Basic knowledge for interviews

Enrollment in the ‘Magistrale in Fisica’

MAT — Mathematics

Algebra
§ **Vector spaces** • Bases and coordinates • Systems of linear equations
§ **Matrices** • Ranks of matrices • Invertible matrices • Change of bases • Eigenvectors and eigenvalues
§ **Determinants** • Cofactors and Cramer’s rule • Tensor products
§ B**ilinear and quadratic forms** • Symmetric **m**atrices • Quadratic forms • Inner products Orthonormal bases • Orthogonal matrices • The principal axis theorem

References: S. Lang, Algebra Lineare, Boringhieri; P. Lax, Linear Algebra, Wiley.

Analysis
§ **Curvilinear integrals** • Work and conservative fields
§ **Curl, Divergence and Gradient and Stokes Theorem** • Gauss and Green formulas
§ **Linear differential equations with constant coefficients** • Separable equations
§ **Complex integration** • Line integrals in the complex plane • Cauchy integral theorem • Cauchy integral formulae
§ **Series of analytic functions** • Power series • Singularities of analytic functions • Laurent series • Residue theorem and its applications
§ **Hilbert spaces** • Scalar product • Schwartz inequality • Completeness • Orthonormal bases • Gram-Schmidt algorithm
§ **Operatori su spazi di Hilbert** • Self-adjoint operators • Spectrum of operators
§ **Orthogonal polynomials**
§ **Fourier series**
§ **Fourier and Laplace transforms**

References: M. Spivak, Calculus, Publish or Perish; Brown & Churchill, Complex Variables, McGraw-Hill; E. Stein, Complex Analysis, Princeton.

FIS01 — General Physics

Mechanics
§ **Kinematics** • vector approach to position, velocity, acceleration, cartesian, spherical, and cylindrical coordinates
§ **Dynamics** • Inertial reference systems • Laws of Dynamics • Non-inertial systems of reference • Vector description of force, impulse, momentum, angular momentum • Work, kinetic energy, conservative fields, potential energy • Field expressed in terms of a potential energy and equilibrium • Harmonic, damped, forced oscillators, resonance
§ **Systems** • Cardinal equations for systems • Koenig Theorem •Two-body systems • Elastic and inelastic collisions • Central collisions • Variable-mass systems
§ **Kepler Laws** • Effective potential • orbits • areal velocity
§ **Rigid bodies** • Rotation around a fixed axis • Gyroscopic motion • energy • statics
§ **Fluids** • Fluid statics and dynamics • Bernouilli's Theorem
§ **Waves** • Wave equation and solutions • Sinusoidal waves and interference

Reference: "Fundamentals of Physics", 10th Ed., by Halliday, Resnick, and Walker.

Thermodynamics

§ **Thermodynamic systems** • State Variables •Zeroth Law • Temperature
§ **Ideal Gases** • Perfect gas equation of state
§ **Heat** • Calorimetry • Dulong-Petit's Law, Debye temperature • Heat transmission • Fourier Equation • Stefan-Boltzmann's Law • Black body • Wien's Law
§ **Thermodynamic processes** • Reversible and irreversible processes • work • cycles • Free expansion
§ **First Law of Thermodynamics** • Joule's experiment • Internal energy
§ **Second Law of Thermodynamics** • Statements of the Second Law • Carnot cycle • Absolute temperature • Performance of a cycle • Otto, Diesel, and Stirling cycle • Clausius Theorem • Entropy • Clausius Integral • Degree of irreversibility • Quality of energy • Entropic diagrams
§ **Real gases** • Critical isotherm, critical point, phase changes •Real gas equation of state • Virial series, Van der Waals Equation • Triple point, triple isotherm
§ **Thermodynamic potentials** • Enthalpy, free energy, Gibbs free energy • Maxwell's equations for thermodynamics
§ **Kinetic theory** • Ideal gases • Microscopic interpretation of pressure, temperature • Maxwell distribution • Energy equipartition • Probability, disorder, Nernst Theorem and statistical interpretation of entropy
§ **Pump** • Volumetric flux, mass flux, pump velocity, discharge time • Vacuum pumps, measuring vacuum

Reference: "Fundamentals of Physics", 10th Ed., by Halliday, Resnick, and Walker.

