Fisica (2024)

10801 - Laboratory of Electronics

PDF, ADOC.

Learning outcomes

At the end of the course, the student has a basic knowledge of : the physics of the main electronic devices based on semiconductors and their applications, the implementation of circuits with discrete and integrated components in the framework of analogue and digital electronics, the related methods of measurement and analysis of experimental data. In particular the student will be able to: implement electronic circuits and measure their functional characteristics, estimate the errors, including the systematic ones, on the laboratory measurements, analyze with a computer the experimental data taken in the Physics laboratory by writing C++ programs and by using statistical and graphical tools and compare the results with theory.

Course contents

Basic principles of semiconductor device physics. The junction diode : characteristics and applications. The bipolar transistor (BJT): characteristics in the three configurations (CB, CE, CC) and applications. The field-effect transistors (JFET, MOSFET, MESFET) : characteristics and applications. The basics of Boolean algebra. Logical functions and digital circuits. Fundamental logic families (TTL, ECL, MOS, CMOS). Basic combinational digital circuits : adders, subtractors, ALU, multipliers, comparators, parity generators and checkers, decoders, demultiplexers, multiplexers, encoders, ROM-PROM, EPROM-EEPROM, PAL, PLA. Basic sequential digital circuits : flip-flops (S-R, J-K, D, T), shift registers, counters. Classification of the integrated circuits : from the standard products to the custom logic. Classification of the PLDs : from the SPLD to the CPLD (FPGA).

The arguments of the practical experiences are:

1) First experience: measurement of the I-V characteristics for two semiconductors diodes (Si, Ge) with the best fit method to calculate the inverse saturation current and the ideality factor.

2) Second experience: measurement of the output characteristics of a BJT in the common emitter configuration for two values of the base current; use of the best fit method in the active region to calculate the current gain and the output conductance.

3) Third experience: analogic and digital applications of the semiconductor diodes; implementation of a two-level clipping circuit with two diodes (Si, Ge).

4) Fourth experience: I part - implementation of a Full Adder circuit with integrated circuits TTL-SSI standard and in the open collector configuration with an external pull-up circuit. II part: implementation of a logic OR gate and AND gate with two Si diodes.

5) Fifth experience: implementation of a Multiplexer for logic functions using integrated circuits

TTL-SSI standard.

6) Sixth experience: I part: implementation of a circuit to decode and display a 4-bit code using TTL-IC (Decoder/Driver, 7-Segment LED display, 4-bit Ripple Counter); II part: implementation of a frequency divider with 4 D-Type Flip-Flop connected to be used as T-type Flip-Flop.

00056 - Astrophysics

PDF, ADOC.

Learning outcomes

The aim is to obtain a general understanding of the most important stellar and extra-galactic topics in modern astrophysics. The student will be able to understand and discuss general observational properties of stars, galaxies and clusters of galaxies. An introduction on the modern cosmology will be also given.

Course contents

Astronomical quantities (measures of distance and magnitude). Introduction to the main emission mechanisms (black body, synchrotron, Bremsstrahlung, inverse Compton). Spectral classification of stars. Physics of stellar interiors and atmospheres' main thermonuclear reactions. Introduction to stellar evolution, supernova explosions, final stages (black holes, neutron stars, white dwarfs). Physical and observational propeties of galaxies (Hubble classification, content in terms of gas and stars, internal dynamics, spiral structure theory). Introduction to the unified model of active galactic nuclei. Clusters and groups of galaxies. The interstellar and intergalactic medium (X-ray and 21 cm emission), rotation curves of spiral galaxies and evidence of dark matter, Introduction to cosmology: the Hubble constant, expansion law, the microwave background radiation, cosmological models.

B6440 - ELEMENTI DI STORIA, EPISTEMOLOGIA E SOCIOLOGIA DELLA FISICA PER L’APPRENDIMENTO

PDF, ADOC.

Learning outcomes

At the end of the course, the student, interested in formal and non-formal education, has conceptual and cultural tools to critically reflect on science (physics, in particular) and its role in contemporary society. Referring to research fields such as epistemology, history, sociology, physics education and learning sciences, the course analyses and discusses methods of production, sharing, validation, organisation, transmission, communication and understanding of science (physics).

Course contents

The course will focus on some historical cases to reflect on physics as a discipline and on the forms of knowledge necessary for its understanding.

