Q1) Consider an electron storage ring, with energy 4 GeV, average current 150 mA and a bend radius of $\rho = 7.5$ m.

a) What is the magnetic field within the bending magnets [2 marks]?
b) What are the instantaneous radiated power and energy loss per turn for a single electron travelling through the bending magnet [4 marks]?
c) What is the average power lost by the electron beam that must be replaced by the RF cavities [2 marks]?
d) What would be the energy loss per turn if the ring contained protons instead of electrons [2 marks]?

Q2) An undulator of length L = 2.0 m, period λ_u = 25 mm and peak-field B_0 = 1.2 T is installed into a 3 GeV electron storage ring.

a) Starting from the Lorentz Force and assuming a magnetic field variation of the form $B_y(z) = B_0 \sin(k_u z)$, use the electron equations of motion to show that the fundamental, on-axis resonant wavelength of the radiation will be $\lambda_r = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$, where $K = \frac{eB_0\lambda_u}{2\pi m_e c}$ [6 marks]
b) Calculate the corresponding photon energy and linewidth for the first harmonic [2 marks]
c) Calculate the maximum horizontal offset and angle for the electron beam as it moves along the device [2 marks].

Q3) A 5 GeV damping ring with circumference 6 km is being designed for a linear collider. The main goal of the damping ring is to reduce the vertical emittance from its initial value of 0.5 µm.rad to a final value of 2 pm.rad. The repetition rate of the damping ring is 5 Hz.

a) By considering the amount of time the electrons are in the damping ring, what damping time would be required if the desired final emittance is to be achieved [2 marks]?
b) If the dipole field is 0.2 Tesla, what is the energy loss per turn [3 marks]?
c) Given this energy loss per turn, what is the actual damping time of the ring [2 marks]?
d) If the desired final emittance is to be achieved, what does the energy loss per turn need to be [2 marks]?
e) If the additional energy loss per turn is to be provided by damping wigglers, what does the additional contribution to the second synchrotron radiation integral (ΔI_2) need to be [3 marks]?
f) Assuming a peak field of 1.5 Tesla in the damping wigglers, what total length of wiggler would be required [3 marks]?

Q4) For a 2 GeV electron storage ring with a dipole field of 0.6 Tesla, calculate the following:

a) Bend radius for the electrons [2 marks]
b) Instantaneous power radiated by a single electron [2 marks]
c) Critical photon energy [2 marks]
d) Total number of photons emitted per second and number of photons emitted per revolution, on average. [4 marks]
e) Average photon energy [2 marks]
f) Equilibrium relative energy spread for the electron beam (assuming the longitudinal damping partition number $J_\epsilon = 2$) [3 marks]

Fundamental Constants

Speed of light	= 299792458 m/s
π	= 3.141593
Permittivity of free space (ε_0)	= 8.854187E-12
Electron mass (m_e)	= 9.10938E-31 kg (0.510999 MeV)
Proton mass (m_p)	= 1.6726E-27 kg (938.272 MeV)
Electron charge	= 1.602176E-19 C
Classical electron radius	= 2.8179403E-15 m ($e^2/4/pi/\varepsilon_0/m_e/c^2$)
Reduced Planks constant (ħ)	= 1.054571e-34