Electromagnetism
§ **Electrostatics in vacuum** • Electric field • Electric field flux and Gauss' Theorem • Divergence Theorem • First Maxwell Equation • Electrostatic potential • Electric dipole • Stokes theorem and curl of the electric field
§ **Conductors** • Coulomb Theorem • Capacitance, capacitance matrix •electrostatic energy • electrostatic pressure • Poisson equation • Method of image charges
§ **Dielectrics** • Polarization • Langevin function • electric susceptibility, Clausius-Mossotti relationship • Electrostatics in dielectrics • Electric displacement vector
§ **Stationary currents** • Electrical current • Current density vector • Continuity equation • Kirchhoff's Laws • Ohm's law, Joule effect, quasi-stationary circuit regime
§ **Magnetic field in vacuum** • Laplace's second law, Lorentz force • Synchrotrons and cyclotrons • Ampère's equivalence theorem • Laplace's first law, Biot and Savart's law • Second Maxwell Equation • Ampère's loop law • Fourth Maxwell Equation • Magnetostatic scalar potential • Vector potential • Forces between circuits • Hall Effects
§ **Magnetic fields in matter** • Atomic model and spin, gyromagnetic ratio • Diamagnets, paramagnets, ferromagnets • Larmor magnetic moment •Magnetic circuits • Electromagnets
§ **Slowly varying fields** • Relativistic field transformations • Faraday Neumann Law • Lenz law • Concatenated flux • Time-dependent Third Maxwell Equation • Inductors • Time-dependent Fourth Maxwell Equation
§ **Alternate current circuits** • RLC circuits • transformers
§ **Rapidly varying field and electromagnetic waves** • Maxwell Equations • Poynting vector • Electrodynamic potentials, gauge transformations, Lorentz and Coulomb gauge • delayed potentials • Radiation from an electric dipole, Larmor formula
§ **Lorentz transformations of fields** • relativistic covariance • Covariant expression of electrodynamics

Reference: "Fundamentals of Physics", 10th Ed., by Halliday, Resnick, and Walker.

Optics
§ **Polarization** • Vector representation
§ **Refraction and reflection** • Snell Law, Fresnel equations, total internal reflection
§ **Interference** • Young, Michelson, and Fabry-Perot interferometers, coherence, degree of coherence
§ **Diffraction** • Fresnel and Fraunhofer regimes
§ **Dielectrics and metals** • Dispersion, absorption, anisotropy

Reference: Grant R. Fowles, Introduction to Modern Optics, Dover Publications Inc., New York

Physics Laboratory
§ **Physical Quantities** • Direct and indirect measurements • Random and systematic errors • Tables, plots, and their use, histograms
§ **Statistical analysis of experimental data** • Propagation of uncertainty • Statistical inference • Evaluation of parameters • Fit, testing hypothesis, Chi2 method

Reference: J.Taylor, "An introduction to error analysis".

FIS02 — Theoretical Physics

Classical and relativistic mechanics
§ **Lagrange formulation and equations of motion** • Lagrangian • Variational principle
§ **Hamilton formulation and equations of motion** • Hamiltonian • Poisson brackets • Canonical transformations • Hamilton-Jacobi equation
§ **Special Relativity** • Lorentz transformations and relativistic kinematics

References: H. Goldstein, Classical Mechanics, Pearson; L.D. Landau e E.M. Lifshitz, Mechanics and The Classical Theory of Fields, Butterworth-Heinemann.

Quantum Mechanics
§ **Blackbody radiation** • Photons and Planck distribution
§ **Rutherford experiment, photoelectric effect and Compton effect**
§ **Probabilistic interpretation of measurement in quantum mechanics**
§ **Schrödinger equation and stationary states**
§ **One-dimensional problems** • Potential wells and barriers • Probability current • Tunnel effect
§ **Hilbert space and quantum states** • Continuous Spectrum • Dirac δ function • Observables • Projection operators • Indetermination relations
§ **Angular momentum and rotations** • Composition of angular momenta • Clebsh-Gordan coefficients
§ **Schrödinger equation in three dimensions** • Central potentials • Spherical Harmonics • Hydrogen atom
§ **Quantum oscillators in 1,2,3 dimensions**
§ **Spin and magnetic moment** • Spin-orbit interaction
§ **Identical particles** • Fermions and Bosons • Quantum statistics • Pauli exclusion principle • Exchange interaction
§ **Time-independent perturbations**
§ **Time dependent perturbations** • Fermi golden rule

References: J.J. Sakurai, Modern Quantum Mechanics, Addison-Wesley; S. Weinberg, Lectures in Quantum Mechanics, Cambridge; L.D. Landau e E.M. Lifshitz, Non-relativistic Quantum Mechanics, Butterworth-Heinemann.

