Admission to Candidacy Exam Syllabus

The following lists of topics are very inclusive and may seem overwhelming. Keep in mind though that many problems can be done using only undergraduate (500) level physics, especially in E&M and Modern Physics.

<u>Classical Mechanics</u>

Reference textbook: H. Goldstein, C. P. Poole and J. L. Safko, "Classical Mechanics", 3rd Edition. The texts by K. R. Symon and by Marion and Thornton are also good.

1. Newton's laws. Solving all types of undergraduate problems: projectiles, relative motion, conservation of energy, momentum and angular momentum. Problems involving collisions of mechancial objects. Motion in accelerating reference frames (see also Sec.8). Static equilibrium of mechanical systems. Problems with friction force.

2. Motion in central potential. Motion of two masses attracted by gravity. Parameters of the planet orbits, their periods, Kepler's laws. Parameters of the parabolic and hyperbolic trajectories. Escape velocity.
[Goldstein Ch. 3, sections 1-3,5,7,8]

3. Systems with constraints. Lagrange equations. Calculation of Lagrangians for mechanical systems with moving and rotating parts (see also Sec.6). Dissipation function for systems with viscous friction. Hamilton's equations. Conservation of H. Variational principles for Lagrangian and Hamiltonian.
[Goldstein Ch. 2. Ch. 8, sections 1-5]

4. Small oscillations. Calculation of eigenfrequencies and eigenvectors (fundamental modes). Forced oscillations, including viscous friction. Mechanical resonance.
[Goldstein Ch. 6, sections 1-5]

5. Kinematics of rigid bodies. Rotation matrices and Euler angles. Angular velocity. Addition of angular velocities. General motion of the rigid body without fixed points.
[Goldstein Ch. 4, sections 1-4, 6-10]

6. Energy and angular momentum of rotating bodies with and without fixed points. Tensor of inertia, its principal axis and the principal moments of inertia.
[Goldstein Ch. 5, sections 1-4]

7. Dynamics of the rigid body rotational motion. Euler equations of motion. Precession of the torque free symmetric top with fixed point. Steady precession (without nutation) of the heavy symmetric top with a fixed point.
[Goldstein Ch. 5, sections 5,6,7]

8. Motion in the rotating reference frames. Coriolis force, angular acceleration, centripetal force.

[Goldstein Ch. 4, section 10]

[Note: the following topics are excluded:
- In central field motion [Ch. 3] sections 9-12 are excluded
- Precession of a heavy top with arbitrary initial conditions, nutations [Ch. 5, most of section 7]
- Principle of least action for the "abbreviated action" [Ch. 8, section 6]
- Canonical transformation, generating functions, Poisson brackets, Hamilton-Jacobi theory, Liouville's theorem, canonical perturbation theory [Ch. 9, Ch. 10, Ch. 12]
- Chaos [Ch. 11]
- Lagrangian and Hamiltonian formulations for continuous systems and fields [Ch. 13]

Thermodynamics and Statistical Physics

Reference textbooks:

"Statistical Physics of Particles" by M. Kardar (2007).
"Thermal Physics" by C. Kittel and H. Kroemer (1980, 2nd Edition).

Thermodynamics [Kardar, Ch.1, Kittel Chs. 2-10.]

a) First law of thermodynamics, work, and heat transfer.
b) Ideal gas law. Processes with a gas: isothermal, adiabatic, etc.
c) Heat engines, Carnot cycle. Reversible and irreversible processes.
d) Second law, entropy. Thermodynamic potentials (free energy, Gibbs energy).
e) Third law.
f) General equations of state. Maxwell relations.
g) Phase transitions. Chemical potentials.

Classical statistical mechanics [Kardar, Ch. 4, Kittel Chs. 1-5]

a) Gibbs distribution. Microcanonical, canonical, grand canonical ensembles. Partition function.
b) Derivation of thermodynamic properties for the ideal gas and for an ensemble of the two-level systems.

Quantum statistical mechanics [Kardar, Ch. 6, Kittel Ch. 1-5]

a) Contribution of molecular rotations and vibrations to thermodynamics properties.
b) Phonons in solid state.
c) Blackbody radiation.

Ideal gas in the quantum limit [Kardar Ch. 7, Kittel Ch. 7]

a) Fermi and Bose gases. Partition function for indistinguishable particles. Occupation numbers.
b) Non-degenerate and degenerate limits. Characteristic density of a crossover between the limits at a given temperature of the gas. Characteristic temperature of a crossover between the limits at a given density of the gas.
c) Degenerate Fermi gas at $T << T_F$
d) Degenerate Bose gas. The Bose-Einstein condensation. Condensation temperature T_B. Bose-Einstein condensation as a phase transition.

Electromagnetism

Reference textbook: J. D. Jackson, "Classical Electrodynamics", 3rd Edition.
[The text by Griffiths is also good.]

- Introduction to Electrodynamics.
- Obtain the charge distribution and / or the potential for a configuration of charges or conductors specified in one of many ways. [Jackson 1.1-1.6. Griffiths Ch. 2]

- Solve boundary value problems in electrostatics using
  - (i) the method of images. Specific well-known problems will be considered as well.
  - (ii) expansions in terms of orthogonal functions as well as using Green functions.
- Examine the effect of charge distributions at large distances using multipoles. Dielectrics. [Jackson 1.7-2.9, 3.1-3.11, 4.1-4.7. Griffiths Chs. 3,4.]

