feynman's Rules (see QED)

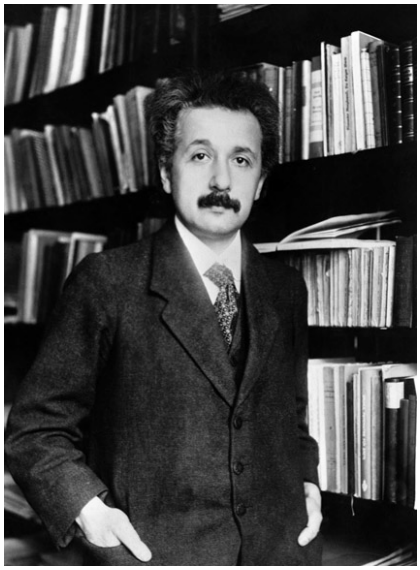
PROBABILITY
$P(x) = |\psi(x)|^2$

ψ(any possible classical state)
$\rightarrow \psi(x_1, x_2, x_3, \ldots\ldots \infty \ldots)$
"Prob. amplitude that the cat is dead, the photon takes slit one, the bomb is working, you passed the midterm, and Sarah Palin is running for president"

One probability for every possible state of everything in the universe!

Is reality dependent on observation?! Is locality (space itself) an illusion?!

These are some of the central questions in modern physics, but let us take a step back to 1905 to see how the same questions arose in Relativity even before Quantum Mechanics.



Advance summary of Special Relativity:

(0) "Special" as opposed to "general": "limited"/"restricted" better

(1) "Relative" as in "relative motion"
How to describe the laws of physics correctly, so that they work no matter relative to whose perspective we apply them?
Really: the theory of absolutes ("invariants")

(2) A pure product of logical deduction

(3) One assumption:
The laws of physics are the same for everyone (in any "reference frame")

(4) One realization: the speed of light is fixed by the laws of physics

(5) Startling, but inevitable, conclusions, e.g.:

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The laws of physics are the same for everyone (in any "reference frame")

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(5) Startling, but inevitable, conclusions, e.g.:
- the notion of simultaneity is *relative* (depends on your perspective)

NB: This does not mean reality is different for different people!
Reality & the "laws" are universal.
Simultaneity is relative the same way velocity is.
A train may travel 50 kph relative to your car but 100 kph relative to me walking.
Two perspectives, one identical reality.

- Distances are relative
- Time is relative
- (Space and time are actually 2 aspects of the same thing)
- Mass is a form of energy (or vice versa)
- Nothing can travel faster than light (or can it?)

Galilean Relativity

http://faraday.physics.utoronto.ca/PVB/Harrison/Flash/ClassMechanics/Relativity/Relativity.html

Recall how Maxwell figured out the speed of light...

Laws of physics tell us

changing E makes a change in B

changing B makes a change in E

and these changes propagate at a velocity

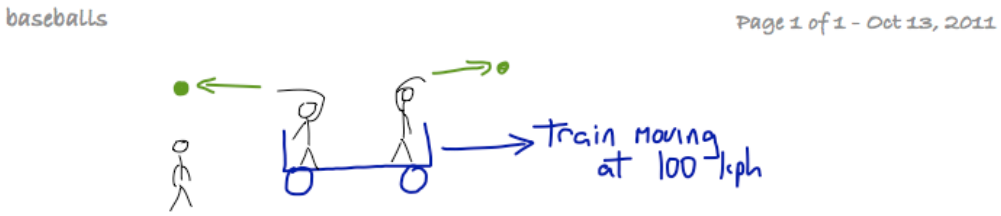
***we can calculate from the laws of physics*.**

Contrast sound waves

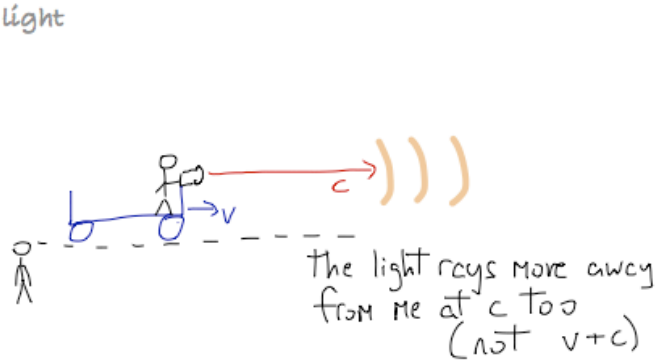
Sound waves move at a constant speed *relative to the air*; water waves move at a speed *relative to the water*; but the em waves aren't waves *in anything*; they are simply a result of the laws of how electric and magnetic fields behave.

If these laws are the same for all observers, then the speed of light is the same from the point of view of any observer.

Addition of velocities (Galilean)



The problem with propagation



Why? Because the speed of light *is a law of physics*; and the laws of physics are *the same* whether you're moving or not (that's Galilean relativity: no way to tell if your boat is moving)

DEFINITIONS!!

What *is* time? What *is* distance? What *is* velocity?

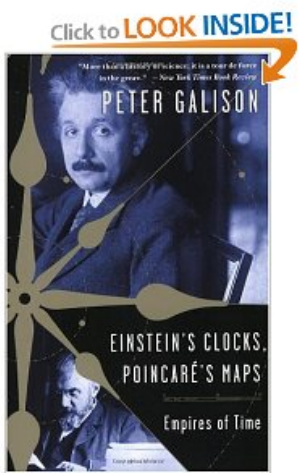
Einstein: **time is what a clock measures.**

distance is what a ruler measures.

To understand what we're going to observe, we actually need to think about the physics behind what we do to carry out the observation.

If you can't measure the difference between two things, as far as physics is concerned, they *are the same*.

“The patent office job — Einstein referred to it, tongue-in-cheek, as his «cobbler's trade» — turned out to be stroke of good fortune because it was excellently paid (3,500 Swiss francs per year) and was undemanding for his nimble intelligence.” --



Recently, Peter Galison of Harvard University and Arthur I. Miller of University College London have argued at length that Einstein’s job as a patent examiner involved analyses of new technologies on the synchronization of clocks. They claim that reflection on such mechanisms led Einstein to conceive the relativity of time.