CHAPTER 1

Radiation

NOTES:

EXERCISE1.2: 1609 meters per mile
Study Guide 1.12: Neutron has a spin of ½ and is affected by electric field but not magnetic field.

Exercise

EXERCISE 1.1 Show that Planck's constant in the cgs system is 6.626 x 10^{-27} erg·sec. One joule is equal to 1 x 10^{7} erg.
SOLUTION:

$$h = (6.626 \times 10^{-34}\ \mathrm{J \cdot s}) \times \frac{1 \times 10^{7}\ \mathrm{erg}}{1\ \mathrm{J}}$$

$$= 6.626 \times 10^{-27}\ \mathrm{erg \cdot s}$$

EXERCISE 1.2 Show that the speed of light is approximately 186,000 miles per second.
SOLUTION:

$$3 \times 10^{8}\ \mathrm{m/s} = (3 \times 10^{8}\ \mathrm{m/s}) \times \frac{0.621 \times 10^{-3}\ \mathrm{mi}}{1\ \mathrm{m}}$$

$$= 1.863 \times 10^{5}\ \mathrm{mi/s}$$

$$= 186{,}300\ \mathrm{mi/s}$$

EXERCISE 1.3 Derive equation (1.4) by substituting the values of h and c into equation (1.3).
SOLUTION:

$$E = \frac{hc}{\lambda}$$

$$= \frac{(6.626 \times 10^{-34}\ \mathrm{J \cdot s})(2.998 \times 10^{8}\ \mathrm{m \cdot s^{-1}})}{\lambda} \times \frac{1\ \mathrm{eV}}{1.6021 \times 10^{-19}\ \mathrm{J}}$$

$$= \frac{12.4 \times 10^{-7}\ \mathrm{m \cdot eV}}{\lambda} \times \frac{1\ \mathrm{keV}}{10^{3}\ \mathrm{eV}}$$

$$= \frac{12.4 \times 10^{-10} \text{m} \cdot \text{keV}}{\lambda} \times \frac{1 \text{ Å}}{1 \times 10^{-10} \text{ m}}$$

$$= \frac{12.4}{\lambda \text{ (Å)}} \text{ keV}$$

EXERCISE 1.4 Derive equation (1.12) by performing binomial expansion on equation (1.11) and allowing β to approach zero.
SOLUTION:

Expanding the $(1-\beta^2)^{1/2}$, we have

$$(1 - \beta^2)^{-1/2} = 1 + \frac{1}{2}\beta^2 + \frac{3}{8}\beta^4 + \ldots$$

In accordance to with equation (1.10), the kinetic energy of a particle can be computed by taking the difference between the relativistic mass and rest mass. From equation (1.7),

$$\begin{aligned} KE &= mc^2 - m_o c^2 \\ &= m_o(1 + \frac{1}{2}\beta^2 + \ldots)c^2 - m_o c^2 \\ &= m_o(\frac{1}{2}\beta^2)c^2 \\ &= \frac{1}{2}m_o v^2 \end{aligned}$$

or

$$\begin{aligned} KE &= E - E_0 = mc^2 - m_0 c^2 \\ &= \frac{m_0 c^2}{\sqrt{1 - v^2/c^2}} - m_0 c^2 = m_0 c^2 (\frac{1}{\sqrt{1 - v^2/c^2}} - 1) \\ &= m_0 c^2 (1 + \frac{1}{2}\frac{v^2}{c^2} + .. - 1) = \frac{1}{2} m_0 v^2 \end{aligned}$$

EXERCISE 1.5 Derive equation (1.13) by solving equation (1.9) for E^2.
SOLUTION:

$$\begin{aligned} E^2 &= (mc^2)^2 \\ &= m^2 c^2 (c^2 + v^2 - v^2) \\ &= m^2 c^2 v^2 + m^2 c^2 (c^2 - v^2) \\ &= p^2 c^2 + m^2 c^4 (1 - (v/c)^2) \\ &= p^2 c^2 + \left[\frac{m_o}{\sqrt{1 - \beta^2}} \right]^2 c^4 (1 - \beta^2) \\ &= p^2 c^2 + m_o^2 c^4 \end{aligned}$$

EXERCISE 1.6 Compute the wavelength of a 1 keV x-ray and compare it to the size of an atom

(≈10^{-10}m).
SOLUTION:

$$\lambda = \frac{12.4}{E} = \frac{12.4}{1} = 12.4 \times 10^{-10}\,\text{m}$$

which is approximately the size of an atom ≈ 10^{-10} m.

