

**The subjects of the final  
examination  
of the Doctoral School of in  
PHYSICS  
at University of Debrecen,  
Hungary**

**2015.**

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Debrecen, 5 February, 2015.

**Main subjects:**  
(topics enclosed)

1. Atomic- and molecular physics
2. Nuclear physics
3. Solid state physics and material science
4. Environmental physics
5. Quantum field theory
6. Thermodynamics and statistical physics
7. Particle physics

# 1. Atomic- and molecular physics

## I. One-electron atoms

The Schrödinger equation of the hydrogen atom, energy levels, bound and continuum states, expectation values, hydrogenlike ions. Dirac equation, relativistic corrections.

## II. Many-electron atoms

Schrödinger equation of the many-electron atoms, Pauli principle, Slater determinants, the independent particle model, approximation of spherical symmetry, Thomas-Fermi model, Hartree-Fock and self consistent field method, L-S and j-j coupling, electron correlation, configuration interaction, density functional methods. Ground and excited states of the two-electron atoms, double excited states, Auger effect. Experimental checking of the calculation of the atomic structure, basic methods of the experimental photon and electron spectrometry.

## III. Interaction of the atoms with the electromagnetic fields

The electromagnetic field and its interaction with atoms with one electron, transition probabilities, dipole approximation, Einstein coefficients, selection rules, line widths and lifetimes, Fine structure, Zeeman effect, Stark effect, Lamb shift, interaction of many-electron atoms with electromagnetic field.

## IV. Atomic collisions

Basic concepts, potential scattering, partial waves, Born approximation. Inelastic scattering, electron scattering on atoms, excitation, ionisation, resonances. Ion-atom and atom-atom collisions, ionisation, electron capture. Experimental identification of collision processes.

## V. Molecular physics

Separation of the motion of the electrons and nuclei, rotational, vibrational and electron states of diatomic molecules, symmetry properties of the electron states. The hydrogen molecule. Basic methods for calculation of the molecular structure, molecular orbit method, valence bond method. Polyatomic molecules, rotational, vibrational and electronic states, symmetry properties of the electronic states. Fundamental experimental methods for the investigation of the molecular structure.

### Literature:

- B.H. Bransden and C. J. Joachain: Physics of Atoms and Molecules, Longman Scientific & Technical, England 1988
- H. A. Bethe and E. E. Salpeter: Quantum Mechanics of One- and Two-Electron Atoms, Plenum Rosetta, New York, 1977.
- H. Friedrich: Theoretical Atomic Physics, Springer-Verlag, 1990.
- H. Haken and H. C. Wolf: Atomic and Quantum Physics, Springer-Verlag, 1991.

- M. Weissbluth: *Atoms and Molecules*, Academic Press, 1978.
- Kapuy E és Török F.: *Az atomok és molekulák kvantumelmélete*, Akadémiai Kiadó Budapest, 1975.
- M. R. C. McDowell and J. P. Coleman: *Introduction to the Theory of Ion-Atom Collisions*, Am. Elsevier, New York, 1970.
- B. H. Brandtsden and M. R. C. McDowell: *Charge Exchange and the Theory of Ion-Atom Collisions*, Oxford Univ. Press (Int. Series of Monographs on Physics No. 82). Clarendon Press, 1992.
- Selected captures in C. Marton (Ed.): *Methods of Experimental Physics*, Academic Press, New York volumes

## 2. Nuclear physics

The static and dynamic properties of the nucleus. Radioactivity Nuclear forces. Nuclear models. Nuclear momentums. Alpha decay, beta-decay, K-capture, electromagnetic de-excitation. Nuclear reactions. Nuclear reaction models. Fission. Thermonuclear reactions. Interaction of the nuclear radiations with the matter (energy and intensity measuring devices and methods).

Particle accelerators. Elementary particles. Heavy-ion physics. Applied nuclear physics (analysis with activation and prompt radiation, reactor physics, radiation protection, isotope technique, diagnostics and therapy, dosimetry).

