1. Electromagnetic waves of length 3 m are used in radar installations. Calculate the frequency of such radiation and the energy of 1 quantum of such radiation.

\[
\nu = \frac{c}{\lambda} \\
= \frac{3.00 \times 10^8 \text{ m} \cdot \text{sec}^{-1}}{3 \text{ m}} \\
= 1.00 \times 10^8 \text{ Hz} \\
= 100 \text{ MHz}
\]

\[
E = h \nu \\
= 6.63 \times 10^{-34} \text{ J} \cdot \text{sec} \times 1.00 \times 10^8 \text{ sec}^{-1} \\
= 6.63 \times 10^{-26} \text{ J} \\
= \frac{6.63 \times 10^{-26} \text{ J}}{1.6 \times 10^{-19} \text{ J/eV}} \\
= 4.14 \times 10^{-7} \text{ eV}
\]

2. An x-ray machine operates with a tube potential of 120 kV. Find the minimum wavelength of the radiation emitted by the x-ray tube, the frequency of this radiation, and the energy of 1 quantum of such radiation.

\[
\lambda_{\text{min}} = \frac{hc}{E_{\text{max}}} \\
= \frac{6.63 \times 10^{-34} \text{ J} \cdot \text{sec} \times 3.00 \times 10^8 \text{ m} \cdot \text{sec}^{-1}}{120 \text{ keV}} \\
= 0.104 \times 10^{-10} \text{ m} \\
= 1.04 \times 10^{-11} \text{ m}
\]

\[
\nu = \frac{c}{\lambda} \\
= \frac{3.00 \times 10^8 \text{ m} \cdot \text{sec}^{-1}}{1.04 \times 10^{-11} \text{ m}} \\
= 2.88 \times 10^{19} \text{ Hz}
\]

\[
E = 120 \text{ keV}
\]
3. An electron has a kinetic energy of 5 MeV. Find its total energy and hence \( \frac{m}{m_0} \). Calculate its velocity relative to the velocity of light. Repeat for 20 MeV electrons and 250 MeV protons.

\[
E_{\text{tot}} = KE + m_0c^2 = mc^2
\]

For electrons with a kinetic energy of 5 MeV, rest energy is 0.511 MeV, so total energy is 5.511 MeV. Then,

\[
\frac{m}{m_0} = \frac{E_{\text{tot}}}{m_0c^2} = \frac{5.511 \text{ MeV}}{0.511 \text{ MeV}} = 10.8
\]

\[
1 - \beta^2 = \left( \frac{1}{\frac{m}{m_0}} \right)^2
\]

\[
\beta^2 = 1 - \left( \frac{1}{\frac{m}{m_0}} \right)^2
\]

\[
\beta = \sqrt{1 - \left( \frac{1}{\frac{m}{m_0}} \right)^2} = \sqrt{1 - \left( \frac{1}{10.8} \right)^2} = 0.996
\]

For electrons with a kinetic energy of 20 MeV, the total energy is 20.511 MeV. Then,
For protons with a kinetic energy of 250 MeV and rest energy of 931 MeV, the total energy is 1181 MeV. Then,

\[
\frac{m}{m_0} = \frac{E_{\text{tot}}}{m_0 c^2} = \frac{1181 \text{ MeV}}{931 \text{ MeV}} = 1.27
\]

\[
\beta = \sqrt{1 - \left( \frac{1}{m/m_0} \right)^2} = \sqrt{1 - \left( \frac{1}{1.27} \right)^2} = 0.616
\]

4. (J & C 1-22) A source of $^{198}\text{Au}$ with a half-life of 2.69 days has an initial activity of 5 Ci. Calculate the activity after 4.0 days. Express this activity in Bq.

A half-life of 2.69 days means a transformation constant of $0.693/2.69 = 0.258 \text{ day}^{-1}$.

\[
A = A_0 e^{-\lambda t} = 5 \text{ Ci} \times e^{-0.258 \times 4} = 1.78 \text{ Ci}
\]

\[
= 1.78 \text{ Ci} \times 3.7 \times 10^{10} \frac{\text{Bq}}{\text{Ci}} = 6.59 \times 10^{10} \text{ Bq}
\]
5. (J & C 1-24) The gamma rays from $^{60}$Co have a half-value layer in lead of 1.1 cm. Estimate the thickness of lead required to attenuate such a beam by a factor of $10^6$. What is the mean range of these photons in lead?

Ten half-value layers would attenuate the beam by a factor of 1024, so to attenuate the beam by a factor of $10^6$ would require approximately 20 half-value layers, which would be a thickness of 22.0 cm.

The mean range is equal to the inverse of the attenuation coefficient, or 1.44 times the half-value layer, which would be 1.58 cm.

6. (J & C 1-26) A tumor containing $10^6$ cells is inactivated by radiation with a mean lethal dose of $D_0 = 1.50$ Gy. Find the number of survivors after a dose of 45 Gy.

If we assume cell kill to be exponential, we can write

$$N = N_0 e^{-D/D_0}$$

$$= 10^6 e^{-45/1.5}$$

$$= 9.35 \times 10^{-8}$$

In other words, all the cells will be killed.

7. (J & C 1-27) From the definition of $\lambda$, the transformation constant, and the use of the equation $\Delta N = -\lambda N \Delta t$, calculate the initial number of disintegrations per second for a $^{198}$Au source of $10^8$ atoms. Express this initial activity in Bq and Ci. Plot the decay of this activity as a function of time and show that the total number of disintegrations is $10^8$.

The activity is given by

$$A = -\frac{\Delta N}{\Delta t} = \lambda N$$

For $^{198}$Au, the transformation constant is $0.693/2.69 = 0.258$ day$^{-1}$. Consequently, the initial activity for a $^{198}$Au source of $10^8$ atoms is

$$A = 0.258 \text{ day}^{-1} \times 10^8 \times \frac{1 \text{ day}}{24 \text{ hr}} \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ sec}}$$

$$= 2.99 \times 10^7 \text{ sec}^{-1}$$

$$= 299 \text{ Bq}$$

$$= 299 \text{ Bq} \times \frac{\text{Ci}}{3.7 \times 10^{10} \text{ Bq}}$$

$$= 8.07 \times 10^{-9} \text{ Ci}$$
8. (J & C 1-31) A cell culture containing $10^8$ cells has a doubling time of 10 hr. Find the number of cells “born” per s.

Assuming exponential cell growth, we can write

$$N = N_0 e^{at}$$

where $N$ is the number of cells at a given time, $N_0$ is the initial number of cells, and $a$ is the growth rate constant. To find the number of cells born per second, we need to calculate $dN/dt$.

The constant $a$ is related to the cell doubling time by $a = 0.693/T_d$. So, for a cell doubling time of 10 hr, the constant $a$ is given by $0.693/10 = 0.0693$ hr$^{-1}$. Then
9. (J & C 1-32) The half-life of $^{198}$Au is 2.69 days. Calculate the transformation constant and the mean life.

The transformation constant is given by $0.693/t_{\frac{1}{2}} = 0.693/2.69 \text{ days} = 0.258 \text{ day}^{-1}$.

The mean life is given by $1.44 \times t_{\frac{1}{2}} = 1.44 \times 2.69 \text{ days} = 3.87 \text{ days}$. 

\[
\frac{dN}{dt} = 0.0693 \text{ hr}^{-1} \times 10^8 \\
= 0.0693 \text{ hr}^{-1} \times 10^8 \times \frac{1 \text{ hr}}{60 \text{ min}} \times \frac{1 \text{ min}}{60 \text{ sec}} \\
= 1928 \text{ sec}^{-1}
\]