EXERCISE 1.7 Using the mass in Appendix C, show that the mass of a proton is about 1836 times heavier than the mass of an electron. Also show that the mass of a neutron is about 1838.5 times heavier than the mass of an electron. A generalization can be made that both protons and neutrons are about 2,000 times heavier than electrons.
SOLUTION:

(a) Ratio of proton mass to electron mass:

$$\frac{m_p}{m_e} = \frac{1.672649 \times 10^{-27}\,\text{kg}}{9.109534 \times 10^{-31}\,\text{kg}} = 1836.12$$

(b) Ratio of neutron mass to electron mass:

$$\frac{m_n}{m_e} = \frac{1.674954 \times 10^{-27}\,\text{kg}}{9.109534 \times 10^{-31}\,\text{kg}} = 1838.68$$

EXERCISE 1.8 Show that 2.08 x 10^{+9} ion pairs per cm^3 of air (STP) are produced in one R.
SOLUTION:

$$1R = \frac{2.58 \times 10^{-4}\,C}{kg} \times \frac{1.293\ \ kg}{m^3}$$

$$= \frac{3.3394 \times 10^{-4}\,C}{m^3} \times \left(\frac{1\ \ m}{10^2\ \ cm}\right)^3$$

$$= \frac{3.3394 \times 10^{-10}\,C}{cm^3} \times \frac{1\ \ \text{ion pair}}{1.6021 \times 10^{-19}\,C}$$

$$= 2.0824 \times 10^9\ \ \text{ion pairs} / cm^3$$

Note that the R is defined in electrostatic units and per cm^3.

EXERCISE 1.9 Show that 33.97 J/C is equivalent to 33.97 eV expended to produce an ion pair.
SOLUTION:

$$33.97\frac{J}{C} = 33.97\frac{J}{C} \times \frac{1\,eV}{1.602 \times 10^{-19}\,J} \times \frac{1.602 \times 10^{-19}\,C}{1\,\text{ion pair}}$$

$$= 33.97\ eV / \text{ion pair}$$

Study Guide

1.1 In your own words, define the following terms:
(a) PET (b) SPECT
(c) radiation (d) corpuscular or particulate radiation

(e) x-rays	(f) gamma rays
(g) teletherapy	(h) brachytherapy
(i) laser	(j) ionization
(k) excitation	(l) photon
(m) quanta	(n) scientific notation
(o) de Broglie wave	(p) relativistic mass
(q) neutrinos	(r) mu mesons
(s) negatron	(t) positron
(u) equivalent dose	(v) absorbed dose
(w) radiation exposure	(x) radioactivity

(a) PET

SOLUTION:

Positron emission tomography – a three dimensional imaging system based on the detection of gamma rays emitted from the annihilation of a positron and an electron giving off two gamma rays that travel in opposite directions

(b) SPECT

SOLUTION:

Single photon emission tomography – a three dimensional imaging system based on the detection of gamma rays emitted from absorbed tracer within the body system

(c) radiation

SOLUTION:

The propagation of energy

(d) corpuscular or particle radiation

SOLUTION:

Radiation that carries a mass

(e) x-rays

SOLUTION:

Radiation emitted during the atomic restructuring of its electrons

(f) gamma rays

SOLUTION:

Radiation emitted during nuclear restructuring of its nucleons

(g) teletherapy

SOLUTION:

Treatment where the radiation source is outside and away from the patient

(h) brachytherapy

SOLUTION:

Treatment where the radiation source is placed inside or near the area to be treated

(i) laser

SOLUTION:

Intense beam with wavelength in the light region

(j) ionization

SOLUTION:
The absorption of energy causing the ejection of electron from an atom

(k) excitation
SOLUTION:
The absorption of energy causing the restructuring of the electrons in an atom