Specifically, starting from a historical reflection on kinematics, Newtonian dynamics and the physics of complex systems, the following epistemological themes will be addressed:

- Images of science (physics) and science education;
- Approaches to the Nature of Science developed in Science Education Research (with particular reference to the Family Resemblance Approach);
- Aims and values, practices, methods and forms of knowledge organization of that characterize physics;
- Forms of reasoning, explanation, modeling and argumentation in science;
- Students' epistemologies and models of cognitive dynamics that allow to compare accredited knowledge and common sense knowledge.

Special attention will be paid on the theme of objectivity and on particular forms of reductionism to compare different epistemological and methodological perspectives, including realism, constructivism and feminist epistemologies.

The historical cases will also allow to introduce elements from the STS (Science & Technological Studies). In particular elements are introduced from the sociology of time and Futures Studies to reflect on the temporal models developed by physics and institutionalized. Furthermore, results of studies on gender and intersectionality will be discussed with particular reference to scientific contexts and places of formal education (schools and universities).

B2292 - FISICA DELL'ENERGIA

PDF, ADOC.

Learning outcomes

Al termine del corso gli studenti acquisiranno le conoscenze di base per avvicinarsi alle complesse

questioni energetiche in modo scientifico e rigoroso, ma senza dover seguire corsi avanzati di fisica classica o di meccanica quantistica.

Infatti il profilo flessibile e interdisciplinare del corso consente agli studenti di sviluppare un approccio versatile alla comprensione delle più dibattute questioni nel campo dell'energia.

Lo studente acquisirà le necessarie abilità per capire non solo le basi scientifiche della produzione energetica nelle sue più svariate forme ma di valutarne l'impatto e l'importanza in altri ambiti: sociali, culturali, o più generalmente transdisciplinari alla Fisica.

Course contents

The three modules will cover the following topics:

Part I: Basic principles of energy (units and scales, different sources of energy: mechanical, heat, electromagnetic, quantum, …)

Part II: Energy production from fossil and renewable sources

Part III: Energy production from nuclear sources (fission and fusion)

In detail:

Motivations and philosophy of the course, importance of numbers, relative quantities and units of measurement, climate and energy issues, general discourse on environmental sustainability.

Energy units, types and scales. Brief summary of thermodynamics, concepts of entropy and temperature, reversible processes and equilibrium.

Mechanical energy and applications. Brief summary of the fundamental concepts of force, work and moments. Friction and resistive force.

Thermal energy and heat: general principles and transfer. Pressure and work. First and second law of thermodynamics. Thermal capacity. Phase Transitions. Heat conduction (Fourier's law), convection and radiation. Heat equation.

General principles of energy conversion: conversion, Carnot cycle, Stirling cycle, Chillers and heat pumps. Thermal engines, Combustion engines

Energy of electromagnetic origin: storage, conversion, transmission and radiation. Electric engines.

Energy from chemical systems and processes

Energy generation from steam/gas cycles, phase diagram

Fossil fuels. Overview of fossil energy sources.

Solar power. Solar radiation, absorption and thermal utilization. Physics of photovoltaic systems.

Production of energy from biological sources.

Wind. Fluid dynamics and wind power, available technologies. In-depth study of fluids, viscosity, flow dynamics, physics and development of turbines.

Geothermal energy.

Energy sources of a nuclear nature: fission and fusion. Relevant notions to understand the basics of nuclear fission and fusion. Introduction to the definition of cross section. Nuclear forces, energy scales and structure, systematics of nuclear binding energy, reactions and decays. Physics of nuclear fission. Physics of nuclear fusion, brief introduction to plasmas and the most relevant characteristics. Operation diagram of a fission reactor. Four factor formula and fuel enrichment. critical systems. PWR and BWR. Nuclear radiation, fuel cycle, waste management (National and Olkiluoto Depot). magnetic fusion vs. inertial fusion. Models and basic functioning of both concepts. Future of nuclear energy: fourth generation, SMR, ADS.

Rea

58358 - Earth Physics

PDF, ADOC.

Learning outcomes

At the end of the course the student has the basic knowledge of the structure and dynamics of the Earth, the gravitational field and the magnetic field of the Earth.

