Medical biophysics semifinal exam questions 2017/18 (EM)

1. General characterization of radiations, classification of them. Physical quantities to describe radiations, simple laws concerning radiations.

Basic concepts: Radiation source, radiation, irradiated target.
Phenomena: Decrease of radiation „strength" for various reasons.
Physical quantities: Radiant power (P), radiant emittance, irradiance (M, E_{in}), radiant flux (I_E), radiant flux density or intensity (J_E), solid angle (Ω).
Laws, relations and the way leading to them: Dependence of irradiance on the symmetry of radiation source, on the distance from it and on the angles. The decrease of intensity passing through medium.
Applications: X-ray image. Planning of irradiation by therapeutic radiation source.

2. What is the leading idea of geometric optics and what simple phenomena and devices can be understood based on it?

Basic concepts: Geometric optics as a model. Light ray, normal of incidence, Fermat's principle.
Phenomena: Spreading of light in straight line, light reflection, light refraction. Total refelction.
Physical quantities: Angles (α, β), absolute and relative index of refraction (n), light velocity in a medium (c).
Laws, relations and the way leading to them: Law of spreading, reflection and refraction of light.
Applications: Refractometry. Endoscopy.

3. Geometrical optical description of complex optical systems.

Basic concepts: Light ray, normal of incidence, Fermat's principle, optical path length.
Phenomena: Image formation.
Physical quantities: Angles (α, β), absolute and relative index of refraction (n), light velocity in a medium (c), object distance (o), image distance (i), focal length (f), magnification (M).
Laws, relations and the way leading to them: Snell's law. Imaging law of single curves surface. Imaging law of multiple curved surfaces, lens equation.
Applications: Optics of human eye. Visus, resolution (in geometrical sense), correction possibilities of refractive disorders, accommodation. Image formation of lenses, simple magnifier, depth of field.

4. What is the leading idea of wave optics and what simple phenomena can be understood based on it?

Basic concepts: Wave optics as model. Oscillations, coherent and non-coherent waves. Huygens-Fresnel principle. The observed pattern. Electromagnetic wave.
Phenomena: Light interference, light diffraction. Young's experiment with double slit. Diffraction on optical grating.
Physical quantities: Amplitude (A), frequency (f), period time (T), wavelength (λ), light velocity (c), phase (φ), phase difference ($\Delta\varphi$).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities. Transformation of path- and time differences into phase differences. The description of pattern obtained on a screen by rotating vectors demonstrating oscillations.
Applications: Principle of structure examination by diffraction. Resolving power of light microscope determined by the diffraction limit, Abbe's principle. Phase contrast microscope.

5. How the wave-particle duality can be applied to light?

Basic concepts: What is light? Electromagnetic waves. Photons.
Phenomena: Light interference, light polarization, birefringence, photoelectric effect.
Physical quantities: Electric field strength (E), magnetic field strength (B), frequency (f), period time (T), wavelength (λ), light velocity (c), phase (φ), phase difference ($\Delta\varphi$), photon energy (ε).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities, Einstein-formula.
Applications: Polarization microscope, optical anisotropy. Photocell. .

6. Proofs of particle-wave duality in case of electron. Matter waves in bound and free cases.

Basic concepts: Bound and free electron. Models of atom. Matter wave. Energy quantum. Quantized quantities.
Phenomena: Cathode ray, Franck–Hertz experiment, interference experiment, Stern–Gerlach experiment, Einstein–de Haas experiment.
Physical quantities: Momentum (p), wavelength (λ), place (x), energy (E), angular momentum (L), quantum numbers (n, l, m_l, m_s).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities. Bohr formula, De Broglie formula. Heisenberg's uncertainty relation.
Applications: Interpretation of covalent chemical bond. Construction of the periodic table.

7. General description of atomic and molecular interactions.

Basic concepts: Attractive and repulsive interactions. Covalent radius, Van der Waals radius.
Phenomena: Chemical reactions, formation of different bonds.
Physical quantities: Potential energy (E_{pot}), bond distance (r_0), bond energy (E_k), electric dipole momentum (p).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities.
Applications: Atomic force microscopy.

8. Possibilities to describe many-particle systems. Ideal and real gases.

Basic concepts: Microstate, interaction, translational and rotational motion, vibration, macrostate.
Phenomena: Collisions, origin of gas pressure. Sensing the temperature of gases (sauna).
Physical quantities: Place (x), velocity (v), pressure (p), volume (V), temperature (T).
Laws, relations and the way leading to them: Gas laws and corrections.
Applications: Breathing.

9. Boltzmann-distrinution and its possible applications.

Basic concepts: Thermal equilibrium. Microstate, macrostate. The most probable macrostate.
Phenomena: Decrease of oxygen concentration in the mountains. functioning of galvanic cells.
Physical quantities: Energy (E), occupation number (n). thermal energy (kT).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities. Boltzmann formula.
Applications: Barometric altitude formula, thermal emission of metals, Nernst equation, equilibrium and velocity of chemical reactions.