(l) photon
SOLUTION:
A quanta or packet of energy

(m) quanta
SOLUTION:
A packet of energy

(n) scientific notation
SOLUTION:
Expression with a value between 1 and 10 times the exponent of 10

(o) De Broglie wave
SOLUTION:
The wave associated with matter

(p) relativistic mass
SOLUTION:
The mass of a particle at relatively fast speed

(q) neutrinos
SOLUTION:
A particle that has no charge and negligible mass

(r) mu mesons
SOLUTION:
A particle can have a -1 or $+1$ charge with a mass of 207 times the electron mass

(s) negatron
SOLUTION:
A particle that has the same mass and charge as an electron

(t) positron
SOLUTION:
A particle that has the same mass but opposite charge of an electron

(u) equivalent dose
SOLUTION:
The amount of biological destructiveness due to radiation

(v) absorbed dose
SOLUTION:
The amount of energy absorbed per unit mass in a medium from radiation

(w) radiation exposure

SOLUTION:
The amount of ionization produced by radiation in air

(x) radioactivity
SOLUTION:
The number of disintegrations per unit time

1.2 Identify four types of electromagnetic radiation used in medical imaging.
SOLUTION:
1) Radio–frequency or radiowaves – MRI,
2) X-rays – radiograph, radiology
3) Gamma rays – nuclear medicine and radiotherapy
4) Light (lasers) – ophthalmology optics
[Not imaging light – surgery]

1.3 Identify three types of benign disease treated with ionizing radiation.
SOLUTION:
(1) arterial-venous malformation
(2) acoustic neuroma
(3) heterotopic bone growth
(4) keloid

1.4 Identify two types of particulate radiation used in medicine.
SOLUTION:
1) electron, protons, and neutrons used in radiation treatment;
2) positron used in positron emission tomography (PET) imaging

1.5 List two properties that differentiate between particulate and electromagnetic radiation.
SOLUTION:
(1) mass

	E&M	Particulate
Mass	No mass	Has mass
Speed	Speed of light	Any speed (KE)
Charge	No charge	Has charge, no charge
Size	No Size	

2) speed:
Electromagnetic radiation travels at the speed of light while particulate velocity changes
3) penetration:
Deepest among all radiation for same energy
4) charge:
All EM radiation has no charge but some particulate radiation has charges and some do not have charges
5) size:

1.6 Classify the following types of radiation — alpha particle, beta particle, gamma ray, proton and neutron — as either ionizing or non-ionizing radiation and either directly or indirectly ionizing radiation.
SOLUTION:

(a) beta particle – directly ionizing
(b) gamma ray – indirectly ionizing
(c) neutron – indirectly ionizing

Radiation that has the ability to remove an electron from the atomic orbit is called ionizing radiation. Directly ionizing are charged particles while indirectly ionizing is non-charged particles. Indirectly ionizing radiation such as neutrons requires an intermediate interaction to cause ionization of atoms

1.7 Identify two types of non-ionizing radiation.
SOLUTION:
1) radiowaves
2) visible light

1.8 What is the difference between a 100 keV x-ray and a 100 keV gamma ray?
SOLUTION:
X-rays arises from extra-nuclear or atomic level activity while gamma rays from intra-nuclear activity.

1.9 Identify the difference between 6.4 MHz radiowaves and 6.4 MHz ultrasound waves.
SOLUTION:
Radiowaves – transverse waves, EM, does not require a medium
Ultrasound – longitudinal waves, mechanical waves, require a medium

1.10 Arrange in order the components of electromagnetic wave spectrum according to their approximate frequencies.
SOLUTION:
Radiowaves, infrared, visible light, x-rays, and gamma rays

1.11 What is an angstrom?
SOLUTION:
1 angstrom (Å) is equal to 1 x 10^{-10} meter

1.12 Compare the radiation properties with respect to mass, charge, and composition (protons, neutrons, electrons) of alpha particle, beta particle, gamma ray, proton, neutron, electron, and positron.
SOLUTION:

radiation	mass (a)	charge	composition
alpha	4	+2	2p, 2n
beta	0	–1	e
gamma	0	0	0
proton	1	+1	p
neutron	1	0	n
electron	0	–1	e
positron	0	+1	e

1.13 What is the difference between electron, negatron, positron, and beta particle?
SOLUTION:
All these particles have the same mass as electron. The source of electrons is from the atomic shell while negatron, positron, and beta particles are from

the nucleus. Except for the source electron and negatron are identical having same mass and unit negative charge. Beta particle is a generic name for either a negatron or positron. Positron has a unit positive charge.

