Medical biophysics II Final exam questions 2018/19

1. Radiations: basic concepts, fundamentals of geometric optics
Types of radiations. Radiometric quantities (radiant emittance, irradiance, intensity), dependence on direction, solid angle). Dependence of irradiance on distance from the source of various geometry (graphical representation). Attenuation of radiation passing through a medium (differential and integral form of the law, interpretation). Geometric optics as a model. Fermat's principle. Absolute and relative index of refraction, the law of refraction and reflection. Calculation of critical angle. The phenomenon of total internal reflection and its application in medicine.

2. Image formation of simple optical systems
Image formation on a single curved surface, refractive power, law of image formation. Image formation by lenses, principal light rays, lens equation. Magnification and angular magnification. Equivalent power of lens combinations. Structure, image formation and magnification of a light microscope.

3. Fundamentals of wave optics
Oscillations and waves, types of waves. The Huygens-Fresnel principle, interference, diffraction on a slit and on an optical grating. Calculation of the angle of diffraction. The concept of polarized light. Application of light polarization: polarimetry, phase contrast and polarization microscope (the principle briefly). Limit of resolution explained with wave optics. Interpretation of colors.

4. Dual nature of light
Phenomena referring to wave nature and interpretation of them. The electromagnetic spectrum. Photoelectric effect, its interpretation by Einstein and applications of it. Photon energy, the eV scale. Interpretation of momentum of light, application: optical tweezers. The concept of a matter wave. Parts and resolution of the electron microscope.

5. Models of the atom, electron as particle and wave
Models of the atom. The Bohr model. Franck-Hertz experiment. The concept of matter wave and calculation of its wavelength. Wave nature of electron (wavelength, experimental proofs). Wave properties of the free electron, Heisenberg's uncertainty relation. Characterization of the bound electron, quantum numbers. Structure of the periodic table.

6. Atomic and molecular interactions
Interactions in physics. General description of intra- and interatomic interactions, potential energy, bond distance, bond energy (concepts and graphical representation). Electronegativity. Primary bonds (covalent, metallic, ionic), secondary bonds (dipole-dipole, van der Waals, hydrogen bond, hydrophobic bond). Atomic radius. Types of scanning probe microscopy: STM, AFM (principle, components, application).

7. Multiatomic systems I. ideal and real gases
Macrostate and microstate. Boltzmann's definition of entropy. Ideal gas. Kinetic gas theory. Origin of the pressure of ideal gases. Maxwell-Boltzmann velocity distribution. State equation of real gases (van der Waals equation). Boltzmann distribution and condition of its validity. The barometric formula, thermal emission of metals, Nernst equation, equilibrium and speed of chemical reactions, Arrhenius plot. Bond strength, interpretation of breaking of various types of bonds by Boltzmann distribution. Temperature dependence of the electric conductivity of semiconductors.

8. Multiatomic systems II. Solids, liquids and liquid crystals
Characterization of crystalline state, unit cell, crystal defects. Energy levels in crystals, and structure (insulators, conductors, intrinsic and doped semiconductors). Interpretation of electric and optical properties of crystalline materials. The function of the semiconductor diode. Order in the liquid state. Properties of mesomorphous state. Thermotropic and lyotropic liquid crystalline structures. Biological examples for liquid crystalline systems. Electro- and thermooptical phenomena and their applications.

9. Interaction of light with atoms and molecules
Light scattering. Rayleigh- and Mie-scattering with examples. Turbidimetry, nephelometry. Dynamic light scattering, and the information obtained from it. Law of radiation attenuation and derivation of the Beer-Lambert law from it. Measurement of the absorption spectrum (parts and function of the equipment) characteristic parameters and information obtained from it. Energy levels and spectra of atoms and molecules.

10. Thermal radiation
Energetics of thermal radiation. Absolute black body. Kirchhoff's law, Stefan-Boltzmann law, Wien's law. Planck's explanation. The emission spectrum of the absolute black body. Explanation of some phenomena (shadow of a candle flame, the color of incandescent bodies). Light sources based on thermal radiation. Medical application of thermal radiation.

11. Luminescence and its forms
Types of luminescence (according to the ways of excitation and relaxation with examples). Emission mechanisms of atoms. Electron-energy system of molecules, Jablonski-diagram (singlet and triplet states, vibrational relaxation, intersystem crossing). Kasha's rule. Luminescence spectra, explanation of Stokes-shift. Quantum yield, luminescence lifetime. Parts and function of fluorescence spectrometer. Medical and biological applications of fluorescence: FRET, FRAP, luminescent microscopic methods.

12. Laser
Fundamentals of production of laser radiation: spontaneous and induced emission, population inversion, the optical resonator, conditions for resonance. Properties of laser light. Types of lasers. Medical (surgical, ophthalmological and dermatological) and other applications of the special properties of laser light with examples.