Course contents

The course provides the basic knowledge on the shape and dynamics of our planet, in view of the solid Earth and in the context of modern Earth System Physics. In the five parts of the course the structure of the Earth will be described through the study of seismic waves, gravity field, heat flow, rheology and the Earth's magnetic field. Starting from multiple experimental data, the theoretical foundations were laid and the physical models useful for the quantitative analysis of the relevant geodynamic processes are introduced. Pragmatically, case studies and classic examples shall be presented, shedding light on the interconnections between Solid Earth and the various parts of the Earth System. The topics covered in the parts of the course will be seen in the great scenario of Plate Tectonics, which shall be illustrated in its essence.

Part 1: "Seismic waves, internal structure of the Earth and earthquakes" Recall, Motivations, Stress and deformation, Elastic behaviour, Elastic waves, Volume waves, Surface waves, Densities and elastic constants inside the Earth, Seismic velocities, Wave fronts and rays, Energy of seismic waves, Earthquakes.

Part 2: "The shape of the Earth and its gravity field" Background, Motivations, The gravity field, Mass distributions, Multipoles of a mass distribution, Moments of inertia, The gravitational field, The gravity field and the shape of the Earth, Anomalies of gravity, Isostasy, Flexion of the lithosphere.

Part 3: "The thermal structure and rheological behavior of the Earth" Terrestrial heat flux, Conduction and convection, Stationary one-dimensional conduction and continental geothermal, Cooling of a half-space, Subsolar temperatures, Oceanic lithosphere, Topography of ocean floors.

Part 4: "Rheology of the earth" Basics of rheology, Elastic behavior, Newtonian fluid behavior, Plastic and non-Newtonian behavior, Maxwell's visco-elastic model, Stationary and transient rheological models, The Kelvin-Voigt element, Generalized Maxwell bodies.

Part 5: "The Earth's magnetic field" Introductory notes, observations, historical digression and motivations, Elements of the Earth's magnetic field, Magnetostatics and dipolar magnetic field, The magnetosphere, Temporal variations of the Earth's magnetic field, Origin of the Earth's magnetic field.

81829 - Introduction to Physics of Condensed Phase

PDF, ADOC.

Learning outcomes

At the end of the course, the student will acquire some basic concepts of condensed matter physics: Simmetry and order/disorder effects in atoms aggregates; mechanical properties of solids; the concept of lenght scale and its influence on the properties of condensed matter. How a solid nucleates and grows. Phase diagrams.

Course contents

Recommended prerequisites/prerequisites

Knowledge of: classical mechanics and thermodynamics are requirements for successful attendance of the course. Mathematical analysis. Knowledge at least at an introductory level of quantum theory or simultaneous attendance of a quantum physics course.

The course is experimental and phenomenological in nature and is aimed mainly but not exclusively at students of Physics and Materials Science. During the lessons, scientific videos and images regarding the phenomena discussed are shown. The aim of the course is to introduce the student to natural phenomena and important effects regarding the condensed states of matter and some quantum phenomena that occur in matter in the solid state. The technological applications of the phenomena considered are highlighted.

The aim of the course is also to introduce students to some of the most current and interesting research areas in the Physics of Condensed States. The course is divided into various parts, which are connected to each other.Contents

1 Sets of atoms and molecules.

The concept of symmetry and symmetry breaking is introduced, with particular emphasis on the symmetry breaking that occurs in the transition from one condensed state to another. The types of rigid symmetries in the plane and in space arise. Examples of symmetries in nature and their breaking are therefore presented: drops of water falling into a puddle; circles in the wheat fields, the trunk of a tree, the deformation of a can.

Periodic systems

A very important case of symmetrical arrangement is that of Crystals. Bravais lattices will then be illustrated and the reciprocal lattice will be defined, with examples of crystals and regular solids, with particular attention to cubic lattices.

The classification of crystals and solids in general also requires analyzing the type of bond established between the atoms and/or molecules that make up the solid. A classification of solids based on bonds will be presented, providing the main characteristics of each.

A macroscopic solid is hardly a single large crystal. Polycrystalline solids and nanometric crystals will therefore be introduced, showing how the mechanical, optical and electrical properties of a polycrystal change compared to those of a single crystal. In particular, the properties of solids made up of nanometric crystals will be discussed. To conclude, Carbon and its phases will be examined: diamond, graphite, fullerenes, nanotubes, graphene.

Aperiodic and disordered systems.