1.14 What is the mass in kilograms of an electron and a proton?
SOLUTION:
electron mass 9.109 x 10^{-31} kg
proton mass 1.6726 x 10^{-27} kg

1.15 Explain how one would identify the types of radiation based on their charge and penetrability properties.
SOLUTION:
Radiation with opposite charges would curve in different direction in a magnetic field. Radiation with no charge would not be deflected in a magnetic field. Large particle like alpha particle has a short range compared to photon. Beta particle can be stopped in a piece of wood while photon would penetrate deep into tissue.

1.16 Identify the SI units of (a) exposure, (b) absorbed dose, (c) equivalent dose, and (d) radioactivity.
SOLUTION:
(a) exposure – C/kg
(b) absorbed dose – Gy
(c) equivalent dose – Sv
(d) radioactivity – Bq

1.17 Radiation exposure rate (R/s) is being replaced with air kerma rate, which is the absorbed dose in air (cGy/s). Which unit has a lower numerical value?
SOLUTION:
1 R/s = 0.876 cGy/s
Air kerma rate is lower by 14%.

1.18 List three effects of ionizing radiation.
SOLUTION:
Any three from below:
1) photographic effect,
2) luminescence effect,
3) ionizing effect,
4) thermoluminescence effect,
5) chemical effect, and
6) biological effect

1.19 List three methods of minimizing radiation exposure to a person in a radiation environment.
SOLUTION:
1. Decrease the time of exposure
2. Increase the distance from the radiation source
3. Add shielding between the source and you

1.20 Understand the historical development leading to their discoveries by Roentgen, Becquerel, and Madame Curie.
SOLUTION:
X-rays was discovered by Roentgen when he observed the luminescence of

barium platinocyanide screen across the room

Becquerel discovered radioactivity when he placed uranium ore on photographic plate.

Madam Curie isolated polonium.

1.21 Does bremsstrahlung radiation have a continuous or discrete energy spectrum?
SOLUTION:
Continuous energy spectrum.

*1.22 Explain how do you convert one roentgen into absorbed dose in tissue?
SOLUTION:
Use the rad/R conversion or f-factor.
1 R is about 0.95 cGy in tissue for most brachytherapy sources. The f-factor depends on the energy of the photon beam.

*1.23 Explain the circumstance under which absorbed dose is independent of the type of medium and dependent on the nature of the medium.
SOLUTION:
Absorbed dose refers to the amount of energy absorbed in any unit mass. However, the amount of energy absorbed is different in different type of mass. For example bone and tissue absorbed differently.

*1.24 Differentiate between radiation sources and radioactive sources.
SOLUTION:
Radiation sources include sources produced through atomic and nuclear interactions.

Problems

1.1 Compute the wavelength in Å of ultraviolet light whose frequency is 3×10^{16} Hz.
SOLUTION:

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^{8}\,\text{m/s}}{3 \times 10^{16}\,\text{s}^{-1}} = (1 \times 10^{-8}\,\text{m}) \times \frac{1\,\text{Å}}{1 \times 10^{-10}\,\text{m}} = 100\,\text{Å}$$

1.2 What is the frequency of radiowaves if the wavelength is 3×10^{3} m?
SOLUTION:

$$\nu = \frac{c}{\lambda} = \frac{3 \times 10^{8}\,\text{m/s}}{3 \times 10^{3}\,\text{m}} = 1 \times 10^{5}\ \text{Hz}$$

