UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Relativity

2122-3-E3001Q073

Aims

Detailed study of Einstein's special relativity, of its consequences, of its apparent paradoxes. Covariant formulation of the laws of the dynamics and of the electromagnetism (Maxwell equations). Lagrangian formalism and introduction to the classical theory of fields, fundamental prerequisite for quantum-field-theory studies.

Contents

Einstein's special relativity. Covariant formulation of the relativistic dynamics and of the classical electromagnetism. Relativistically-invariant Lagrangian formalism. The classical theory of fields: scalar and vector fields.

Detailed program

1. **Introduction to the Lorentz transformations, relativistic kinematics. Four-vectors and tensors.**
   Refs. [Taylor, Jackson, Weinberg]
   - Bases of the special relativity. Inertial frames, consequences of the invariance of the speed of light. Lorentz transformations. Consequences of the Lorentz transformations and their experimental tests. Discussion of the most famous "paradoxes". Relativistic composition of velocities, light aberration, relativistic Doppler effect.
   - Maxwell equations, scalar and vector potentials, gauge invariance. Compact notation for vector quantities and derivatives in three dimensions.
   - The Lorentz group and its generators, the algebra of the Lorentz group. Classification of the Lorentz transformations and their general properties. Four-vectors and covariant and contravariant tensors. Relativistic invariants. The metric tensor.
   - Four-velocity, four-acceleration and four-momentum. The Einstein's relation between mass and

energy. Four-momenta conservation for arbitrary scattering processes.
    - Composition of Lorentz boosts in different directions. The Thomas precession.

2. **Dynamics of a particle and covariant form of the Maxwell equations.**
   Refs. [Jackson, Weinberg, Landau, Feynman]
    - Dynamics of a relativistic particle.
    - Maxwell equations in covariant form, gauge transformations, conserved currents. The $F_{??}$ tensor. The transformation laws of electric and magnetic fields in arbitrary inertial frames.
    - Interaction among electromagnetic fields with charges, Lorentz force, motion of charged particles in constant and uniform electric and magnetic fields.
    - Motion of a charged particle with spin in an electromagnetic field. Equation of Bargmann-Michel-Telegdi. Spin-orbit interaction of an electron in a central field.

3. **Lagrangian formulation. Classical scalar and vector fields. The energy-momentum tensor.**
   Refs. [Jackson, Landau]
    - Least-action principle and Lagrangian formulation of the relativistic equations of motion.
    - Classical theory of fields. Scalar fields and the Klein-Gordon equation for real and complex scalar fields. Vector fields: the Lagrangian of electric and magnetic fields in interaction with currents.
    - The energy-momentum tensor for free electromagnetic fields and in interaction. Noether's theorem.

Prerequisites

Classical mechanics, classical electrodynamics, calculus (integrals, differential equations, Dirac delta)

Teaching form

Lessons.

Textbook and teaching resource

1. *Spacetime Physics*, E.F. Taylor e J.A. Wheeler
   First edition at the web page: https://virgilio.mib.infn.it/~oleari

2. *Classical Electrodynamics* , J.D. Jackson
   Chapter 11: Special Theory of Relativity
   Chapter 12: Dynamics of Relativistic Particles and Electromagnetic Fields

3. *Gravitation and Cosmology* , S. Weinberg
   Chapter 2: Special Relativity

4. *The Classical Theory of Fields (Volume 2)* , L.D. Landau e E.M. Lifshitz
   Chapters from 1 to 4.

5. *The Feynman Lectures on Physics* , R.D. Feynman, R.B. Leighton, M. Sands
   Chapters 25 and 26.

6. *Relativity* , W. Rindler

Semester

First semester

Assessment method

The exam consists in a written and an oral test. The evaluation is expressed with a grade in thirtieths.

Only who passes the written test is admitted to the oral test. The oral test follows by a few days the written one.

- **Written test**
  The written test consists in the resolution of problems concerning the course topics.
  In this way, the real understanding of the course subjects and the ability to apply the acquired knowledge are assessed.
  Students are strongly encouraged to solve previous tests, before coming to the examination.
  The teacher is always available for any clarifications and suggestions for their resolution.

- **Oral test**
  During the oral examination the exposition skills and knowledge of the course topics are evaluated.
  Each student has the possibility to start the discussion of the oral test with a topic of his/her choice. From there, the oral test will probe also the knowledge on all the other parts of the course.

During the year at least five exam sessions are provided, typically in the following periods: January, February, June, July, September, October.

Office hours

By appointment.