10. Many-particle systems: solids.

Basic concepts: Crystalline state, space-lattice, unit cell, energy bands, crystal lattice defects, dopants.
Phenomena: Electric conduction, insulation, transparency, manifestation of anisotropy.
Physical quantities: Width of forbidden band ($\Delta\varepsilon$), conductivity (σ).
Laws, relations and the way leading to them: Interpretation of properties by the means of Boltzmann formula.
Applications: Scintillation and semiconductor detectors, microelectronics.

11. Many-particle systems: liquid crystals.

Basic concepts: Anisotropic liquids, translational and orientational order, thermotropic and lyotropic systems.
Phenomena: Thermo- and electrooptical phenomena. Phase transitions.
Physical quantities: Temperature (T), concentration (c).
Laws, relations and the way leading to them: Macroscopic and microscopic description of phase transitions.
Applications: Contact thermography, liquid crystal displays (LCD), liposomes. Biological membranes.

12. How the light can interact with atoms and molecules?

Basic concepts: Light scattering, Rayleigh-scattering, Mie-scattering, light absorption.
Phenomena: Blue sky, white and grey clouds, transparency.
Physical quantities: Light intensity (J), electric dipole momentum (p), absorbance (A).
Laws, relations and the way leading to them: Attenuation of light intensity passing through medium. Dependence of scattered light intensity on the wavelength. Lambert–Beer-law.
Applications: Measurement of static light scattering and absorption, absorption spectrometry, determination of concentration. Dark field microscope.

13. Fundamental laws describing thermal radiation

Basic concepts: Absolute black body, electromagnetic radiation.
Phenomena: Shadow of candle, color and brightness of incandescent lamp.
Physical quantities: Radiant emittance (M), absorption coefficient (α), temperature (T), wavelength belonging to maximum radiant emittance (λ_{max}).
Laws, relations and the way leading to them: Prévost-law, Kirchhoff's law of thermal radiation, Stefan-Boltzmann law, Wien's displacement law.
Applications: Light sources, telethermography, heat loss of human body.

14. Luminescence and its forms.

Basic concepts: Ground state, excited state, vibrational levels, light emission, fluorescence, phosphorescence.
Phenomena: Fireflies and visibility vests. Light of enamel and white t-shirt in disco.
Physical quantities: Light intensity (J), lifetime of excited state (τ), fluorescence quantum yield (Q_F).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities, Kasha's rule, Stokes-shift.
Applications: Fluorescent labeling, fluorescence microscopy, emission spectrometry, diagnostics and therapy.

15. Fundamentals of light amplification. Conditions for laser oscillator. Properties of laser radiation.

Basic concepts: Spontaneous and induced emission, saturation of a state, population inversion, optical pumping, optical resonator.
Phenomena: Light trail of high power laser pointer, "writing and drawing" with it.
Physical quantities: Einstein coefficients (A, B), number of transitions (ΔN), light intensity (J).
Laws, relations and the way leading to them: Ratio of electrons in different states according to Boltzmann distribution. Change of light intensity passing through a medium with population inversion. Resonance condition.
Applications: Laser surgery, dermatology, ophthalmology, CD player.

16. Atomic nucleus, isotopes. Ways of radioactive decay, nuclear radiations.

Basic concepts: Proton, neutron, nuclear forces, unstable nuclei, α-, β^--, β^+- and γ-particles, neutrino, antineutrino.
Phenomena: Mass defect, α-, β-, and γ-radiation, annihilation.
Physical quantities: Bond energy (E_k), particle energy (ε).
Laws, relations and the way leading to them: Conservation laws. characteristics and explanation of particle spectra.
Applications: Radioactive labeling, diagnostics, therapy.

17. Different forms of radioactive decay law. Characteristics of radioactive isotopes.

Basic concepts: Proton, neutron, unstable nuclei, α-, β^--, β^+- and γ-particles.
Phenomena: Mass defect, α-, β-, and γ-radiation.
Physical quantities: Number of undecayed atoms (N), activity (Λ), decay constant (λ), average lifetime (τ), half-life (T).
Laws, relations and the way leading to them: Decay law: differential form, integral form.
Applications: Radioactive labeling, diagnostics, therapy.

18. Interaction of nuclear radiations with atomic systems, effects of radiations in the living organism.

Basic concepts: α-, β^--, β^+- and γ-particles, proton, neutron, Bragg-peak.
Phenomena: Direct ionization, indirect ionization, photoeffect, Compton-effect, pair production.
Physical quantities: Linear ion density (n/l), stopping power (s), particle energy (ε), effective range (x).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities. Energy conservation. Momentum conservation.
Applications: Damage of DNA and proteins, radiotherapy.