1.3 The wavelength range of visible light is from 4000 Å – 7000 Å. What is the energy in eV of green light whose wavelength is 5000 Å?
SOLUTION:

$$E = \frac{hc}{\lambda} = \frac{(6.626 \times 10^{-34}\ J \cdot s)(3.0 \times 10^{8} m/s)}{5.000 \times 10^{-7} m}$$

$$= 3.9756 \times 10^{-19} J \times \frac{1 eV}{1.6021 \times 10^{-19} J} = 2.48\ eV$$

or

$$E\ (keV) = \frac{12.4}{\lambda\ (\text{Å})} = \frac{12.4}{5000} = 0.00248\ keV = 2.48\ eV$$

1.4 Write the measured values of 3.1×10^{6} Hz and 5.0×10^{-6} m using prefixes.

SOLUTION:

3.1×10^{6} Hz = 3.1 MHz
5.0×10^{-6} m = 5.0 μm

1.5 Compute the speed and mass of a 100 keV photon.

SOLUTION:

Travel at the speed of light and has no mass

1.6 Calculate the wavelength in Å of photons whose energies are (a) 1 eV, (b) 1 keV, and (c) 1 MeV.

SOLUTION:

(a) $$\lambda\ (\text{Å}) = \frac{12.4}{E\ (keV)} = \frac{12.4}{1 \times 10^{-3} keV} = 1.24 \times 10^{4}\ \text{Å}$$

(b) $$\lambda\ (\text{Å}) = \frac{12.4}{E\ (keV)} = \frac{12.4}{1 keV} = 1.24 \times 10^{1}\ \text{Å}$$

(c) $$\lambda\ (\text{Å}) = \frac{12.4}{E\ (keV)} = \frac{12.4}{1 \times 10^{3} keV} = 1.24 \times 10^{-2}\ \text{Å}$$

1.7 Calculate the frequency in Hz of photons whose energies are (a) 1 eV, (b) 1 keV, and (c) 1 MeV.

SOLUTION:

You can also use previous problem values to compute the frequency and $c = \lambda\nu$

(a)

$$\nu = \frac{E}{h} = \frac{1\ eV}{6.626 \times 10^{-34} J \cdot s} \times \frac{1.6021 \times 10^{-19} J}{1\ eV} = 2.418 \times 10^{14} Hz$$

or

$$\nu = \frac{c}{\lambda} = (1 \times 10^{10}) \frac{c\ E\ (keV)}{12.4}$$

$$= (1 \times 10^{10}) \frac{(2.998 \times 10^{8}\ m/s) \times (1 \times 10^{-3}\ keV)}{12.4}$$

$$= 2.418 \times 10^{14}\ Hz$$

(b)

$$\nu = \frac{E}{h} = \frac{1 \times 10^{3}\ \text{eV}}{6.626 \times 10^{-34}\ \text{J}\cdot\text{s}} \times \frac{1.6021 \times 10^{-19}\ \text{J}}{1\ \text{eV}} = 2.418 \times 10^{17}\ \text{Hz}$$

(c)

$$\nu = \frac{E}{h} = \frac{1 \times 10^{6}\ \text{eV}}{6.626 \times 10^{-34}\ \text{J}\cdot\text{s}} \times \frac{1.6021 \times 10^{-19}\ \text{J}}{1\ \text{eV}} = 2.418 \times 10^{20}\ \text{Hz}$$

1.8 Calculate the momentum of a particle whose wavelength is 1 angstrom.

SOLUTION:

$$p = \frac{h}{\lambda} = \frac{6.626 \times 10^{-34}\ \text{J}\cdot\text{s}}{1 \times 10^{-10}\ \text{m}} = 6.626 \times 10^{-24}\ \text{kg}\cdot\text{m/s}$$

1.9 Express the dose of 0.05 Gy in rads

SOLUTION:

$$0.05\ \text{Gy} = 0.05\ \text{Gy} \times \frac{100\ \text{rad}}{1\ \text{Gy}} = 5\ \text{rad}$$

1.10 Express 550 rads in terms of Gy.

SOLUTION:

$$550\ \text{rad} = 550\ \text{rad} \times \frac{1\ \text{Gy}}{100\ \text{rad}} = 5.5\ \text{Gy}$$

1.11 During a radiation treatment 200 rad was delivered to 100 gm of tissue. What dose would 1 gm of tissue have received?

