Content of the course in questions

I. Kinematics.

1. Give strict definitions of instantaneous velocity and acceleration in 3D motion. What is speed?
2. Classify basic kinds of motion in 1D.
3. How position, velocity and acceleration depend on time in the uniform and the uniformly accelerated motion in 1D?
4. Explain the difference between the terms ‘reference system’ and ‘coordinate system’; give some examples of coordinate systems used in physics.

II. Newton’s laws of motion.

5. Formulate the First Newton’s Law of Motion without using the term ‘force’.
6. Basing on the First Newton’s Law of Motion describe the concept of ‘inertial reference frame’; in view of this, what is ‘non-inertial’ reference frame?
7. How would you define ‘Force’?
8. Explain the role of mass in the Second Newton’s Law of Motion; how the standard of the unit of mass is defined in SI unit system? What is its name?
9. Formulate the Second and the Third Newton’s laws of motion.
10. What are the basic interactions in nature? Order them with respect to the range of interaction.
11. What are the contact forces (give examples)? Which basic interactions are responsible for contact forces?
12. What is the equation of motion of a point mass or a system of point masses and what does it mean to solve the equation (give some examples)?

III. **Linear momentum**.

13. Give the definition of a linear momentum.
14. Formulate the Second Newton’s Law of Motion in terms of the linear momentum.
15. Formulate the Liner Momentum Conservation Principle for a system of particles; explain the concept of a mass center.
16. Give examples and describe physical phenomena exhibiting the momentum conservation principle (inelastic collision, recoil of a rifle)

IV. **Work and mechanical energy. Mechanical Energy Conservation Principle**.

17. Give the definition of the elementary work (infinitesimally small) and the work on an arbitrary path.
18. Define the kinetic energy
19. Explain the meaning of the notion: the work of resultant force is equal to the change in kinetic energy; give some examples.
20. Under which circumstances the concept of potential energy can be applied? What is the conservative force?
21. How do we define the potential energy?
22. What are the expressions for potential energy for a uniform gravitational field (e.g. near the surface of the Earth), for a gravitational field of a planet (at any distance from the center, above the surface), for a spring force F=-kx?
23. What is the mechanical energy?
24. Explain the meaning of the notion: the work of external force is equal to the change in mechanical energy of a system; give some examples.

25. Formulate the Mechanical Energy Conservation Principle.
26. Write down equations describing the physics of perfectly elastic collision of two bodies in 1D.
27. Show how to calculate:
    - speed at the surface of the earth of a body released at a height H.
    - speed at the surface of the earth of a body falling down from infinity (outer space), where it was at rest.
    - speed of a ball suspended from a cord in its lowest position (the pendulum), if the pendulum was released at a certain angle.
    - speed of a skier at the foot of a hill of the length L and the inclination angle α (neglecting the friction).
    - speed at equilibrium point (x=0) of a mass attached to a spring if it was released from the point x (the spring constant k is known).

V. **Dynamics of a rotational motion. Angular momentum. Rigid body**.

28. Give some examples of systems and/or phenomena to which the general term 'rotational motion' applies.
29. Give general definitions of torque (moment of force) and angular momentum.
30. How the Second Newton's Law can be formulated in terms of the torque and the angular momentum, for a single particle and for a system of particles.
31. Formulate the Angular Momentum Conservation Principle.
32. Give examples of phenomena in which the angular momentum conservation principle is exhibited.
33. Give examples of how the angular momentum conservation principle is exploited in technics and sport.
34. In which way the angular momentum conservation principle is responsible for the seasons of the year.
35. Describe the concept of a Rigid Body, give its strict definiction.
36. Define the Moment of Inertia of a rigid body with respect to a fixed axis.
37. Show the analogy between the mathematical description of the dynamics of a point mass in 1D and the dynamics of a rigid body about a fixed axis.
38. A solid cylinder ($I=MR^2/2$) is rolling with a speed v. What is its total kinetic energy?

VI. Oscillations.

39. Give examples of periodic phenomena in nature.
40. Write down the basic function describing harmonic motion and explain the meaning of parameters appearing in it (amplitude, frequency, initial phase).
41. Write down the differential equation describing the harmonic motion.
42. Discuss the physics of systems performing the harmonic motion: a mass attached to a spring, the pendulum, the LC electric circuit.
43. Write down the differential equation of the model damped oscillations (in which dissipative force is proportional to velocity), explain the role of the dissipative force, and discuss qualitatively the possible solutions.
44. Write down the differential equation of the model forced oscillations (in which the sinusoidal driving force is applied to the damped oscillator from previous point), discuss the physics of the forced oscillations from the point of view of energy, describe qualitatively the motion.
45. Describe the phenomenon of resonance; give some examples of situations where the phenomenon of resonance plays crucial role; discuss the meaning of this phenomenon in modern technology.