Not all solids and certainly not liquids can be described as periodic aggregates. In some cases the solid cannot be described as a Bravais lattice. Quasi-Crystals are then presented and the problem of tessellations is discussed, firstly presenting the problem of the aperiodic Penrose tessellation of the plane. We subsequently discuss the recent discovery of the Einstein (not Albert) tile which allows an aperiodic covering of the plane with a single type of tile. The structure of amorphous substances such as glass is then described and compared with that of liquids. Finally, multi-phase systems are presented. As an example, we will illustrate the case of airgel, which is a material less dense than air and with exceptional thermal insulation properties, used both in NASA missions and in building cladding.

2 Energy/Surface tension

In liquids, surface tension is an important phenomenon and is crucial in many phenomena. This concept and the associated one of surface energy are introduced. The wonders of soap bubbles are shown and superhydrophobic surfaces are discussed. The behavior of a drop falling into water and the phenomenon of wine tears will be shown. You will discover how spiders and water striders walk on water.

3 Nucleation theory.

Having previously described the types of solids, we will now discuss how they are formed. The process by which a new condensed phase originates is more complex than is commonly imagined. Whether the solid will be a single crystal, a polycrystal or an amorphous depends on a number of factors that will be examined. We will illustrate the essence of the theory of Nucleation, which can be homogeneous or, much more commonly, heterogeneous. This is of particular importance in phenomena such as cloud formation and precipitation. As a particular case, the formation of snowflakes will be described, a problem that has fascinated great scientists such as Kepler, who was the first to scientifically describe this phenomenon, also making a conjecture on the regular aggregation of atoms in solids which has only been proven a few years ago be true.

4 Binary phase diagrams

Phase diagrams for pure substances are introduced in introductory thermodynamics courses. However, many substances are made up of 2 or more components. Important examples are metallic alloys and rocks. This leads us to consider binary phase diagrams. In a binary phase diagram the system is usually described as a function of composition and temperature. In the case of solids and liquids, the pressure dependence is not particularly relevant and in any case these are systems that are usually at ambient pressure. The main phenomena that appear in a binary phase diagram are presented: coexistence of solid and liquid in a range of temperatures; presence of eutectics; phase separation in both the liquid and solid phases. The phase diagram of water and salt (Sodium Chloride) and that of steel are described as illustrative and particularly important cases.

You will understand why the twin towers in New York collapsed and why ice chimneys (brinicles) form.

5 Mechanical properties of solids.

Why don’t we sink into the floor? Why is glass (usually) fragile and metals are ductile? In this part of the course we investigate which factors determine the fragility, hardness and ductility of solids. We will first understand why the elastic constants of solids do not have much to do with the resistance of a material. The elastic modulus and yield strength of a solid will be defined. The various types of defects in solids will be illustrated and in particular the concept of dislocation will be introduced, a true deus ex machina of the mechanical properties of materials. We will describe how defects greatly influence not only the mechanical but also the optical and electromagnetic properties of solids, starting with those of semiconductors. Finally we will mention shape memory materials. These substances possess very particular mechanical properties thanks to a deformation mechanism that is completely different from that of other substances. You will see a crumpled Nitinol wire that returns to its initial shape, motors based on martensitic deformation and metal alloys with an elastic deformability comparable to that of a polymer rubber band.

1. Collective quantum phenomena

Introduction to collective quantum phenomena in condensed matter. Physical properties of ferromagnetic materials, superconductors, superfluids and their applications.

1. Quantum materials and quantum technologies

Materials for quantum computing and quantum sensors.

1. The new frontiers of research in the Physics of Matter

The course will include a cycle of introductory lectures on some current research topics in the field of condensed state physics, from quantum materials to nanomaterials.

81851 - Introduction to Complex Systems’ Physics

PDF, ADOC.

Learning outcomes

Basic knowledge of physical and mathematical methods to develop dynamic and statistical model for the study of complex systems.

Course contents

Introduction to the Physics of Complex Systems, definition of the complexity concept and emergent properties.

The role of models in Physics: concept of dynamical system, linear dynamical systems and their integration, elements of control theory, integrable and chaotic systems, Ljapunov exponents and the concept of predictivity.

Definition of a complex system model and role of interactions and use of complex networks to classify the interaction structure.

Examples for applications of dynamical systems to the complex systems physics.

Central limit theorem and introduction to stochastic dynamical systems: properties of discrete Markov processes, concept of entropy and entropy production, equilibria in detailed balance and stochastic reversibility, Maximum Entropy Principles.