SOLUTION:

Since 200 rad means 200 ergs of energy is delivered to 1 gm of tissue, the dose would be 200 rad.

1.12 During a calorimetric investigation, 10 joules of energy were imparted onto a kilogram of water. Compute the radiation dose in cGy.

SOLUTION:

$$\frac{10\ \text{J}}{1\ \text{kg}} = 10\ \text{J/kg} \times \frac{\text{Gy}}{\text{J/kg}} = 10\ \text{Gy} \times \frac{100\ \text{cGy}}{\text{Gy}} = 1000\ \text{cGy}$$

1.13 Express the radiation exposure of 2 R/min in SI unit (C/kg·min).

SOLUTION:

$$2\ \text{R/min} = 2\ \text{R/min} \times \frac{2.58 \times 10^{-4}\ \text{C/kg}}{1\ \text{R}} = 5.16 \times 10^{-4}\ \text{C/kg - min}$$

1.14 Express the radioactivity of 15 mCi in SI unit (Bq).

SOLUTION:

$$15\ \text{mCi} = 15\ \text{mCi} \times \frac{3.70 \times 10^{7}\ \text{Bq}}{1\ \text{mCi}} = 5.55 \times 10^{8}\ \text{Bq}$$

1.15 A radioactive sample has a disintegration rate of 8.3×10^6 Bq. Express this activity in microCuries (μCi).

SOLUTION:

$$8.3 \times 10^6 \text{ Bq} = 8.3 \times 10^6 \text{ Bq} \times \frac{1\ \mu\text{Ci}}{3.7 \times 10^4 \text{ Bq}} = 224.3\ \mu\text{Ci}$$

*1.16 Compute the wavelength of a 100 keV electron (electron mass $= 9.10908 \times 10^{-31}$ kg).

SOLUTION:

Solve for velocity v:

$$E = \frac{1}{2} mv^2$$

or

$$v = \sqrt{\frac{2E}{m}} = \sqrt{\frac{2(100 \text{x} 10^3 \text{ ev})}{9.10908 \text{x} 10^{-31} \text{kg}} \text{x} \frac{1.6021 \text{x} 10^{-19} \text{ J}}{1 \text{ev}}}$$

$$= \sqrt{3.5176 \text{x} 10^{16}} \text{ m/s}$$

$$= 1.875 \text{x} 10^8 \text{ m/s}$$

Substitute velocity into equation:

$$\lambda = \frac{h}{mv} = \frac{6.626 \times 10^{-34} \text{ J} \cdot \text{s}}{(9.10908 \times 10^{-31} \text{ kg})(1.875 \times 10^8 \text{ m/s})}$$

$$= 3.878 \times 10^{-12} \text{ m}$$

*1.17 Show that the phase velocity which is the product of wavelength and frequency of a particle is given as $\lambda\nu = c^2/v$, where v is the velocity of a particle. Also show that in the non-relativistic region where the rest mass is neglected and the total energy is the kinetic energy, the phase velocity is equal to v/2.

SOLUTION:

The phase velocity is the speed of a wave with frequency ν and $\lambda = h/p$

$$\lambda\nu = \left(\frac{h}{p}\right)\left(\frac{E}{h}\right) = \frac{E}{p} = \frac{mc^2}{mv} = \frac{c^2}{v}$$

for $v << c$, neglect rest mass, E becomes kinetic energy $E = p^2/2m$

$$\lambda\nu = (h/p)(E/h) = E/p = p/2m = v/2$$

The group velocity is the speed of a strong constructive interference region consisting of packet of waves with differing frequencies and in phase speed. Group velocity has the same velocity as the velocity of the particle

$v = dE/dp = d(E_0 + (pc)^2)^{1/2} /dp = pc^2/E = mvc^2/mc^2 = v$

Group velocity of photon is $v = dE/dp = d(E_0 + (pc)^2)^{1/2} /dp = pc^2/E = Ec/E = c$ since $E = pc$ with rest mass $= 0$.

*1.18 Show that the average energy needed to produce an ion pair in air is 33.97 eV.