### Literature:

- K. N. Muhin: Kísérleti magfizika, Tankönyvkiadó, 1985.
- Györgyi Géza: Elméleti magfizika, Műszaki Könyvkiadó, Budapest, 1962.
- L. Eisenbud, - G.T. Garvey - E.P. Wigner: Az atommag szerkezete, Akadémiai Kiadó, Budapest 1969.
- Kiss D., Kajcsos Zs.: Nukleáris technika, Tankönyvkiadó, Budapest, 1984.
- A. Bohr - B. R. Mottelson: Nuclear Structure I-II. Benjamin Inc., New York, 1969.
- J. Csikai: Handbook of fast neutron generators, Vol. I-II. CRC Press, Inc. Boca Raton, Florida, 1987.
- K. L. G. Heyde: The nuclear shell model, Springer, Berlin, 1990.
- I. Lovas (ed.): Atommagok kollektív gerjesztései, Akadémiai Kiadó, Budapest, 1991.
- Fényes T.: Új  $\gamma$ - és elektron spektroszkópiai módszerek, Akadémiai Kiadó, Budapest, 1990.
- Kiss Dezső: Bevezetés a kísérleti részecskefizikába, Akadémiai Kiadó, Budapest, 1990

### 3. Solid state physics and material science

1. **Bonding types** (Madelung constant). Crystallographical concepts, reciprocal lattice.
2. Similarity of the potential shape and its consequences (**law of corresponding states**).
3. **Bloch theorem**, cyclic boundary conditions.
4. **Diffraction**, Debye-Waller factor.
5. **Lattice vibrations**: phonons, inelastic neutron scattering.
6. **Electron states**: quasi free electron model, Kronig-Penney model, Bloch functions. Wannier functions, Drude model, Sommerfeld model, Semiclassical-model.
7. **Electrical conductivity**; Temperature dependence for conductors and isolators, effects of impurities.
8. **Superconductivity. Thermoelectricity. Optical properties of solids.**
9. **Magnetic properties** (dia-, para- and ferromagnetism).
10. **Dislocations** and plasticity.
11. **Point defects**: vacancies, interstitial atoms. Atomic transport phenomena: diffusion, (cross effects).
12. **Surface energy**, structure. Structure of grain and phase boundaries (DSL, DSC lattices, relaxations) and their properties.
13. **Regular solid solutions**: ordering, precipitations, solubility.
14. **Surface and grain boundary segregation.**

#### Literature:

- C. Kittel: Introduction to Solid State Physics, Eighth Edition, John and Wiley, 2005
- J. M. Ziman: Principles of the Theory of Solids, Cambridge, University Press. Third Edition, 1972
- R. W. Cahn, P. Haasen: Physical Metallurgy, North-Holland, Amsterdam, 1983
- P. Haasen: Physical Metallurgy, Third Edition, Cambridge, University Press, 2003
- N.W. Ashcroft and N.D. Mermin: Solid State Physics, Brooks/Cole, 1976

## 4. Environmental physics

Environment, risk, civilisation

Energy and civilization; Hazards and their sources; Risks in natural and anthropogenic processes; Perspectives, some remarks on environmental protection.

Atmosphere and climate

Constituents influencing the climate, air pollution; Climate models, climate theories – IPCC models.

Atmospheric aerosol: origin (emission sources, natural and anthropogenic components), transport, physical and chemical properties, its role; The detection and analysis of atmospheric aerosols; Long term observation of aerosol concentrations.

Greenhouse gases: Changes in the concentrations, their measuring techniques; The changing in the quantity of the atmospheric fossil CO<sub>2</sub>, its measuring techniques (<sup>14</sup>C method, CO method, etc.); The sources of CH<sub>4</sub> in the environment (natural, antropogenic); Detection of the changes of carbon-cycle with the help of global monitoring network. Ozone: stratospheric ozone layer, tropospheric ozone.

Radioactivity in the atmosphere and its environmental effects: Basic concepts of the dosimetry; Natural atmospheric radioactivity; Radon; Cosmogenic isotopes; Antropogenic atmospheric activity; Atmospheric tests of nuclear weapons; Emission from nuclear power stations under normal operational conditions; Reactor accidents; Radioactive emission of coal-fueled electric power stations.

Lithosphere and hydrosphere. Testing the conditions of geological environment

The radon as natural radioactive tracer. Underground motion of air and water. Microclimate of caves indicating the state of the environment, therapeutic uses. Underground waters; Water age determination (C-14, H-3, Freon, SF<sub>6</sub>, Kr-85 and Ar-39 method). The influence of the mean residence time on the decay of pollutants. Methods for measuring the mean residence time of water.

Isotope hydrological measurements for selecting proper sites for radioactive waste deposits. The classification of radioactive wastes. The principle of multiple protection. Radiometric geochronological methods in geological protection; Global survey of radioactive waste deposition plants.

Physical problems and perspectives of alternative energy sources

World energy problem, sources and their influences.

