Medical biophysics semifinal questions EM 2018

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.