19. Dosimetry, dose concepts.

Basic concepts: Risk, threshold dose, electron equilibrium.
Phenomena: Direct ionization, indirect ionization, direct and indirect radiation effect, stochastic and deterministic effect, acute and chronic radiation injury.
Physical quantities: Absorbed dose (D), exposure (X), radiation weighting factor (w_R), equivalent dose (H), tissue weighting factor (w_T), effective dose (E).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities. Law of reciprocity.
Applications: Radiation protection.

20. Nuclear measurement technique. Dose measuring devices.

Basic concepts: Scintillation counter, gas ionization chamber, Geiger-Muller counter, thermoluminescent dosimeter.
Phenomena: Scintillation, ionization, thermoluminescence.
Physical quantities: Ionization voltage (U), ionization current (I), particle energy (ε).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities.
Applications: Detectors of diagnostic devices, radiation protection.

21. Isotope diagnostics. Selection principles of isotopes.

Basic concepts: In vitro and in vivo examinations, radiopharmaceuticals.
Phenomena: α-, β-, and γ-radiation, β^+-decay, annihilation, scintillation.
Physical quantities: Activity (A), half-life (T), particle energy (ε).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities, extension of decay law.
Applications: Radiotracing, gamma camera, static and dynamic examinations, planar scintigraphy, SPECT, PET.

22. Kinds of biological signals, signal processing.

Basic concepts: Analog and digital signal, periodic signal, pulse signal, detectors, transducers, noise, feedback, frequency response characteristics. Sampling.
Phenomena: Voltage division, amplification, filtering..
Physical quantities: Voltage (U), current intensity (I), capacity (C), voltage gain (A_U), power gain (A_P), feedback factor (β).
Laws, relations and the way leading to them: Relations between the characteristic physical quantities, Ohm's law, Fourier theorem, Shannon Nyquist theorem.
Applications: Voltage divider, RC-circuit, diode, amplifier, LCD.

Practice questions on the semifinal exam 2017/18 I. semester (EM)

1. Microscopy I.
   Theoretical background:
   - types of optical lenses, parameters of them
   - image formation of convex lenses
   - lens laws
   - image formation and magnification of microscope
   - resolving power of microscope (Abbe's principle)
   Quantities to be determined based on the given data:
   calibration value of eyepiece scale and size of the object.

2. Refractometry
   Theoretical background:
   - law of light refraction, definition of index of refraction
   - critical angle, total reflection
   - formation of Snell circle
   - factors influencing the value of index of refraction
   - parts and function of Abbe-refractometer
   Quantities to be determined based on the given data after proper graphical representation:
   the unknown concentrations.

3. Light absorption
   Theoretical background:
   - derivation of Lambert-Beer law from the absorption law
   - absorbance, transmittance and the relation of them
   - absorption spectrum and the information available from it
   - parts of absorption spectrometer
   - application of absorbance measurement in laboratory diagnostics
   Quantities to be determined based on the given data after proper graphical representation:
   photon energy belonging to electron transition (in eV units)

4. Polarimetry
   Theoretical background:
   - linearly polarized, circularly polarized light and the connection between them
   - definition and interpretation of optical activity
   - Biot-law, specific rotation
   - parts and function of polarimeter
   Quantities to be determined based on the given data:
   the type of given sugar and the unknown concentration.

5. Optics of the eye
   Theoretical background:
   - refractive media and image formation of the eye
   - accommodation
   - refractive disorders of eye and the way for correction of them
   - limiting angle of vision, visual acuity (visus), factors influencing the visual acuity
   - distribution of photoreceptors on the retina
   Quantities to be determined based on the given data:
   accommodation power and visual acuity.

6. Nuclear medicine
   Theoretical background:
   - parts of scintillation counter
   - possible processes happening in the scintillation crystal
   - processes happening in the photomultiplier
   - signal selection, function of the discriminator, sources of noise pulses
   - optimal setting of scintillation counter

Quantities to be determined based on the given data after proper graphical representation:
the optimal discrimination level.

7. Gamma-absorption
   Theoretical background:
   - attenuation law of radiation, attenuation coefficient, mass attenuation coefficient
   - processes of attenuation on the atomic scale (photoeffect, Compton-scattering, pair production, elastic scattering)
   - the dependence of mass attenuation coefficients due to different processes on the photon energy
   - viewpoints of radiation protection
   Quantities to be determined based on the given data after proper graphical representation:
   D, μ, μ_{m}, for all the absorbents and ε, τ_{mPb}, σ_{mPb}.

8. Resonance
   Theoretical background:
   - elastic deformation, Hooke's law
   - harmonic oscillation
   - undamped and damped free oscillation
   - driven oscillation, resonance
   - effect of external force (depending on the distance) on the driven oscillation (working principle of AFM)
   Quantities to be determined based on the given data after proper graphical representation:
   the spring constant.

9. Skin impedance
   Theoretical background:
   - definition and components of impedance
   - electric model of the skin and the possible simplifications on the model
   - frequency dependence of capacitive reactance, approximation of skin impedance in case of low and high frequencies
   - practical applications of impedance measurement
   Quantities to be determined based on the given data:
   specific resistance and specific capacity of the skin.