SOLUTION:

$$\frac{W}{e} = 33.97\frac{J}{C}$$

$$W = 33.97\frac{J}{C}\ x\ e = 33.97\frac{J}{C}\ x\ \left(1.6021\ x\ 10^{-19}\ C\right) x \left(\frac{1\ eV}{1.6021 x 10^{-19}\ J}\right)$$

$$= 33.97\ eV$$

*1.19 Calculate the number of photons having 1 MeV needed to produce 1 rad. Assume that the energy absorption efficiency (energy absorption coefficient) is 0.03.
SOLUTION:

$$1\,rad = \frac{100\ erg}{gm} = \frac{100\ erg}{gm}\ x\ \frac{1\ J}{10^7\ erg}\ x\ \frac{1\ eV}{1.602\ x\ 10^{-19}\ J}\ x\ \frac{10^{-6}\ MeV}{1\ eV}$$

$$= \frac{10^{-4}\,MeV}{1.6021\ x\ 10^{-12}\,gm} = 6.24\ x\ 10^7\,MeV$$

Since the energy deposition is highly inefficient (only 3%), more photons are needed to deposit 1 rad
Then the number of photon needed would be

$$No. = \frac{6.24\ x\ 10^7}{0.03} photons = 2.0\ x\ 10^9\ photons$$

Multiple Choice Questions

Choose one correct answer.

1.1. Which modality does NOT utilize electromagnetic radiation in the formation of images?
a) radiography
b) ultrasound imaging
c) magnetic resonance imaging
d) positron emission tomography
e) None of the above

SOLUTION: b

1.2 Which statement is NOT true of photons?
a) Photons have no charge.
b) Photons have no mass.
c) Photon energy is given as $E = h\nu$ where ν is the frequency.
d) Photons travel at the speed of light.
e) none of the above.

SOLUTION: e

1.3 A **fermi** (1.0×10^{-15} m) is a unit commonly used in nuclear physics to express the size of the mass. The SI unit prefix is
a) kilometer.
b) millimeter.

c) micrometer.
d) nanometer.
e) femtometer.

SOLUTION: e

1.4 Express 161.5 cm in scientific notation
a) 16.15 x 10^1 cm
b) 1.615 x 10^2 cm
c) 16.15 x 10^3 m
d) 1.615 x 10^4 m
e) 0.1615 x 10^5 m

SOLUTION: b

1.5 Which of the following is NOT a particulate radiation?
a) proton
b) neutron
c) β particle
d) α particle
e) none of the above

SOLUTION: e

1.6 Which of the following statements is NOT true about corpuscular radiation?
a) Corpuscular radiation is particle radiation.
b) Neutron is an example of non-charged particle radiation.
c) Charged particles are alpha particles, beta particles, and protons.
d) Charged particles can cause ionization and excitation of target atoms.
e) none of the above.

SOLUTION: e

1.7 What is the speed of a photon whose wavelength is 4×10^{-8} m compared to the speed of light, c?
a) speed is less than c
b) speed is equal to c
c) speed is more than c
d) speed is c/λ
e) none of the above

SOLUTION: b

1.8 All these particles have the same mass except the
a) positron.
b) negatron.
c) electron.
d) neutron.
e) beta particle.

SOLUTION: d

1.9 Which of the following is NOT true of β particles?

a) Negatron and positron are alike except for the charge.
b) The charge of a negatron is $+1.60 \times 10^{-19}$ C.
c) Except for their origins, negatron and electron are identical.
d) Positron is unstable or short lived.
e) none of the above.

SOLUTION: b

1.10 Which of the following radiation has the shortest range in tissue?
a) alpha
b) beta
c) positron
d) neutrino
e) gamma

SOLUTION: a

1.11 Which of the following is INCORRECT about Roentgen?
a) It is a unit of exposure and not a unit of absorbed dose.
b) It is applicable to both particulate and electromagnetic radiation.
c) It is applicable to photons with energies less than 3 MeV.
d) It is applicable only in air.
e) none of the above.

SOLUTION: b

1.12 Spontaneous activity was discovered by
a) W.C. Roentgen.
b) H.A. Becquerel.
c) Marie Curie.
d) E. Rutherford.
e) none of the above.

SOLUTION: b