Statistical mechanics
§ **Theory of probability** • Binomial, Poisson and Gauss distributions • Law of large numbers • Central limit theorem
§ **Entropy** • Equipartition theorem • Ideal Gas
§ **Microcanonical Ensamble** • Time averages of observables • Ergodic hypothesis
§ **Canonical Ensamble** • Partition function • Equivalence with microcanonical ensamble
§ **Classical ideal Gas** • Maxwell-Boltzmann statistics • Maxwell velocity distribution
§ **Gran-canonical ensamble** • Particle number fluctuations • Thermodynamic quantities
§ **Phase transitions** • Ising model • Mean field • Correlation functions
§ **Quantum gases** • Fermi energy • Specific heat • Bose-Einstein condensation

Livello della trattazione: K. Huang, Statistical Mechanics, Wiley; L.D. Landau e E.M. Lifshitz, Statistical Physics,Butterworth-Heinemann.

FIS04 — Nuclear and Subnuclear Physics / Structure of Matter

Atomic Physics
§ **Basic Experiments** (Franck-Hertz, Stern-Gerlach,...) • Atomic Spectra
§ **Hydrogen atom** • Schroedinger Equation • Time-independent perturbation theory.
§ **Light-matter interaction** • Fermi's golden rule • Absorption and stimulated emissione • Dipole approximation • Spontaneous emission and Einstein coefficients
§ **Magnetic and electric fields: static case** • Stark Effect • Zeeman, Paschen-Bach, and anomalous Zeeman regimes • Selection rules
§ **Atoms with more than one electron** • Pauli principle • Interacting electrons, mean electrostatic field • Screening and Hartree approach • Alcaline atoms
§ **Two electron atoms** • Wavefunction symmetries • Exchange interactions • Orthohelium and parahelium.

Molecular Physics
§ **Diatomic molecules** • Born-Oppenheimer approximation • The H_2^+ molecular ion • The H_2 hydrogen molecule • LCAO approximation • Nuclear dynamics • Frank-Condon Principle • Diatomic heteronuclear molecules • Diatomic molecules with more than one electron
§ **Polyatomic molecules** • Cyclic polyatomic molecules.
Physics of Solids
§ **From molecules to solids** • Linear chain • Nearest-neighbor tight binding
§ **Energy bands** • Density of states. Fermi energy. Fermi surface • Electrical conductivity. Effective mass.
§ **Free electron** • Drude and Sommerfeld model. Fermion gas. Electron specific heat.

Reference: Bransden B.H., Joachain C.J., Physics of atoms and molecules, Longman London and New York - N.W. Ashcroft and N.D. Mermin, Solid State Physics, Saunders, Philadelphia 1976.

Nuclear and particle Physics
§ **Scattering experiments** • Cross section • Rate • Flux
§ **Radiation-matter interaction** • Energy loss by charged particles • The $-dE/dx$ Formula
§ **Detectors**
§ **Nuclei and Yukawa potential** • The pion • Isospin and nucleons • Weizsäker Formula • α, β, γ decays
§ **Cosmic Rays** • Positrons • Muons
§ **Strange particles** • Kaons • Hyperons
§ **Particle accelerators**
§ **Neutrino** • Oscillations
§ **Discrete symmetries P, C, T** • Parity violations
§ **Hadron resonances** • Quark model

References: R.H. Cahn and G. Goldhaber, The experimental Foundations of Particle Physics, Cambridge University Press.

INF — Computer Science

Calculus Laboratory
§ **Programming in C** • Basic instructions (iterations, arrays, pointers, functions, char variables, strings) • Numerical methods (interpolation, numerical integration, solution of differential equations)

Computational Physics Laboratory I

§ **Ordinary differential equations** • Integration with given initial conditions • Euler Method and Euler-Cromer method • Integration error and stability.
§ **Input/output** • stdin • stdout • stderr
§ **Integration methods** • Reversibility in Euler-Cromer and Verlet methods.
§ **Implementations** • Harmonic Oscillator • Pendulum • Planar motion • Coupled equations
§ **Runge-Kutta methods of II and IV order**
§ **Conditional Compilation and macro functions**.
§ **Dynamic memory allocation** • malloc()• calloc() • realloc(), free(), sizeof()
§ **Random paths** • Brownian motion • Random Walks • Lattice gas
§ **Generation of random numbers** • Congruential generator • method of the inverse cumulative distribution • Accept/Reject method.
§ **Noticeable Generators** • C library functions for random generators
§ **Histograms of stochastic variables**
§ **List management** • Dictionaries • Clustering • Percolation

References: Barone, Marinari, Organtini & Ricci-Tersenghi, Programmazione Scientifica, Pearson; Press, Teukolsky, Vetterling & Flannery, Numerical Recipes in C, Cambridge University Press