Ref. No. : Ex/PE/PC/B/T/322/2024

B.E. POWER ENGINEERING THIRD YEAR
SECOND SEMESTER
EXAM – 2024
NUCLEAR POWER GENERATION

Time : 3 hours | Full Marks : 100

All Sections (A, B & C) are compulsory.

m_e	=	0.0005486 (u)	R_0	=	$1.2\,fm$
m_p	=	1.007825 (u)	$1\,u$	=	$931.5\ MeV/c^2$
m_n	=	1.008665(u)	N_A	=	6.022×10^{23}
k	:	*Boltzman Constant* $= 1.3806 \times 10^{-23} \frac{Joule}{keV}$; $= 8.6 \times 10^{-5} \frac{eV}{K}$;			

Section A

All questions are compulsory and carry 3 marks each.

1	What do you understand by the term "rest mass" of a particle? What does this term signify ? What is the rest mass energy for an electron $(m_e = 9 \times 10^{-31}\ kg)$ in eV ? If we were to only create an electron would it violate any fundamental conservation law? If so what is the solution?
2	State the relevance of de-Brogile hypothesis for sub atomic particles. Why it is it of relevance for neutrons especially for thermal neutrons. Compare the de-Brogile wavelength for thermal and fast neutrons (2 MeV)
3	Define Neutron Flux, Reactor period.
4	How many moles and molecules are contained in 100 gms of water?
5	Describe briefly two fundamental mechanisms by which radiation can affect an organelle.
6	Define "atom density", "microscopic cross section" and "macroscopic cross section". How are they related?
6	Describe the desirable and undesirable characteristics of Liquid Na as a coolant. Enumerate the need for two Na loops.
7	Why is steel not the preferred material in the core of the reactor? What is the preferred material?
8	Define "exposure", "absorbed dose", "Linear Energy Transfer",
9	What do you comprehend by the term "attenuation of radiation"? Which radiation(s) undergo attenuation? Define Half-Value Thickness.
10	Define breeding or conversion ratio with relevance to fast breeder reactor. What do you comprehend by the term "fissile" material? Is it only sufficient that the fuel should be "fissile" for use as a fuel or any other property is desirable?

Section B

Attempt any 5 questions each carry 6 marks.

1a.	The probability of photo-electric interaction (cross section) is given by $\sigma \propto \frac{Z^4}{E^3}$. If both Z and E are doubled, how does it affect the interaction cross-section? If Z is reduced by a factor of 2 and E is increased by the same factor, how does it affect the interaction cross-section? If Z is doubled and E is reduced by a factor of 2, how does it affect the interaction cross-section?
1b.	What fraction of 140 keV photons will escape without undergoing interaction from the centre of a 0.30 m sphere filled with water, given $\mu_{water}^{140\ keV} = 0.15\ cm^{-1}$?
2a.	Given the mass of 208Pb (Z=82) nucleus is 207.97664 u, compute the energy required to assemble a Pb nucleus starting with independent individual constituent nucleons.
2b.	Compute the wavelength of 1 MeV photon. Compare it with the wavelength of 1 MeV neutron, given that $m_n = 1.67 \times 10^{-27} kg$.
3a.	The Ra_{92}^{226} nucleus decays following alpha decay, with 1600 years as the half life. Calculate the activity of 1 micro-gram of given Ra sample. Assuming one alpha particle is emitted per decay, how many alpha particles per second are emitted in this decay?

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3b. Given the observations that the elastic scattering cross section is directly proportional to the surface area of the nucleus *viz.*

$$\sigma = 4\pi R^2$$

Between O^{16} & U^{235} explain which is expected to have a larger scattering cross section.

4 Stainless Steel has a density of 7.86 gm/cm^3 and $M = 55.847$. The nominal composition is as follows carbon 0.08%, chromium 19%, nickel 10% and 10% iron. Given the microscopic absorption cross section at thermal neutron energies as $\sigma_C = 0.0034b$; $\sigma_{Cr} = 3.1b$; $\sigma_{Ni} = 4.43\ b$; $\sigma_{Fe} = 2.55\ b$. Compute the macroscopic absorption cross-section.

5a. If the radioactive element disintegrates over a time equal to its average life τ , what fraction of the original amount remains ?

