MEDICAL PHYSICS 2
SS 2021

Fakultät für Physik und Astronomie, Universität Heidelberg

Preliminary schedule

	Overview: Biophysics, Medical Physics, imaging techniques (US, CT, PET, MR)
	1. X–rays Röntgen 1895, Hounsfield units, X–ray tube, Richardson–Dusham equation, X–ray spectrum, Lambert–Beer law, interactions of high–energy photons with matter
	2. Radioactive–tracer techniques, nuclear medicine 2.1. Requirements for *in vivo* tracer, injected activities and amounts of β^+–tracer in PET 2.2. Scintigraphy, SPECT γ–camera, Anger camera, SPECT scanner, ^{99m}Tc generator, PET, FDG 2.3. Elementary processes in Positron Emission Tomography (PET) Interactions of e^+: Bhabha scattering; Mott scattering; Bremsstrahlung Electron–positron annihilation in 2 and 3 photons Interactions of photons with matter: Rayleigh scattering; Photoeffect; Compton scattering, Klein–Nishina differential cross section
	2.4. Principles of PET Tracer production, radionuclides for PET, detection of annihilation quanta, Anger–Logic, block detector, determination of LoR, energy window, properties of scintillator materials employed in PET scanners, digital image reconstruction in PET, image resolution 2.5. Time–of–Flight (TOF) PET
	2.6. Physiological imaging Energy metabolism of the cell: glycolysis, citric acid cycle, oxidative phosphorylation ① Disposition kinetics of FDG: 3–compartment–model for transport and phosphorylation of FDG, trapping ② Cardiac lipid metabolism: β–oxidation

	③ Stroke: rCBF (perfusion), rCBV, susceptibility–weighted dynamic MRI, glucoCEST ④ Neocortical activity: BOLD effect, functional MRI (fMRI) ⑤ Neurotransmitter metabolism ⑥ Catabolism of 5–fluorouracil (5–FU)
	2.7. Quantitative PET and biological models ① Linear kinetics: 1– and 2–compartment model ② Nonlinear kinetics: Michaelis–Menten model, saturation of 5–FU catabolism in the liver, nonlinear 3–compartment model for 5–FU catabolism *in vivo* 2.8. Radiation exposure
	3. Magnetic Resonance 3.1. Magnetism is a quantum phenomenon Ferromagnetism, diamagnetism, paramagnetism Magnetic moment, Landé–*g* factor of the elektron, nuclear magneton Stern–Gerlach 1921, Pauli 1924, Rabi 1938 Angular momenta, Zeeman–splitting, Larmor frequency, magnetization, magnetization density for spin–½ systems and for spin I in general Saturation in extremely strong magnetic fields, high–temperature approximation, polarization, static nuclear susceptibility, Curie law, Langevin paramagnetismus of free spins Magnetization of living tissue in static magnetic field B_0, paramagnetism of ^1H and ^{31}P *in vivo*
	3.2. Dynamics of systems of isolated spins – in Euclidean space Temporal evolution of the expectation value of the magnetic moment Equation of motion of magnetic moments – classical treatment, Larmor precession Transformation into rotating frame, effective field B_{eff} Oscillating field ($B_1(t)$), Bloch–Siegert shift Relaxation → Bloch equations Dipolar couplings → Solomon equations Chemical exchange → Bloch–McConnell equations Diffusion → Bloch–Torrey equations Bloch equations in laboratory and rotating frame

	Solutions of the Bloch equations Complex susceptibility, Lorentzian lineshape, impedance, filling factor, quality factor, RF energy absorbed by living tissue, specific absorption rate (SAR) Relaxation, minimal width of an NMR line, life time (T_1), Phasengedächtniszeit (T_2), homogeneous linebroadening (T_2), inhomogeneous linebroadening (T_2*) QED: spontaneous transition probability of an excited proton spin in external magnetic field B_0
	3.3. Pulsed Fourier–Transform NMR ① Measurement of T_1: inversion recovery sequence ② Measurement of T_2: spin echo sequence, phase evolution, multiecho sequence (CP, CPMG) ③ Stimulated echo, 2D NMR spectroscopy ④ Gradient echo (T_2*) ⑤ Rotary echo ⑥ Measurement of $T_{1\rho}$: spin lock ⑦ Measurement of the diffusion coefficient → diffusion–weighted MR imaging → diffusion tensor imaging → kurtosis tensor imaging Solution of the Bloch–Torrey equations for a spin echo experiment in the presence of magnetic field gradients
	3.4. MR Imaging (MRI) Localization of spin packets in 3–dimensional space Slice selection, frequency encoding, phase encoding Sampling theorem, Nyquist theorem, spatial resolution 2D–Fourier technique, *k*–space, multislice imaging, 3D–Fourier technique, spin echo imaging sequence, signal equation for spin echo, T_{1w}–/T_{2w}–MRI, spoiled gradient echo sequence (FLASH), signal equation for FLASH, T_{2w}*–MRI
	3.5. Technical Aspects of MRI Magnet Coils, RF coils, gradient systems
	3.7. Fast MRI techniques and applications Turbo Spin Echo, Echo Planar Imaging Flow, Diffusion, Perfusion, fMRI, Hyperpolarization