PhD18-30

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

# 2018.

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# Main subjects:

(topics enclosed)

1. Atomic- and molecular physics
2. Complex systems
3. Environmental physics
4. Nuclear physics
5. Solar physics
6. Particle physics
7. Solid state physics and material science

# 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.

II. 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.

III. 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.

IV. 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 bound 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. Brandsden 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. Brandsden 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. Complex systems

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 $^{1}$ 0 Green-functions; perturbative and non-perturbative deduction. Matsubara frequencies.

8. The relation between thermodynamical potentials and the T $^{1}$ 0 Green-functions.

9. Kadanoff-construction. Renormalisation groups. Wilson-recurence 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. Sauermann: 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.

# 3. 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 $CO_2$, its measuring techniques ($^{14}C$ method, CO method, etc.); The sources of $CH_4$ 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, SF6, 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 11th 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.

# 4. Nuclear physics

1. **Fundamental properties of atomic nuclei**: size, mass, binding energy, parity, spin, electric and magnetic moments, isospin. (Basic experimental facts and their explanation)
2. **Nuclear forces, the nucleon-nucleon interaction**: general features of nuclear forces, two-nucleon systems, nucleon-nucleon scattering, phenomenological potentials, meson field theory. Theory of the strong interaction. Fundamental interactions.
3. **Interaction of radiation with matter, detection of nuclear radiation**: charged particles, interaction of gamma-rays and neutrons with matter, gas-filled ionization chambers, scintillation and Cherenkov detectors, semiconductor detectors, nuclear track detectors.
4. **Measurement of nuclear properties, spectrometers, foundations of dosimetry**: Measurement of nuclear masses, nuclear radii, nuclear moments, measuring of decay constants, alpha- and beta-spectrometers, gamma-spectrometry, Penning trap and the Mössbauer effect and their applications, basics of dosimetry.
5. **Accelerators**: ion sources, electrostatic accelerators, linear accelerators, cyclotrons, betatron, high-energy accelerators, storage rings, beam parameters. Preparation of radioactive beams.
6. **Single-particle states in nuclei**: magic numbers, independent particle model, nuclear shell model and its extensions: Nilsson model, large scale shell model, no core shell models, ab-initio methods. Effective interactions.
7. **Collective states in nuclei**: Binding energy, liquid drop model, rotational and vibrational states. Dipole collectivity and clusterization. Giant resonances. Symmetries in nuclei, link between basic nuclear models, microscopic interpretation of collectivity.
8. **Radioactivity, alpha-, and beta-decay of nuclei**: law of radioactive decay, theoretical grounds of alpha- and beta-decay, parity non-conservation in beta-decay. Gamma-decay and electron conversion.
9. **Nuclear reactions and their models**: classification of nuclear reactions, their main features (conservation laws, cross sections, excitation functions), direct reactions, compound nuclear reactions, heavy-ion reactions, relativistic heavy ion reactions. Nuclear reactions in inverse kinematics.
10. **Nuclear fission, basic principles of fission and fusion reactors**: main features of nuclear fission, thermal, fast, and breeder reactors, fusion reactor concepts.
11. **Applications of nuclear physics:** X-ray analysis, activation analysis, Rutherford back scattering spectrometry, scanning proton microprobe, geologic dating. Medical applications.
12. **Nuclear Astrophysics:** Star formation and evolution of the stars. Nuclear burning cycles. Nucleosynthesis in stars and in the early universe. Evolution of the Universe and puzzles associated with it: dark matter and dark energy.

**Literature:**


- J. Lilley: Nuclear Physics, Principles and Applications (John Wiley & Sons, NY, 2001).
- S.S.M. Wong: Introductory Nuclear Physics, (Wiley & Sons, NY, 1998).
- W.S.C. Williams: Nuclear and Particle Physics (Oxford Science Publications, Oxford, 1991).
- K. Heyde: Basic Ideas and Concepts in Nuclear Physics (IoP,  London, 1999).
- S.G. Nilsson and B. Ragnarsson: Shapes and shells in nuclear structure, (Cambridge University Press, 1995).
- W.R. Leo: Techniques for Nuclear and Particle Physics Experiments (Springer, Berlin, 1994).
- Ch. Iliadis: Nuclear Physics of Stars (Wiley & Co., NY, 2007).