Discrete stochastic systems and physical applications.

Introduction to statistical mechanics: concept of emergent properties, critical states and phase transitions.

Study of empirical distributions obtained from big data of complex systems: exponential laws and power law distributions.

Analytical and numerical methods for the study and validation of a stochastic dynamical model for the simulation of complex systems.

Examples of models for Complex Systems Physics with applications to chemistry, biology, economics and social systems.

Study of emergent properties: phase transitions, synchronization, soliton formation, reaction diffusion models.

31098 - Elements of Medical and Health Physics

PDF, ADOC.

72566 - Introduction to Quantum Optics

PDF, ADOC.

Learning outcomes

The student will learn elementary quantum optics and matter-wave interaction theory in order to understand the recent experimental advances in the field of laser-assisted manipulation of atoms, specifically laser cooling and trapping for both fundamental and applied physics.

Course contents

Matter-wave interaction: A e B di Einstein’s A and B.

Two levels atom in a classical field: optical Bloch equations, Bloch’s vector, rotating wave approximation, Rabi’s oscillations, Ramsey’s method.

Two levels atom in a quantized field (Jaynes-Cummings' model): Fock’s states and coherent states, spontaneous decay, micromaser.

dressed atom: energy levels, fluorescence spectrum.

Laser cooling: Doppler cooling, Doppler limit, elements of sub-Doppler cooling.

Ion traps: RF traps (Paul), static traps (Penning).

Atom traps: magneto-optical traps, magnetic traps (Quadrupole,Joffe,Time Orbiting Potential), optical traps, optical lattices.

Some special lasers: ultrastable CW lasers, optical combs, measurement of optical frequencies.

Some notions on: evaporative cooling, reaching quantum degeneracy, optical clocks, atom interferometry, quantum computers

81827 - Basics of Theory of General Relativity

PDF, ADOC.

Learning outcomes

The aim of the course is to provide an introduction to the principles of general relativity and some of their main observational consequences (relativistic kinematics, cosmology, black holes).

Course contents

The course is divided into three main parts:

1) After a brief recap of the principle of Special Relativity, the covariant formalism is introduced (Minkowski space-time, Lorentz tensors) in order to write the laws of electrodynamics in a simple form. This part ends with a brief analysis of the Lorentz group and its representations (including spinors).

2) Elements of differential geometry. The student is introduced with the necessary notions and tools to describe geometric spaces independently of the reference frame. Differential manifolds are defined as well as general tensors and tensorial operations. In particular, the Lie and covariant derivatives are introduced. The role of the metric tensor is studied in details, given its key role in general relativity.

3) Introduction to General Relativity. The principles of general relativity, of equivalence and of general covariance are introduced. We show how geodesics determine the motion of test particles on a given space-time, and how Einstein equations determine the latter from the energy-momentum tensor of a source. The three classical tests re reviewed: Mercury’s perihelion precession, light deflection and gravitational redshift. The general formalism is applied to the two

most relevant cases:

a) the space outside a compact spherical source, described by the Schwarzschild metric. Radial geodesics are studied and the nature of the Schwarzschild horizon uncovered, thus introducing the notion of black hole.

b) the evolution of the universe is investigated from the cosmological principle of homogeneity and isotropy, leading to simple Friedman-Robertson-Walker models. The course ends with the Hubble law.

81828 - Basics of Physic of the Atmosphere and Meteorology

PDF, ADOC.

Learning outcomes

At the end of the course the student has acquired the basic knowledge of the long term mean properties of the atmosphere and of the basic equations of fluid dynamics. The laws of thermodynamics are applied to a gaseous fluid with phase changes. The equations of atmospheric motion are introduced with applications to some aspects of synoptic meteorology of mid-latitude weather systems with the aid of meteorological chart and satellite imagery. The fundamental radiative processes are introduced to interpret observations from space and to justify the simple planetary energy budget that introduces to the greenhouse effect

Course contents

Module 1

Spatial and temporal scales. Basic concepts of atmospheric fluid dynamics (Knudsen Number, air parcel, eulerian and lagrangian views, total derivative).

Navier-Stokes equation, viscous and inertial forces. Qualitative sketch on transport phenomena. Reynolds number and regimes, linearity and non-linearity, examples. Mass conservation equation with eulerian and lagrangian approach.

Equation of motion on a rotating system: scale analysis.

