Atomic and Nuclear

1. Explain the possible energy levels for X-rays (discrete or continuous).

Solution:
Bremsstrahlung \( E_{k_2} - E_{k_1} = h \)
X-ray energy levels are continuous due to production process of Bremsstrahlung where a high energy electron passes near a massive nucleus and creates a photon as it slows. The frequency distribution does have some high peaks at discrete frequencies where a lower level electron was shifted to an outer shell following a collision and the unstable atom releases a photon when another electron fills the vacancy.

2. What is the Schrödinger wave equation? What is it used for, and what information about the hydrogen atom can it be used to determine?

Solution:

\[
\frac{i}{\hbar} \frac{d}{dt} \Psi(x,t) = \frac{1}{2m} \nabla^2 \Psi(x,t) + V(x) \Psi(x,t)
\]

The Schrödinger wave equation is an equation that describes how the quantum state of a physical system changes in time. Solutions to Schrödinger's equation describe atomic and subatomic systems, electrons and atoms, but also macroscopic systems, possibly even the whole universe. Using this equation, Schrödinger computed the spectral lines for hydrogen by treating a hydrogen atom's single negatively charged electron as a wave, \( \Psi(x,t) \), moving in a potential well, \( V(x) \), created by the positively charged proton. This computation reproduced the energy levels of the Bohr model.

3. Given a substance (plasma) which must be sustained at a high temperature, how would you do it?

Solution:
Confining magnetic fields are generated by superconducting magnets located around the reactor chamber and by electrical currents flowing in the plasma itself.

4. What is Buckling?

Solution:
The size-shape factor that appears in the general nuclear reactor equation and is a measure of the curvature of the neutron density distribution in the reactor.

5. What does a pressurizer do? Why is it important?

Solution:
A high-strength tank containing steam and water used to control the pressure of the reactor coolant in the primary loop. Prevents steam bubble formation within reactor vessel.

6. Draw a block diagram of a nuclear reactor.

Solution:
7. Define fission and fusion. What are their differences? How does a breeder reactor work?

\textit{Solution:}
\begin{itemize}
\item \textit{Fusion}: The combination of two light nuclei to form a heavier nucleus with the release of some binding energy
\item \textit{Fission}: The process in which the nucleus of a heavy atom splits into two or more parts, releasing energy and two or three free neutrons
\item A reactor that is designed to produce more fissile material than it consumes; also sometimes called "fast reactor" since most breeder reactors use fast neutrons for sustaining the nuclear chain reaction
\end{itemize}

8. What is criticality? What is the neutron multiplication factor? Write and explain the four factor formula.

\textit{Solution:}
\begin{itemize}
\item a fission process where the neutron production rate equals the neutron loss rate to absorption or leakage. A nuclear reactor is "critical" when it is operating
\item \[ k = \frac{\text{number of neutron in one generation}}{\text{number of neutrons in the preceding generation}} \]
\end{itemize}
Four factor formula:

\[ k_{\infty} = \eta f p \epsilon \]

\( \eta \) = The number of fission neutrons produced per absorption in the fuel.

\( f \) = The thermal utilization factor Probability that a neutron that gets absorbed does so in the fuel material.

\( p \) = The resonance escape probability Fraction of fission neutrons that manage to slow down from fission to thermal energies without being absorbed.

\( \epsilon \) = \( \frac{\text{total number of fission neutrons}}{\text{number of neutrons from thermal fissions}} \)

9. What is binding energy? How does this relate to nuclear power?

Solution:

Nuclear binding energy is derived from the strong nuclear force and is the energy required to disassemble a nucleus into free unbound neutrons and protons, strictly so that the relative distances of the particles from each other are infinite (essentially far enough so that the strong nuclear force can no longer cause the particles to interact).

Nuclear fuels undergo fission when struck by free neutrons and in turn generate neutrons when they break apart. This makes possible a self-sustaining chain reaction that releases energy at a controlled rate in a nuclear reactor or at a very rapid uncontrolled rate in a nuclear weapon.

10. What happens to a PWR (pressurized water reactor) as the temperature increases?

Solution:

The higher temperature decreases moderator density. More neutrons leak, therefore less fission happens and reactor power decreases.

11. Explain the difference between a PWR and a BWR (boiling water reactor). Sketch a primary and secondary loop for a PWR.

Solution:

Pressurized water reactors (PWRs) use ordinary water under high pressure (superheated water) as coolant and neutron moderator. The primary coolant loop is kept under high pressure to prevent the water from reaching film boiling,
In BWRs the steam going to the turbine that powers the electrical generator is produced in the reactor core rather than in steam generators or heat exchangers.

12. Describe how radiation is stopped by shielding. What types of material are best for various types of radiation and why?

Solution:
The greater the thickness and density of shielding around a radiation source, the smaller the exposure. Charged particles lose energy and are thus attenuated and stopped primarily as a result of coulombic interactions with electrons of the stopping medium. For neutron attenuation, the lightest shields are usually hydrogenous, and the thinnest shields contain a high proportion of iron or other dense material. For gamma-ray attenuation, the high-atomic-number elements are generally the best. For heat removal, particularly from the inner layers of a shield, there may be a requirement for external cooling with the attendant requirement for shielding the coolant to provide protection from induced radioactivity.