13. Atomic nucleus, isotopes. Ways of radioactive decay, nuclear radiations
Structure of the atomic nucleus and the factors influencing its stability. Isotopes. Types of decays, detailed description of them. What determines the type of decay of an element? Comparison of electron and positron (interpretation of their production and annihilation on the basis of conservation laws). Production of gamma radiation. Energy spectra of alpha-, beta-, and gamma-radiations. Ways of production of isotopes (natural and artificial).

14. Radioactive decay law. Characteristics of radioactive isotopes. Interactions of nuclear radiations with matter
Definition of activity. Differential and integral form of decay law. Half-life and average lifetime. The decrease of activity in the function of time. Classification of ionizing radiations according to the interaction with matter. Interaction of α-, β--, β+- and γ-radiations with matter. Effect of neutron radiation. Proton radiation, the Bragg-peak, and its significance.

15. Measurement of nuclear radiations
Parts and function of the devices used for measurement of nuclear radiations: scintillation counter, detectors based on gas ionization, thermoluminescent dosimeter, photographic (film) methods, semiconductor detectors. Field of application of them.

16. Dosimetry, dose concepts, radiation protection

Biological effects of ionizing radiations: mechanism of radiation effect (physical, chemical, biological phases) stochastic and deterministic effect. Dose concepts: absorbed dose, exposure, equivalent dose, effective dose, dose rate. Measurement of exposure, relations of doses in air and in tissue, weighting factors and meaning of them. Radiation protection: ALARA-principle (graphical explanation) dose limits.

17. Fundamentals of isotope diagnostics. Viewpoints for selection of the proper isotope

Information obtained from isotope tests. Cost-benefit principle. Viewpoints for selection of the isotope: chemical element (definition of radiopharmaceutical), activity, half-life, type and energy of emitted radiation, the practical significance of them. Parts and function of Tc-generator.

18. Methods of isotope diagnostics, fundamentals of radiotherapy

Classification of isotope diagnostic methods. Parts and function of gamma-camera. Scintigraphy. Dynamic examination, ROI. Interpretation of typical isotope accumulation curve. Determination of the biological half-life of an organ. SPECT. Parts and working principle of PET. Multimodal imaging. Selection of radiation used based on the absorption and ionization processes. Relative depth dose. The applied dose. Radiation sources. Teletherapy, geometric viewpoints. concept and role of collimators (examples), gamma-knife. Principles of brachytherapy.

19. Types of biological signals, signal processing

Classification of signals according to different viewpoints (with examples). Comparison of signals (decibel scale). Fourier-theorem for periodic and aperiodic signals (examples). Typical frequency and amplitude ranges of biological signals. The voltage divider, parts and function of filter circuits for alternating current. The function of the amplifier, functions showing the working of an amplifier, effect of feedback. Digitalization of analog signals. Shannon-Nyquist theorem. Processing of pulse signals, examples for medical application.

20. Production and characterization of x-rays and its interaction with matter

Typical wavelength and photon energy range of x-rays. Production of x-rays, structure and function of the x-ray tube. Spectrum of Bremsstrahlung. Power and efficiency of x-ray tube. Duane–Hunt-law. Production of characteristic x-rays, fields of application.

21. Fundamentals of x-ray diagnostics

Mechanisms and energy dependence of x-ray absorption. The energy range applied in diagnostics. Summation image. Contrast media, image amplifier, DSA. X-ray densitometry. Principles of computer tomography, CAT-scan generations, image reconstruction. Hounsfield unit, windowing. Special applications in modern CAT-scan imaging. Disadvantages of CAT-scan. Production of high-energy x-rays, fields of application.

22. Fluid flow

Basic concepts: Volumetric flow rate, streamlines, viscosity. Types of flow. Ideal fluids: Continuity equation. Bernoulli's law, plasma skimming. Real fluids: Newton's law of friction, Reynolds-number, critical velocity. Stokes-law, Hagen–Poiseuille-law, Flow resistance. Comparison of flow and electric resistances. Determinants of blood viscosity.

23. Diffusion and the laws of it. Osmosis

Concept of diffusion. Thermal motion. Brownian motion. Random walk of particles. Physical quantities used for describing the transport of matter. Fick's I. law and its conditions of validity. The diffusion coefficient. Einstein–Stokes-equation. Gas exchange between blood and alveoli. Fick's II. law. Thermodiffusion. Heat transport, Fourier's law. Osmosis, osmotic pressure, osmolarity. Medical significance of osmosis.

24. Thermodynamics I
Types of thermodynamic systems. The human body as a thermodynamic system. Types of energies in thermodynamic systems, internal energy and its components. Change of internal energy. Extensive and intensive quantities. I. law of thermodynamics and its applications for biological systems. Entropy, thermal and configurational entropy, its connections with order.

25. Thermodynamics II
Thermodynamic probability. Statistical definition of entropy. II. law of thermodynamics, direction of processes. The III. law. Usable part of internal energy in different systems (isobaric, isothermal, isothermal-isobaric). Thermodynamic potentials. Direction of processes in isolated, isothermal, and isothermal-isobaric systems. Condition for equilibrium.