5b. Compute the energy required to remove one proton from ${}^{12}_{5}B$ nucleus, given $M_{{}^{11}_{4}Be} = 11.021661080$ $M_{{}^{12}_{5}B} = 12.01435638$ and $m_p = 1.00727$, in units of amu.

6a. 20,000 neutrons exit at the beginning of the neutron cycle. Calculate the number of neutrons at various stages given $\epsilon = 1.031$; $p = 08.03, f = 0.751$; $\eta = 2.012$; $L_f = 0.889$; $L_t = 0.905$

6b. For every 1000 neutrons emitted in fission, 100 escape while slowing down and 150 escape after having attained thermal energy. Of those neutrons absorbed at thermal energies 60% are absorbed in the fissile material. What is the multiplication factor if $\eta = 2.012$. If the thermal leakage is reduced by a factor of two what is the value of K?

7 For a successive radioactive disintegration, we know that

$$N_2 = \frac{N_0 * \lambda_1}{\lambda_2 - \lambda_1}\{e^{-\lambda_1 t} - e^{-\lambda_2 t}\}$$

Where the symbols have their usual meaning. Use this relation to deduce the expression for "secular & transient" equilibrium.

Section C

Attempt any **four** questions. All questions carry 10 marks each.
Attempt all sub-sections within one question.

1	a)	What is the conventional unit used to describe the mass of sub-atomic particle. Prove that one such unit is equal to the reciprocal of Avogadro's Number (N_A).	3
	b)	Prove that there is considerable empty space in an atom. Prove that the density of ^{235}U is identical to the density of ^{16}O. Define Binding Energy.	4
	c)	Compute the Q value for the reaction $${}^{4}_{2}He + {}^{1}_{1}p \rightarrow {}^{3}_{2}He + {}^{2}_{1}d$$ Given $M_{He^4} = 4.002604\,u$; $M_{He^3} = 3.01603\,u$; $M_{d^2} = 2.014102\,u$ What can you conclude about the reaction from the Q value.	3
2	a)	What is Reactivity. Explain the significance of delayed neutrons in controlling the reactivity of the reactor. What effect does an increase in the temperature of the fuel have on reactivity and why.	5
	b)	How does the Liquid Drop Model explain the spontaneous fission process.	5
3	a)	Detail the various neutron-nucleus interaction mechanisms. Discuss the phenomena of Resonance in this regards. For any one reaction mechanism plot its cross-section as a function of the incident neutron energy and highlight the three regions.	4
	b)	Derive the expression for the energy of the elastic scattered neutron in terms of its incident energy, the scattering angle, the atomic number of the nucleus from where the scattering originates	6
4	a)	When a body is in motion, its mass increases relative to an observer at rest, according as $m = \frac{m_0}{\sqrt{1 - v^2/c^2}}$. Prove that the conventional equation for Kinetic Energy is valid for most cases when v $\leq$0.2 c. Given a 1MeV electron would you consider it as a relativistic particle. On the other hand would you consider a 1 MeV neutron classically.	6
	b)	Deduce the equation	4

$$p = \frac{1}{c}\sqrt{E_{total}^2 - E_{rest}^2}$$

Where the quantities have their usual meaning.

5	a)	Describe briefly the general components of a nuclear reactor, with a suitable diagram.	4
	b)	Describe the phenomena of fission induced by a thermal neutron. Based on this explain the principle of nuclear reactor. If the gain in B.E/A in fission of heavy nucleus is around 1 MeV/A compute the approximate energy released in the fission of 1 mole of ^{235}U.	6
6		Define the term "neutron multiplication factor". Describe the life-cycle of a neutron in an ideal reactor, with reference to the various terms in the expression for the neutron multiplication factor. Based on the value of the neutron multiplication factor, what are the three stages of criticality of a nuclear reactor?	10
7	a)	Describe the conventional classification of nuclear reactors. Explain in details the working of a Pressurized Heavy Water Reactor and its advantages. Discuss briefly the "calandria tube"	6
	b)	Define "absorbed dose", What is the conventional and SI unit for absorbed dose? What is the relation between them?	4
8	a)	With the help of a neat diagram describe in details the various components of a living cell.	4
	b)	Describe the working of a Gas Cooled Reactor.	4
	c)	A point source emits S $neutrons/second$ isotropically in an infinite vacuum. Show that the neutron flux at a distance r from the source is given by $$\phi = \frac{S}{4\pi r^2}$$	2