8.20 MIT Introduction to Special Relativity
IAP 2005
Tentative Outline

1   Main Headings

   I Introduction and relativity pre-Einstein

  II Einstein's principle of relativity and a new concept of spacetime

 III The great kinematic consequences of relativity

  IV Velocity addition and other differential transformations

   V Kinematics and "Paradoxes"

  VI Relativistic momentum and energy I: Basics

 VII Relativistic momentum and energy II: Four vectors and transformation properties

VIII General relativity: Einstein's theory of gravity

2   More Detail

I.0 Summary of organization

I.1 Intuition and familiarity in physical law.

I.2 Relativity before Einstein

- Inertial frames
- Galilean relativity
- Form invariance of Newton's Laws
- Galilean transformation
- Non-inertial frames
- Galilean velocity addition
- Getting wet in the rain

I.3 Electromagnetism, light and absolute motion.

- Particle and wave interpretations of light
- Measurement of c
- Maxwell's theory $\rightarrow$ electromagnetic waves
- Maxwell waves $\leftrightarrow$ light.

I.4 Search for the aether

- Properties of the aether
- Michelson-Morley experiment
- Aether drag & stellar aberration

I.5 Precursors of Einstein

- Lorentz and Poincaré
- Lorentz contraction
- Lorentz invariance of electromagnetism

II.1 Principles of relativity

- Postulates
- Resolution of Michelson-Morley experiment
- Need for a transformation of time.

II.2 Intertial systems, clock and meter sticks, reconsidered.

- Setting up a frame
- Synchronization
- Infinite family of inertial frames

II.3 Lorentz transformation

- The need for a transformation between inertial frames
- Derivation of the Lorentz transformation

II.4 Immediate consequences

- Relativity of simultaneity
- Spacetime, world lines, events
- Lorentz transformation of events

II.5 Algebra of Lorentz transformations

- β, γ, and the rapidity, η.
- Analogy to rotations

- Inverse Lorentz transformation.

III.1 Length contraction

- Proper length
- Careful measurements of length → length contraction
- Is length contraction real?

III.2 Time dilation

- Proper time
- Careful measurements of duration → time dilation
- Is time dilation real?

III.3 Examples

- Time dilation as a measured phenomenon
- Duality between length contraction and time dilation

III.4 Intervals, causality, etc.

- Invariance of the interval under Lorentz transformation
- Spacelike, timelike, and lightlike intervals
- Causality: the Future, the Past, and Elsewhere
- Minkowski space and coordinate systems

IV.1 Differential form of the Lorentz transformation

IV.2 Addition of velocities

- The transformation: parallel and perpendicular
- Examples: relative velocities

IV.3 Transformation of angles

- Static angles: transforming geometry
- Dynamical angles: transforming rectilinear motion
- Relativistic aberration

IV.4 The Doppler Effect

- Frequencies
- Longitudinal Doppler effect
- Transverse Doppler effect
- Doppler effect for arbitrary motion
- Comparison with non-relativistic Doppler effect

IV.5 Visual appearance of objects at relativistic velocities.

V.1 The pole vaulter and the failure of rigidity

- Naive analysis
- Careful analysis of events
- Rigidity inconsistent with relativity

V.2 The log and the hole in the ice

V.3 Acceleration in special relativity

- The meaning of acceleration in the context of special relativity
- Lorentz transformation of acceleration
- Proper acceleration
- "Hyperbolic" motion
- Time in an accelerating frame

V.4 The ice boat paradox

V.5 The twin paradox

- The twin at rest
- The twin in motion
- The result and the experimental verification with accelerated particles.
- The confusion
- The resolution

VI.1 Constructing relativistic momentum and energy

- Derivation from "physical construction"
- Rest mass
- Reality of the rest energy
- Examples of mass $\Leftrightarrow$ energy.
- Relation between momentum, energy and rest mass: $E^2 - p^2c^2 = m^2c^4$
- Massless particles
- Pressure of light

VI.2 Relativistic decays and collisions

- $A \rightarrow 2B$ in A rest frame
- Photon emission and absorption

- Doppler shift and Mössbauer effect
- Compton scattering

VII.1 Properties of objects under Lorentz transformation

- Invariants and things that change
- The instantaneous rest frame
- The proper time as a Lorentz invariant
- Four-vectors
- Definition through transformation properties
- The four-vector as a vector in Minkowski space

VII.2 Another four-vector: the four velocity

VII.3 The Lorentz transformation of energy and momentum

- E and $\vec{p}$ form a four-vector
- Examples: boosting a particle at rest; boosting from the center of mass to the lab

VII.4 The invariant scalar product

- Invariance of the interval as a property of four-vectors
- $E^2 - p^2 c^2 = m^2 c^4$ again
- Invariance of $p_a \cdot p_b$

VII.5 Using invariants to simplify kinematic calculations

- Compton scattering
- $p\bar{p}$ threshold in pp scattering
- $Kp \to \pi\Lambda$
- Generalities

VIII.1 Incompleteness of special relativity

- Non-inertial reference frames

VIII.2 The Equivalence Principle

- Experimental evidence for equality of gravitational and inertial mass
- Acceleration $\Leftrightarrow$ gravitational fields
- General principle of relativity

VIII.3 Consequences of the Equivalence Principle

- Gravitational red shift
- Gravitational time delay

VIII.4 Mach's Principle and looking forward to General Relativity