26. Bioelectric phenomena I. The resting potential
Stimulus, transduction. Resting potential, ion distribution, diffusion of ions across membrane. Theory of Donnan-equilibrium and its restrictions. Starting points of the transport model. Goldman–Hodgkin–Katz-equation. Electric model of the membrane. Changes of membrane potential due to stimulation (experiment, biological examples). Changes in the membrane potential as the function of time and space, factors influencing it.

27. Bioelectric phenomena II. The action potential and its propagation
Temporal changes in membrane potential and ion currents during the action potential. Electrochemical potential as driving force. Propagation of action potential, saltatory propagation, speed of propagation, refractory period and its role. Synapse. Electric signals measured on the body surface, detection of them and the diagnostic methods related to them.

28. Production and characterization of ultrasound. Ultrasound diagnostics and therapy
Sound as wave, frequency and intensity ranges, intensity level. Production and detection of ultrasound, piezoelectric effect. Propagation, speed and absorption of ultrasound. Acoustic impedance. Refraction and reflection, reflectivity. Doppler-effect. Effects of ultrasound, therapeutic applications. Principles of ultrasound diagnostics, imaging methods (A, B, M), examples for application.

29. Water and biological macromolecules
Molecular structure, size and dynamics of water molecules. Structures in liquid and solid state. Special physical properties of water and the phenomena originating from them (good solvent, temperature distribution in natural waters, capillarity). Phase diagram. Biopolymers: subunit, bond, examples. Analogy between random walk and polymer conformation. Contour length, persistence length. Entropic elasticity. Structure and elasticity of DNA. Force curves taken by optical tweezers. Structure of proteins, interactions stabilizing the structure. Protein folding, unfolding of single proteins by AFM.

30. Biophysics of sensory organs
Sensory receptors. Steps of signal transduction. Coding of information in case of receptor- and action potential. Psychophysical laws. Adaptation. Biophysics of vision: structure of the eye, photoreceptors, photochemical reaction, that is the basis of light sensation. Basis of color sensation. Sound as mechanical wave, frequency and intensity ranges. Phon and sone scales. Simplified scheme of the ear. Signal transduction and amplification in the middle ear. Inner ear, cochlea, hair cells. Békésy's travelling waves.

31. Biomechanics: biomolecular and tissue mechanics
Basic concepts: stress, strain. Stress-strain diagram and its ranges, Hooke's law, Young-modulus. Biomechanics of elastic arteries. Collagen and elastin, distensibility. Laplace–Frank-equation. Biomechanical characteristics of bone and enamel. Viscoelasticity: mechanical model, stress-relaxation, energy dissipation. Examples: intervertebral disk, periodontal ligament. Elasticity of muscle tissue, titin. Sonoelastography.

32. Molecular mechanisms of biological motion
Structure and types of motor proteins. Duty cycle, the typical range of force and working distance, processivity. Basic phenomena of muscle biophysics: contraction, summation, tetanus, isometric and isotonic contraction, work and power. Force-velocity curve. Sliding filament model. Parts of the contractile apparatus, duty cycle of myosin, regulation of muscle contraction.

33. Examination of biomolecular structure: X-ray crystallography and mass spectrometry.
Phenomenon of diffraction, condition for diffraction. Bragg-diffraction. Determination of molecular structure by x-ray crystallography. Principles of mass spectrometry. Ionization methods: electrospray, MALDI. Motion of charged particles in electric and magnetic field. Mass analysis by magnetic and time of flight method. Applications proteomics, diagnostics, onkoknife.

34. Examination of biomolecular structure: radio spectroscopies
Stern–Gerlach-experiment, magnetic moment, splitting of energy levels in magnetic field (Zeeman-effect), Larmor-precession, resonance condition Macroscopic magnetization (Boltzmann-distribution). Relaxations, relaxation times (T1, T2). Spin echo. NMR and ESR spectroscopies. Bases of MRI: space coding, imaging: proton density, T1 and T2 weighting. Special MRI methods.

35. Biophysics of blood circulation and heart function
Function of the blood vessel system. Flow as a transport process. Changes in pressure, cross section of vessels, total cross section, and flow velocity in the blood vessel system. Mechanics of the elastic vessel wall. Pressure relations in the arterial system, auxiliary factors of circulation. Combined description of mechanical and electric function of the heart. Pressure changes during the heart cycle. Work of the heart.

36. Respiratory biophysics. Biophysical basis of physical examination
Universal gas law, partial pressure, Henry's law, capillary phenomenon. Human respiratory system: box, tube system, gas exchange surface. Intrapulmonary, pleural and transpulmonary pressure. Respiratory volumes and capacities. Processes and dynamics of the respiratory cycle. Compliance, Hagen–Poiseuille-law. Respiratory work. Inspection. Palpation: biomechanics, viscoelasticity. Percussion: sound, resonance. Auscultation: Korotkov-sound, turbulent flow, heart sounds and murmurs, respiratory sounds.