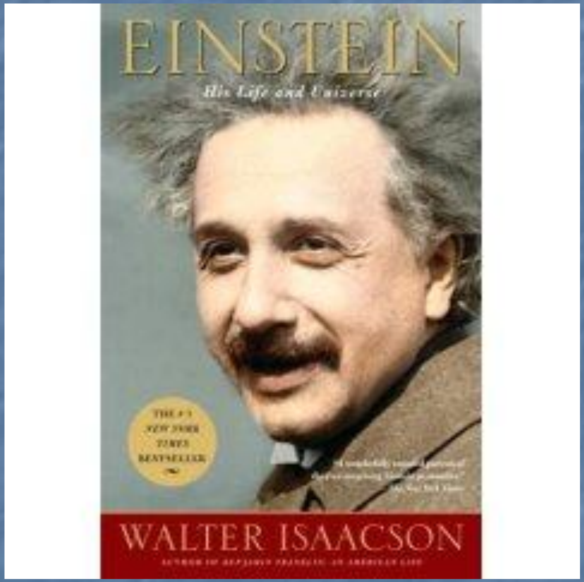
Physics 214: Special Relativity

An Introduction

Many books


EINSTEIN
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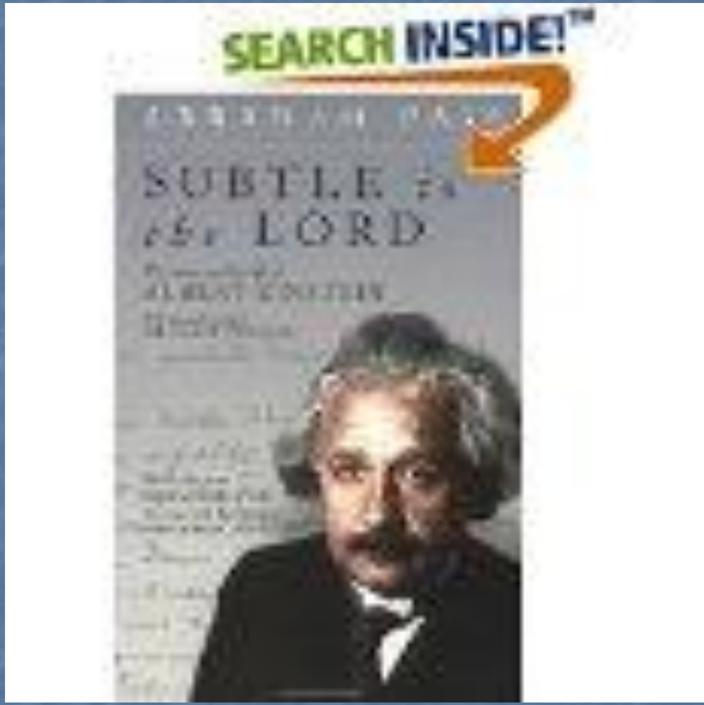
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SUBTLE is the LORD

Indices: Summation Convention

- Introduced in 1916 (with final formulation of GR). Repeated indices summed. Einstein joked “I have made a great discovery in mathematics; I have suppressed the summation sign every time that the summation must be made over an index which occurs twice…” $x_i x_i = \sum x_i x_i$

Features of Newton’s Laws

- Action at a distance -- almost ghostly. A source of skepticism, initially; Newton was defensive about it.
- Equivalence of gravitational mass and inertial mass (Eotvos)
- Galilean Invariance

Galileo and Galilean Invariance

- Galileo on Relativity: Galileo Defends Copernicus
- "Shut yourself up with some friend in the main cabin below decks on some large ship, and have with you there some flies, butterflies, and other small flying animals. Have a large bowl of water with some fish in it; hang up a bottle that empties drop by drop into a wide vessel beneath it. With the ship standing still, observe carefully how the little animals fly with equal speed to all sides of the cabin. The fish swim indifferently in all directions; the drops fall into the vessel beneath; and, in throwing something to your friend, you need throw it nor more strongly in one direction than another, the distances being equal; jumping with your feet together, you pass equal spaces in every direction. When you have observed all these things carefully, have the ship proceed with any speed you like, so long as the motion is uniform and not fluctuating this way and that. You will discover not the least change in all the effects named, nor could you tell from any of them whether the ship was moving or standing still."

Modern Description of Galilean Invariance

$$\vec{x}' = \vec{x} + \vec{v}t \qquad t' = t$$

$$\frac{d^2\vec{x}'}{dt^2} = \frac{d^2\vec{x}}{dt^2}$$

Not a feature of Maxwell’s equations

- Speed of light just a constant
- Einstein’s Problem With Galileo/Maxwell

$$c^2 = (\epsilon_0 \mu_0)^{-1}$$

“If I pursue a beam of light with the velocity c, I should observe such a beam of light as an electromagnetic field at rest though spatially oscillating. There is no such thing.”

The fall of absolute time

- Newton: Newton on Absolute Time (Principia): "Absolute, true and mathematical time, of itself and from its own nature, flows equably without relation to anything external…Absolute space, in its own nature, without relation to anything stable, remains always similar and immovable."
- But:
- "Absolute time is not an object of perception…The Deity endures forever and is everywhere present, and by existing always and everywhere, He constitutes duration and space."
- And Mach (one of Einstein's early heroes): absolute time is a "useless metaphysical concept, and cannot be produced in experience." Newton "acted contrary to his expressed intention only to investigate actual facts."
- And Poincare
- "Not only do we have no direct intuition of the equality of two times, we do not even have one of the simultaneity of two events occurring in different places."
- Poincare had much of the mathematics of special relativity, as did Lorentz, but neither made the final leap; they were too wedded to the ether concept.

Difference between Einstein and Poincare

(Dyson) The essential difference between Poincare and Einstsein was that Poincare and Einstein was that Poincare was by temperament conservative and Einstein was by temperament revolutionary. When Poincare looked for a new theory of electromagnetism, he tried to preserve as much as he could of the old. He loved the ether and continued to believe in it, even when his own theory showed that it was unobservable. His version of relativity theory was a patchwork quilt. The new idea of local time, depending on the motion of the observer, was patched onto the old framework of absolute space and time defined by a rigid and immovable ether. Einstein, on the other hand, saw the old framework as cumbersome and unnecessary and was delighted to be rid of it…All the complicated explanations of electric and magnetic forces as elastic stresses in the ether could be swept into the dustbin of history, together with the famous old professors who still believed in them."

Special Relativity

- Einstein: realized that the symmetry of Maxwell's equations is not Galilean invariance, but Lorentz invariance – argues this is what should be taken seriously. [Demise of action at a distance]
- Indices again: Upstairs/downstairs: Einstein borrowed, it seems, from mathematicians: "Following Ricci and Levi-Civita, we denote the contravariant character in such a way that we place the index in the upper position…" But other notational improvements only came later.
- In this way, Maxwell's equations look simple:

Maxwell's Equations in Relativistic Form

$$\partial_\mu F^{\mu\nu} = j^\nu$$

Einstein on Maxwell and the field concept

- "A new concept appeared in physics, the most important invention since Newton's time: the field. It needed great scientific imagination to realize that it is not the charges nor the particles but the field in the space between the charges and the particles that is essential for the description of physical phenomena. The field concept proved successful when it led to the formulation of Maxwell's equations describing the structure of the electromagnetic field."