VII. Waves.

46. Formulate the most general definition of a wave.
47. Which of the three physical quantities is transported by a wave: mass, energy, momentum?
48. Give some examples of waves together with the description of their basic properties (longitudinal/transversal, vector/scalar, mechanical, other).
49. Write down the basic function describing a wave in 1D and explain the meaning of the parameters appearing in the function (amplitude, angular frequency, wave number).
50. What is the phase speed of a wave and how it is expressed by the angular frequency and the wave number?
51. Write down the differential equation for a wave in 1D. How does this equation look like for an electromagnetic wave? How the phase speed is related to the electromagnetic constants?
52. What is the superposition principle for waves?
53. What is the standing wave? Give some examples of standing waves.
54. What are the Chladni patterns?
55. Explain the phenomenon of resonance for a standing wave? (give some examples).
56. Give the solutions for a standing wave in a string of length L (allowed spatial frequencies, corresponding wavelengths, wave functions, time frequencies).

VIII. Interference and diffraction of waves.

57. Explain the phenomenon of wave interference. What is the constructive and the destructive interference? What are the two conditions necessary for the interference to occur (coherence)?
58. Describe the Young experiment which revealed the wave nature of light (1805).
59. Why in the Young experiment a sequence of two apertures is necessary: the first with one slit and the second with two slits?
60. Tell the difference between interference by division of a wave front and division of an amplitude?
61. Give examples of interference by division of amplitude and explain the resulting phenomena (a soap bubble, an oil on water surface, a layer of a transparent paint, Michelson interferometer)
62. What is the diffraction grating and what are its applications?

IX. Failures of classical physics.

63. Explain the failures of classical physics related to such phenomena like: black body radiation and the external photoelectric effect. What is the ultraviolet catastrophe?
64. What is the 3K background radiation?
65. Explain the mechanism of the greenhouse effect?
66. On what assumptions is the quantum theory of light based and how does it explain the black body radiation spectrum and the external photoelectric effect ?

X. Linear spectra of gases.

67. Describe qualitatively the phenomenon of the linear spectrum of hydrogen (and other gases).
68. Describe the first models of hydrogen atom and explain why they failed.
69. How the atomic nucleus has been discovered (the Rutherford experiment, 1909)?
70. On which postulates the Bohr model of hydrogen atom was based? What were the advantages and disadvantages of the model.
71. What was the de Broglie hypothesis and how was it confirmed experimentally (Davisson-Germer experiment)?

72. Draw analogy between the interference of light on a thin layer (division of amplitude) and the scattering of electrons on a surface of a metal (e.g. Ni)

XI. Basics of quantum mechanics.

73. Describe the experiment of electron diffraction on a double slit. What are the main conclusions which can be drawn from this experiment?
74. Explain the concept of a quantum state and how it is represented (a wave function), give some examples.
75. What does the Born probabilistic interpretation of the wave function say?
76. What does it mean that a quantum system can be simultaneously in many states (the superposition principle), give some examples (e.g. an electron can have simultaneously many different positions, or an electron can be simultaneously in states corresponding to its passage through two slits, in the double slit experiment).
77. What does it mean that the measurement leads to a collapse of a quantum state into an eigenstate of the measured quantity? (Explain on the example of the double slit experiment.)
78. What does the Heisenberg uncertainty principle say?
79. Write down the time independent (stationary) Schrödinger equation. What kind of mathematical problem is it? What is the form of solution of such a problem?

XII. Basic quantum systems.

80. Describe qualitatively the solution of the Schrödinger equation for an infinite rectangular quantum well.
81. Describe qualitatively the solution of the Schrödinger equation for the hydrogen atom. What is the meaning of the quantum numbers n,l,m and s, and what values they assume?
82. Describe qualitatively the solution of the Schrödinger equation for a many electron atom. In which way does it differ (qualitatively) from the hydrogen atom solution?
83. What is the Pauli Exclusion Principle? What is the connection between the electronic quantum structure of many electron atom and the Periodic Table of Elements?
84. Describe qualitatively the solution of the Schrödinger equation for a finite rectangular quantum well, and a double well. What is quantum tunneling?
85. Explain the difference between the ionic and the covalent bonding using the picture of neighboring quantum wells.
86. Describe qualitatively the quantum structure of a sequence of many identical quantum wells. What kind of matter does such a model represent?
87. Describe the basic phenomenological differences between metals, semiconductors and insulators (consider only the electrical and the optical properties)
88. Explain the phenomenological differences (electrical and optical) between metals and dielectrics using the quantum picture of condensed matter (electronic band structure).