Einstein, the Aether and Special Relativity
Challenges to the foundations of classical physics

- Radioactivity and X-rays
- Sub-atomic particles (electrons) and structure of the atom
- Quantum explanations of blackbody radiation
- Quantum explanations of light in photoelectric effect--is light a particle?
Newton and Einstein

- Both experienced a “Great Year”
- Both non-typical personalities
- Both famous during lifetime
- Both developed new styles of doing science
  - Are falling apples are like the falling moon?
  - What would I see if I could ride a beam of light?
- Both helped define new worldview for physics and culture more generally
“Classical” world picture rejected by the “moderns”

- Absolute time and space
- Measurement unproblematic
- Deterministic, causal laws
- Continuously varying processes
- Objective world, independent of observer
Albert Einstein (1879-1955)

- Son of failed businessman (electrical systems)
- Carefree youth in Italy, failed exams
- Studied physics at ETH Zurich
- Bern patent officer, 1902-9
- Professor in Zurich, Prague, Berlin (1914)
- World celebrity with 1919 eclipse results
- 1921 Nobel Prize and growing anti-Semitism
- Emigration to Princeton, 1933
- Search for deterministic unified field theory
- Guru of pacifism, Zionism, A-bomb
The first 1905 paper

“On a heuristic viewpoint regarding the production and transformation of light” (the light quanta paper)

- Applied old theory (Planck’s) to old data (Hertz’s photoelectric effect)
- Heuristic = aid to solving a problem, not otherwise justifiable (makes light quantized particle, not wave)
- Controversial challenge to wave theory, not widely accepted until 1915 (earns Nobel Prize, 1921)
The second 1905 paper

- Brownian motion
  - Old theory (heat is motion) applied to old data (botanist Robert Brown’s “jumping” pollen particles, 1827)
  - Used statistics to derive atomic parameters from measurements of visible motions of particles
  - Proved existence of atoms (contra Ernst Mach’s “positivism”)
- Asks simple, yet profound questions
The third 1905 paper (SR)

- Theory of measurement and how we know, not a theory about nature
- Not general relativity (later, 1907-16)
- Continues style of asking simple, profound questions
- Contributions from Mileva Maric?
  - “When you’re my dear little wife we’ll diligently work on science together so we won’t become old philistines, right?” Einstein to Maric, 1901
Newton’s implicit theory of measurement

- Abolute time and space
- Instantaneous communication
- Velocities add
- Galileo’s ‘principle of relativity’ (same physics in inertial reference frames)

\[ V_{\text{ball}} = V_{\text{train}} + v_{\text{ball}} \]
"Aether drift" problem, 1880s (do light velocities add?)

Assume aether fixed wrt stars

\[ V_e = 3 \times 10^4 \text{ m/s} \]
\[ c = 3 \times 10^8 \text{ m/s} \]

Two ad-hoc solutions to measured "null" result
--Earth drags aether around sun?
--Length contraction against aether wind?

\[ V_{\text{Jan measured}} = c + V_e ? \]
\[ V_{\text{Jun measured}} = c - V_e ? \]
Einstein’s “Electrodynamics of Moving Bodies” (1905)

- Asymmetries in Maxwell equations
  - no absolute rest with respect to an aether

- Begins with two postulates
  - I. Principle of relativity
    - Physics invariant in inertial reference frames
  - II. Invariance of speed of light
    - Predicted by Maxwell’s equations

- Einstein calls theory the “invariance of light”
  - Planck coined term “relativity” in 1906
Relativity of simultaneity

Simultaneity always relative to reference frame!

Thunderbolt 1

Joe fixed on the landscape (1, 2 same time)

Thunderbolt 2

Sue moving on train (first 2, then 1)

Mirrors

Start

Later

High v

Simultaneity always relative to reference frame!
Time dilation (moving clocks slow down)

Time = Distance/Velocity

Stationary clock, \( T_s \)
- Mirror
- Tock
- Tick
- \( d \)

Moving clock, \( T_m \)
- Tock
- V
- Tick
- \( d \)

\[ T_s = \frac{2d}{c} \]

<table>
<thead>
<tr>
<th>( T_s )</th>
<th>( T_m )</th>
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</thead>
<tbody>
<tr>
<td>1 sec</td>
<td>( 1.3 ) sec</td>
</tr>
<tr>
<td>0.6c</td>
<td>( 1.7 ) sec</td>
</tr>
<tr>
<td>0.8c</td>
<td>( 1.7 ) sec</td>
</tr>
<tr>
<td>0.99c</td>
<td>( 7.1 ) sec</td>
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</tbody>
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Some algebra yields:

\[ T_m = \frac{T_s}{\sqrt{1 - \frac{v^2}{c^2}}} \]
Moving lengths contract

Stationary length, same time as when stationary clock is vertical

Moving length, same time as when moving clock is vertical

... a little algebra yields:  \( L_m = L_s \sqrt{1 - \frac{v^2}{c^2}} \)

... and moving masses increase:  \( M_m = \frac{M_s}{\sqrt{1 - \frac{v^2}{c^2}}} \)
Consequences of 2 postulates

- Electrodynamics without an aether
- New theory of measurement because simultaneity becomes relative
  - Simultaneous = Same time and same place
  - Arrival of train at 7 means “the pointing of the small hand on my watch to 7 and the arrival of the train [beside me] are simultaneous events”
- Moving clocks, lengths, and masses change!
- Holds only for inertial motion (General Relativity is for accelerated motion)
More consequences of SR

- \( E = mc^2 \)
- “Events” happen in a given place at a given time (“spacetime”)

One-dimensional spacetime (Minkowski)
World of 3-d is actually 4-d spacetime