- Application of the Laws of Biot and Savart and of Faraday to magnetostatic problems.
- The basis of electrodynamics: the Maxwell equations, the potential formulation, Green functions and retarded potentials. Gauge invariance.
  [Jackson 5.1-5.11, 5.15-5.17, 6.1-6.5. Griffiths Chs. 5, 6, 7, 10.]

- Electromagnetic radiation and its propagation in
  - (i) Uniform homogeneous media.
  - (ii) Understand the propagation of electromagnetic radiation in waveguides.
- Obtain the transmitted wave that propagates through media by considering the effects of the electronic properties of molecules. [Jackson 7.1-7.6, 8.1-8.5. Griffiths Chs. 8,9.]

- Radiation due to oscillating current distributions, including simple antennas.
- The general solution to the Helmholtz equation in the radiation zone as a multipole expansion and how to obtain each term from given source distributions.
- The scattering of waves by media at various wavelengths.
  [Jackson Ch. 9, 10.1-10.5. Griffiths Ch. 11.]]

- Einstein's theory of relativity and its connections to electromagnetism. We consider especially relativistic kinematics, the electromagnetic field tensor, covariance thereof and the relativistic precession of spin. [Jackson Ch. 11. Griffiths Chs. 8, 12.]

- Lagrangian for charged particles in electromagnetic fields and the motion of charged particles in electromagnetic fields using the action principle.
- The energy loss of charged particles in dense media; Cherenkov radiation and transition radiation.
  [Jackson 12.1-12.4, 13.1-13.4, 14.1-14.3.]

Modern Physics

Reference textbook: K. S. Krane, "Modern Physics", 2nd Edition. This is a lower-level text, so you should also consult "Subatomic Physics" by E.M. Henley and A. Garcia.

Particular attention should be paid to

(i) Special Relativity: Time dilation, Lorentz contraction, abandonment of simultaneity, velocity addition, relativistic Doppler effect, relativistic invariants, relativistic kinematic processes including, e.g., Compton scattering.
(ii) Basic Modern Physics: Blackbody spectra, photoelectric effect, pair production and annihilation, de Broglie waves and other topics in basic quantum mechanics.
(iii) Nuclear physics - basic types of radioactive decay, fission, fusion.
(iv) Basic astrophysics - energy production in stars. Hydrostatic equilibrium in main sequence stars, white dwarfs and neutron stars, remnant black-body radiation, general knowledge of the Big Bang Scenario.
(v) Particle physics - broad outlines of the Standard Model, quarks, leptons, bosons. Hadrons and their organization, symmetry principles and conservation laws.
(vi) Condensed matter physics - band structure, metals/insulators, free electron model, doped semiconductors.

Students are expected to be very familiar with the contents of the following courses: PHYS 501 (Modern Physics), 502 (Quantum Physics), 506 (Thermal Physics), 511 (Nuclear/Particle Physics) and 512 (Condensed Matter Physics).

PHYS 506 covers both Thermodynamics and introduction to Statistical Physics (quantum distribution functions and their consequences etc.).

PHYS 511 is an introductory course in nuclear and particle physics and covers symmetry principles, conservation laws of strong and weak interactions, nuclear liquid drop model, nuclear shell model, fission and fusion, quark models etc. Students are expected to also know about neutrino oscillations and K^0-K^0bar (and similar) oscillations as well as the basis for this mixing.

PHYS 512 is an introduction to condensed matter physics. It covers the Drude, Sommerfeld, and Fermi free electron gas models for metals, Bloch's theorem, the concept of energy bands, and the effective mass, electrical conduction in semiconductors and insulators, semiconductor devices: including p-n junctions, the transistor, and the semiconductor laser, and magnetism: para-, dia, and ferro/ferri.

Quantum Mechanics

Reference textbook: J. J. Sakurai, "Modern Quantum Mechanics", Revised Edition.
[The text by Griffiths is also good.]

The two-slit and Stern Gerlach experiments and their implications. Formal structure of quantum mechanics using Dirac notation and state vectors. Expansion coefficients, matrix representations and operators, with special emphasis on hermitian and unitary operators.

Time development of quantum systems. Time development is illustrated using the Schrodinger and Heisenberg pictures, using the time evolution operator, using the Schrodinger equation and using the Feynman propagator and path integral approaches. The Aharonov-Bohm effect and gauge invariance.

Concepts and techniques of angular momentum. Rotation operators and density matrices. Addition of angular momenta, including physical applications and operator techniques. Tensor operators and the Wigner Eckart theorem.

Symmetry operations in quantum mechanics. Continuous symmetries such as rotational symmetry as well as discrete symmetries such as parity and time reversal. Identical particles and the constraints that they impose. Two-electron systems such as the helium atom.

Time-independent and time-dependent perturbation theory including in particular atomic physics. The interaction of atoms with electromagnetic radiation.

Scattering theory. The Born approximation and the optical theorem. Spherical waves. The method of partial waves. Modifications dealing with identical particles and symmetry considerations. Resonance scattering and inelastic scattering.

[This list is essentially all of Sakurai's text minus sections 3.8, 7.12, 7.13.]