

PH4032 - Special Relativity and Fields

Credits:	15.0	Semester:	1
Number of Lectures:	27	Lecturer:	Dr Natalia Korolkova
Academic Year:	2016-17		

Overview

Relativity is closely related to the concept of fields. Historically, Special Relativity emerged from the theory of electromagnetic fields. On a more fundamental level, the principle that every cause takes a finite time to have an effect on a different location calls for a mediator of interactions, a field. Every point in space may carry field strengths that could be scalars, four dimensional vectors, tensors, spinors etc. According to the principle of relativity, the field equations are the same in all coordinate frames that are in uniform motion relative to each other. Additionally, fields satisfy the Principle of Least Action and possible some internal symmetries. From these fundamental ideas follows a most remarkable wealth of connections in the physical world - Maxwell's electromagnetism, the Lorentz force, the relativistic wave equations, antiparticles, spin etc. The theory of fields unifies classical physics and shows some general recipes for guessing the laws of Nature.

Aims & Objectives

To present a comprehensive theory of special relativity and an introduction to the theory of fields, including

- derivation and the basic properties of the Lorentz transformations
- space-time metric and proper time
- tensors and spinors
- relativistic dynamics, energy, momentum and forces
- derivation of the Lorentz force from first principles
- motion of charges in uniform electromagnetic fields
- ideas of gauge invariance
- electromagnetic potentials and the electromagnetic field tensor
- derivation of Maxwell's equations from first principles
- Principle of Least Action for fields
- Relation between symmetries and conservation laws
- retarded potentials and electromagnetic radiation
- energy-momentum tensor
- derivation of the Dirac equation from first principles
- transformations of Dirac spinors – antiparticles
- local phase invariance and gauge fields
- derivation of the Pauli equation including the gyromagnetic ratio of spins

Learning Outcomes

By the end of the module, students will have a comprehensive knowledge of the topics covered in the lectures and will have acquired some important skills in theoretical physics, in particular to

- derive relativistic dynamical laws and solve some of the resulting equations of motion
- work with four-vectors, spinors and tensors, including their transformations
- derive relativistic field equations such as Maxwell's equations and the Dirac equation
- calculate energy-momentum tensors
- calculate retarded potentials
- derive the non-relativistic limit

Synopsis

1. The principle of relativity (relativistic kinematics)
2. Relativistic mechanics (Lagrangian, energy, momentum, force)
3. Charges in electromagnetic fields (electromagnetic potentials, Lorentz force, field-strength tensor)

4. The electromagnetic field equations (dual tensor, Principle of Least Action, electromagnetic Lagrangian, four-dimensional current, Maxwell's equations, retarded potentials, dipole radiation, energy-momentum tensor)

5. Relativistic matter waves (Dirac equation, transformation of Dirac spinors, antiparticles, non-relativistic limit and Pauli equation) Recommended book L D Landau and E M Lifshitz, The Classical Theory of Fields (Butterworth, Oxford, 2002)

Pre-requisites

PH3007, PH3081 (or MT equivalent), PH4038

Anti-requisites

None

Assessment

Continuous Assessment = (assessed tutorial questions) 25%, 2 Hour Examination = 75%

Additional information on continuous assessment etc

Please note that the definitive comments on continuous assessment will be communicated within the module. This section is intended to give an indication of the likely breakdown and timing of the continuous assessment.

This module contains a significant continuous assessment component (25% of the module mark). This continuous assessment is based on tutorial solutions that are handed in for marking mostly at weekly intervals through the semester. Some longer sheets will have slightly longer preparation times.

There will be eight sheets in total, each worth 20 marks. The tutorial solutions are to be submitted as fully written-out solutions and are marked, returned and discussed during the in-class tutorials. This working with the material and discussion of the outcomes should form an important and valuable part of your learning on this module. There will be three sheets with "long" problems to solve, one of which will be unassessed. There will be three sheets comprising a number of short questions, 2-3 marks each, aimed at revising and testing the understanding of the lecture material. There will be two sheets combining longer problems with short questions.

Accreditation Matters

This module may not contain material that is part of the IOP "Core of Physics", but does contribute to the wider and deeper learning expected in an accredited degree programme. The skills developed in this module, and others, contribute towards the requirements of the IOP "Graduate Skill Base".

Recommended Books

Please view University online record:

<http://resourcelists.st-andrews.ac.uk/modules/ph4032.html>

General Information

Please also read the general information in the School's honours handbook.