# 5. Solar physics

1. **The solar interior, helioseismology** (Standard solar model, nuclear reactions, the solar neutrino problem. Energy production, solar neutrino experiments. The three main layers of the solar interior, energy transport. Eigenmodes, k-omega diagram. Measurement of the sound speed and the differential rotation and their results.)

2. **Theory of convection and differential rotation** (Convective instability, mixing-length theory, statistical theories, overshooting. The observed characteristics of solar granulation. The origin of differential rotation and its observed features. Tachocline.)

3. **Magnetohydrodynamics, MHD waves** (The basic equations and their derivation from the Maxwell- and Vlasov-equations. Connection between the equations and the conservation theorems. Frozen-in fields, magnetic forces. Alfvén waves, magnetoacoustic and magneto-gravity waves. Tube waves. MHD discontinuities.)

4. **The solar dynamo** (Definition of the solar dynamo, anti-dynamo theorems. Mean-field theory, alpha-effect, alpha-omega dynamo. The global magnetic field of the Sun and its cyclic variation. Models of the solar dynamo. Dynamo in planets.)

5. **Force-free magnetic field** (Characteristics of potential fields, linear and non-linear force-free magnetic fields. The role of magnetic helicity. Magnetic free energy. The role of eruptive phenomena in the energy- and helicity-balance of the solar corona.)

6. **Solar activity phenomena in the photosphere and their origin** (Observed features, distributions, statistics and models of sunspots and solar faculae. 'Magnetic tree' structure, models of flux emergence and expansion.)

7. **Solar activity in the chromosphere and the corona** (Types and models of prominences. Magnetic reconnection, flares, Coronal Mass Ejections (CMEs). Their connection to other phenomena on the solar surface. Radio emission of the Sun. The problem of chromospheric and the coronal heating.)

8. **Observational methods of solar physics** (Types and properties of solar telescopes. Detailed description of the largest solar telescopes. Solar observation spacecrafts. Polarisation of light and its applications in solar physics.)

9. **The effects of solar activity on terrestrial life (**Terrestrial effects of solar eruptions. Magnetic storms: mechanism, predictability. Effects on the upper atmosphere and the climate of the Earth. Forbush-effect, reconstruction of the solar activity. Terrestrial effects of CMEs. Space Weather. Ground and Space-based observation of Space Weather)

# 6. Particle physics

1. **Symmetries and conserved quatities**, 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.
6. Sources of **neutrinos** and means of their detection. Masses and mixing of neutrinos and discovery of neutrino oscillations. Neutrinos in the standard model.
7. P**arton model**; quark constituents of hadrons, the quark-quark interaction.
8. **Quantum Chromo-Dynamics**, and its experimental foundations. Asymptotic freedom. Predictions of cross sections and their uncertainties.
9. **Particle accelerators**: Linear accelerator, cyclotron, synchrocyclotron, synchrotron; Guiding, shaping and cooling of particle beams; storage rings and colliders.
10. **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 ionazation potential and effective charge.
11. **Particle detection**: Ionization, proportional, streamer, drift and bubble chambers; plastic, cristal, glass, liquid and gas scintillation detectors, scintillation wires; semiconductor and microstrip detectors; particle identification with Cherenkov-detectors; sandwich and shower detectors, hodoscopes, hadron and müon calorimeters.
12. **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.
13. **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, Viley-VCH, 2009.

# 7. 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 deffects**: 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 Whiley, 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

# 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. Waves
14. Isotope analysis
15. Instruments of the experimental nuclear physics
16. Effects of the environmental radiation, dosimetry
17. Quantum chemistry
18. Nuclear models
19. Nuclear reactions
20. Nuclear spectroscopy and nuclear structure
21. Non equilibrium statistical physics
22. Neutron physics
23. Physics of alloys
24. Plasma physics
25. Detection of the radioactive radiation, signal processing
26. Radiometric methods for the determination of the age
27. Lattice defects
28. Lattice dynamics
29. Roentgen- and Auger-electron-spectroscopy
30. Electric and magnetic properties of the solid states
31. Many body problem in solid state physics
32. Experimental methods of the solid state research
33. Symmetries in quantum theory
34. Solar Magnetohydrodynamics