Renewable energy sources, flows of solar energy. Biomass: environmental impact and perspectives. Hydroenergy sources: environmental impact and perspectives. Wind energy: environmental impact and perspectives. Solar energy: perspectives. The comparison of efficiencies and environmental impacts of different renewable energy sources.

Nuclear fission systems with decreased environmental impact.



**Literature:**

- Boeker, E. and van Grondelle, R.: Environmental Physics, John Wiley & Sons, Chicester, 1995.
- Protecting the Earth's Atmosphere, An International Challenge, Interim Report of the Study Commission of the 11<sup>th</sup> German Bundestag "Preventive Measures to Protect the Earth's Atmosphere" Publ. by the German Bundestag, Publ. Sect., 1989.
- Reid, S.J.: Ozone and Climate Change, A beginner's Guide, Gordon & Breach Science Publishers, Australia, 2000.
- Clark, I.D. and Fritz, P.: Environmental Isotopes in Hydrogeology, Boca Raton, CRC press, 1997.
- Ramsey, Charles B., Modarres, Mohammad: Commercial Nuclear Power: Assuring Safety for the Future, BookSurge Publishing 2006.

## 5. Quantum field theory

1. Poincaré symmetry and field equations of classical free fields.
2. Classical Dirac equation. Reconciliation of special relativity and quantum mechanics: failure of the one-particle interpretation, Dirac sea.
3. Canonical quantization of the free Dirac field. Fock field. Particle and antiparticle states.
4. Canonical quantization of the free scalar and vector fields. Gauge symmetry and quantization of the electromagnetic fields.
5. Quantization using Feynman path integrals in quantum mechanics and quantum field theory. Generating functionals of connected and 1PI Green's functions. Loop expansion.
6. Path integral quantization of fermion fields.
7. Regularisation procedures. (Pauli-Villars, dimensional and lattice regularisation)
8. Perturbative renormalisation of UV divergences. The Callan-Symanzik equation.
9. Renormalisation group. Homogenous renormalisation group equation. Relation between the massless and massive theory and IR divergences. Running coupling, asymptotic freedom and dimensional transmutation.
10. General theory of the renormalisation. Relation between quantum field theory and statistical physics.
11. Path integral quantization of Abelian and non-abelian gauge fields. Ward identities.
12. Quantum electrodynamics as Abelian field theory. Running coupling. Lamb shift, magnetic momentum of the electron. Compton scattering. Pair creation in external field.
13. Spontaneous symmetry breaking in case of discrete, global, continuous and gauge symmetry. Goldstone bosons. Higgs mechanism.
14. The Standard Model of the electroweak interaction.
15. Quantum chromodynamics. Asymptotic freedom and confinement. Perturbative description of high energy scatterings, structure functions, parton amplitudes. Problematics of infrared divergences.

16. Quantum chromodynamics on the lattice. Confining-nonconfining and chiral phase transition.

**Literature:**

- J. Zinn-Justin: Quantum Field Theory and Critical Phenomena, Clarendon Press, Oxford, 1990. (chapters relevant to the subject)
- S. Pokorski: Gauge Field Theories, Cambridge University Press, Cambridge, 1990.
- P. Ramond: Field Theory. A Modern Primer, The Benjamin/Cummings Publ. Co., London, 1981.

## 6. Thermodynamics and statistical physics

1. Density operator. The principle of unbiased statistical inference.
2. Density operator in thermodynamic equilibrium, partition function. The equivalence of equilibrium distributions in thermodynamical limit, thermodynamical potentials.
3. Statistical foundation of the I. and II. law of thermodynamics. Entropy compatible with the description level.
4. The Kubo theory of the linear response. Fluctuation-dissipation theorem.
5. Boltzmann equation, collision integral. Equilibrium, local equilibrium, law of detailed equilibrium.
6. Relevant and irrelevant parts of the density operator. Robertson-equation.
7.  $T \rightarrow 0$  Green-functions; perturbative and non-perturbative deduction. Matsubara frequencies.
8. The relation between thermodynamical potentials and the  $T \rightarrow 0$  Green-functions.
9. Kadanoff-construction. Renormalisation groups. Wilson-recurrence relations, universality classes.
10. Fix points, relevant and irrelevant parameters, critical exponents. The relation between renormalisation groups and critical phenomena. Gauss and Wilson fix points.
11. Phase transition in localised spin systems.
12. Neuron networks. Learning rules, thermal noise, replica procedure.
13. Chaos. Attractors. Ljapunov exponents.

