Indian Institute of Technology, Delhi
Centre for Energy Studies

ESL 734: NUCLEAR ENERGY

Major Examinations
Duration: 120 minutes

Marks: 40
08 May. 2016

NOTE: Any assumption made should be clearly mentioned and intermediate steps in derivations should be clearly shown. Answer all questions in the same copy.

SECTION – A

1. **[4]**

   a. Why heavy water is necessary in a natural uranium fuelled reactor?

   b. Describe briefly, with suitable diagram, how heavy water is produced by GS dual temperature exchange process.

2. **[4]**

   a. A 1 MeV γ-ray photon is Compton scattered through an angle of 30^0. Find out the wavelength of the scattered photon and the recoil energy of the electron.

   b. Explain why in annihilation radiation always two photons of equal energy are produced.

SECTION – B

3. Choose the correct answer(s): ***(Multiple answers possible; Given terms have their usual meaning)*** **[5]**

   a. Effective dose can be measured in:

   i. rem ii. Sv iii. Curie iv. Gray v. None of the above

   b. Plasma beta can be written as proportional to

   i. nB/T ii. B^2nT iii. nT/B iv. nT/B^2 v. None of the above

   c. Magnetic moment (μ) of a charged particle moving in a magnetic field is:

   i. $mv_\perp^2/2B$ ii. q/mv iii. $mv_{||}^2/2B$ iv. mv/q v. None of the above

   d. The ideal fusion ignition temperature for the D-D fusion reaction is:

   i. 10 keV ii. 13.6 eV iii. 4.4 keV iv. 48 keV v. 8.9 keV vi. None of the above

   $\frac{P}{B^2}$ nT

   e. The radiation shields for nuclear reactors use Boron

   i. Due to their high heat transfer properties
   ii. due to their high absorption cross-section for fast neutrons
   iii. due to their high absorption cross-section for thermal neutrons
   iv. due to emission of gamma-rays by fast neutrons
   v. due to emission of gamma-rays by thermal neutrons

4. State True of False: **[3]**

   a. Plasma beta is the ratio of plasma pressure to magnetic pressure.

   b. In a tokamak, the vertical magnetic field, is the largest of the externally applied magnetic fields (i.e., toroidal, poloidal and vertical).

   c. **E × B** drifts due to motion of a charged particle in a magnetic field are charge dependent.

5. Consider a bare slab reactor (comprising of the fuel and coolant only) of thickness 'a' and infinite extent in the other directions. Assuming the neutron flux independent of position and all neutrons are absorbed either in the fuel or coolant, **[10]**
   a. Show that the multiplication factor for the infinite reactor is proportional to the fuel utilization.
   b. Use the above information for the infinite bare reactor to estimate the relation between the buckling factor of the reactor and the reactor thickness.
   c. Given that the operating reactor power is P and E_R the recoverable energy per fission reaction, derive a relation for the neutron flux in the reactor in terms of buckling of the reactor.
   d. Using the above information show that the condition for criticality requires multiplication factor to be one.

$\frac{K_\infty}{1+B^2L^2} = 1$

$K_\infty - 1 = B^2L^2$

$\left(\frac{K_\infty - 1}{L^2} = B^2\right)$

6. Plasma particles are injected into a region in space such that their initial velocities are directed along a direction of 20^o with respect to the x-axis. Assuming that the particles are to be confined by a simple mirror machine concept (with its axis along the x-axis) within the region close to where they are injected, **[4]**
   a. Design the simple mirror configuration so as to initially confine all the plasma particles having total kinetic energy 1 keV. Explain your results.
   b. State the dominant confinement time that determines the loss rate in such plasma. Give reasons.

7. A particle (charge q_1) with velocity v_1 and mass m_1 is deflected by another particle (charge q_2) with velocity v_2 and mass m_2.
   a. Derive a relation for the scattering cross-section of the particle; for **[10]**
      i. a single collision resulting in a deflection of the particle greater than 90^o
      ii. Multiple collisions resulting in a deflection of the particle greater than 90^o

      Compare these two cross-sections for two plasma systems, one with temperature 4.4 keV and density 10^{20} m^{-3} and another with 1 eV and 10^{16} m^{-3} respectively.
   b. If one now considering the effect of acceleration of particles under the action of an electric field with this ordered momentum being destroyed by collisions, use the equation of motion to derive the Ohm's law, in terms of the Coulomb logarithm.
   c. Why is it necessary that auxiliary heating mechanisms be used in magnetic fusion devices?

$\omega_p = \frac{nq}{mc}$

$P_L \cdot k_\infty = 1$

$k = \frac{1}{P_L}$

$P_L = \frac{1}{1+B^2L^2}$

$J = -D\nabla\phi$

$\Sigma_a \phi L^2$

Given the following constants:

Avagadro's number, N_A=0.6022 × 10^{24} /mol
Boltzmann constant, k_B= 1.38 × 10^{-23} J/°K
Electron charge, q=1.602 × 10^{-19} C
Electron rest mass, m_e=9.109 × 10^{-31} kg=0.00549 amu
Proton rest mass, m_p=1.672 × 10^{-27} kg=1.007276 amu
Neutron rest mass, m_n=1.675 × 10^{-27} kg=1.008665 amu
Speed of light, c=3 × 10^8 m/s
1 eV=1.602 × 10^{-19} J=11604 K
1 amu=1.660531 × 10^{-27} kg
Permittivity of free space= 8.8542 × 10^{-12} F/m
Permeability of free space= 4 × 10^{-7} H/m
Atomic weight of ^1_1H=1.007825 amu
Atomic weight of ^2_1H=2.014102 amu
Atomic weight of ^3_1H=3.016046 amu