Simple equilibrium configurations: inertial motion, geostrophic motion (with and without friction), example of finite difference method.

Gradient wind, role of pressure gradient in the evolution of baric systems. Cyclostrophic wind, Rossby Number.

Isobaric and isentropic coordinates, thermal wind. Barotropicity and baroclinicity. Horizontal divergence and vertical motion

(application to global circulation).

Fronts: pressure, temperature and winds across frontal surfaces. Sketch of extra-tropical cyclone structure. Examples on meteorological charts.

Fronts and cyclones in meteorological satellite imagery: conveyor belt, dry intrusion, warm sector, gust fronts, squall lines.

Basic introduction to weather forecast: nowcasting, NWP, data assimilation, ensamble forecast. Available global products (ERA, NCEP, Globo), and regional (bolam, moloch).

Module 2

Introduction to atmospheric physics and meteorology. Observational network (in situ and remote sensing). Temporal and spatial mean atmospheric variables. Vertical profile of chemical species and physical quantities.

Equation of state of dry air and adiabatic processes; thermodynamic properties of water. Potential temperature and equivalent potential temperature, moist adiabats, stability and CAPE. Thermodynamic diagrams.

Introduction to radiative processes: emission, diffusion, absorption.

Theory of the general circulation of the atmosphere. Simple energy balance models. The Earth climate systems: definitions and observations.

B1046 - GRANDI CONQUISTE E TRAGUARDI DELLA FISICA DELLE PARTICELLE

PDF, ADOC.

99476 - INTRODUZIONE ALLA SCIENZA E TECNOLOGIA QUANTISTICA

PDF, ADOC.

Learning outcomes

Students will be introduced to the fundamental laws and the innovative technologies that are at the heart of the new quantum revolution, which is expected to have also a profound impact on culture and society.

At the end of the course, students will know the basics of:

- theory and main applications of quantum information, communication and computation;
- physical realizations of quantum resources and protocols.

At the end of the course students will be able to:

- analyze simple protocols of quantum information processing;
- describe and compare available experimental platforms.

Course contents

Il corso coprirà gli aspetti fondamentali della moderna teoria dell’informazione e computazione quantistica, affrontando le tematiche sia dal punto di vista teorico (prof.ssa Ercolessi) che sperimentale (prof. Minardi), con un approfondimento degli aspetti concettuali e fondazionali (prof.ssa Levrini) e uno sguardo alle applicazioni tecnologiche.

Descrivere un oggetto quantistico

Una nuova logica per una nuova unità di informazione.

Il qubit: stati, evoluzione e misura; stati puri e misti

Sistemi composti: separabilità e entanglement

Il paradosso EPR, il teorema di Bell e gli esperimenti di Aspect

Elementi di teoria della computazione quantistica

Simulare, emulare o computare?

Gates quantistici elementari e circuiti; parallelismo quantistico e algoritmo di Grover; cenni su altri algoritmi

Copiare uno stato: distinguibilità e "fidelity"; teorema di no Cloning e l’implementazione della computazione classica; il protocollo di teletrasporto

Elementi di teoria dell’informazione e comunicazione quantistica

Evoluzione e misure di un sistema aperto.

Canali quantistici. Esempi a un qubit.

Entropia di Shannon e entropia di Von Neumann, informazione mutua

Dense coding e crittografia quantistica (cenni)

Piattaforme sperimentali

Implementazione fisica di qubit

- qubit superconduttivi
- atomi freddi
- sistemi a stato solido (spin)

Implementazione di gates e computer quantistici

Approccio analogico e simulatori quantistici

Vantaggi e problematiche nelle varie realizzazioni

Readings/B

94165 - Topics in Mathematical Methods and Models in Theoretical Physics

PDF, ADOC.

Learning outcomes

The course introduces students to topics and tools of modern theoretical physics.

At the end of the course, students will be able to deal with appropriate mathematical methods and apply theoretical models to the description of some among the most significative problems of physics

Course contents

1. Foundation of Special Relativity
2. Lorentz group
3. Minkowski space time
4. Tensor formalism
5. Rindler coordinates
6. Mandelstam variables
7. Electromagnetism, Lorentz force
8. Maxwell equations, gauge invariance
9. Electromagnetic waves
10. Green functions, retarded potentials
11. Energy momentum tensor
12. Perfect fluids
13. Relativistic field theory