### Literature:

- E. Fick, G. Sauermaun: The Quantum Statistics of Dynamic Processes, Springer, Berlin, 1990.
- Shang-Keng Ma: Modern Theory of Critical Phenomena, W.A. Benjamin, London, 1976.
- A. A. Abrikosov, L.P. Gorkov, I. Ye. Dzyaloshinskii: Quantum Field Theoretical Methods in Statistical Physics, Pergamon Press, Oxford, 1965.

## 7. Particle physics

1. **Symmetries and conserved quantities**, Noether's theorem. Continuous symmetries and fundamental interactions. Discrete symmetries: CPT-symmetry, parity violation, CP-violation.
2. **Abelian and non-abelian gauge theories**, spontaneous symmetry breaking and Abelian Higgs-mechanism.
3. **Standard model of particle interactions**: lepton and quark families and their quantum numbers, interactions.
4. **Brout-Englert-Higgs mechanism** in the standard model, masses of gauge bosons. Properties of the Higgs particle.
5. Flavour changing neutral current, **GIM mechanism**. Masses of fermions, their mixing, the Cabibbo-Kobayashi-Maskawa matrix; oscillation and mixing of neutrinos keveredése.
6. **Parton model**; quark constituents of hadrons, the quark-quark interaction.
7. **Quantum Chromo-Dynamics**, and its experimental foundations. Asymptotic freedom. Predictions of cross sections and their uncertainties.
8. **Particle accelerators**: Linear accelerator, cyclotron, synchrocyclotron, synchrotron; Guiding, shaping and cooling of particle beams; storage rings and colliders.
9. **Particle deceleration in matter**: Mechanisms of energy-loss of photons and electrons. Deceleration processes of heavy charged particles. The non-relativistic and relativistic Bethe-Bloch formulae; mean ionization potential and effective charge.
10. **Particle detection**: Ionization, proportional, streamer, drift and bubble chambers; plastic, crystal, glass, liquid and gas scintillation detectors, scintillation wires; semiconductor and microstrip detectors; particle identification with Cherenkov-detectors; sandwich and shower detectors, hodoscopes, hadron and muon calorimeters.
11. **Data acquisition, storage, analysis**: Event collection, trigger-logic, methods of on-line and off-line analyses. Data bases, event selection, kinematical conditions (discrimination). Monte-Carlo simulations, determination of efficiency and spectrum shape. Curve fitting,  $\chi^2$ , statistical and systematic errors, covariance and correlation.
12. **Description of a historical particle physics experiment**  
(E.g.: CP-violation, discovery of  $W^{+-}$ , measurement of the decay width of the Z-boson at LEP and its utilization for the determination of number of lepton families.)

### Literature:

- D. Horváth, Z. Trócsányi: Introduction to Particle Physics, e-learning textbook <http://falcon.phys.unideb.hu/kisfiz/okts.html>
- F. Halzen, A. D. Martin: Quarks and Leptons, Wiley, New York, 1984.

- D. H. Perkins: Introduction to High Energy Physics, Addison-Wesley, Reading, MA, 1982
- M.E. Peskin, D.V. Schroeder: An Introduction to Quantum Field Theory, Perseus Books, 1995.
- D. Griffiths, Introduction to Elementary Particles, Wiley-VCH, 2009.

## **Secondary subjects:**

(topics should be defined at time of the application for the examination)

1. Fundamental interactions
2. Applied nuclear physics
3. Analytical methods in environmental research
4. Many body problem in atomic physics
5. Description and identification of the atomic collision processes
6. Atomic and nuclear microanalysis
7. Experimental methods in particle physics
8. Dosimetry and therapy
9. Emission and absorption of electromagnetic radiation, optical spectroscopy
10. Statistical physics of the phase transitions and critical phenomena
11. Physics of the surfaces and thin films
12. Accelerator physics
13. Isotope analysis
14. Instruments of the experimental nuclear physics
15. Effects of the environmental radiation, dosimetry
16. Quantum chemistry
17. Nuclear models
18. Nuclear reactions
19. Nuclear spectroscopy and nuclear structure
20. Non equilibrium statistical physics
21. Neutron physics
22. Physics of alloys
23. Detection of the radioactive radiation, signal processing
24. Radiometric methods for the determination of the age
25. Lattice defects
26. Lattice dynamics
27. Roentgen- and Auger-electron-spectroscopy
28. Electric and magnetic properties of the solid states
29. Many body problem in solid state physics
30. Experimental methods of the solid state research
31. Symmetries in quantum theory