Name_______________________________________

Physics 111 Quiz #7, November 10, 2017

Please show all work, thoughts and/or reasoning in order to receive partial credit. The quiz is worth 10 points total.

I affirm that I have carried out my academic endeavors with full academic honesty.

____

Radon gas is a naturally occurring byproduct of the radioactive decay of uranium in the soil and when inhaled, the radioactive radon gas atoms become imbedded in the lining of the lung where they decay and the decay products of radon are one factor that leads to the development of lung cancer in humans. Radon gas is a carcinogen and it is the 2nd leading cause of lung cancers in the US. According to the US department of environmental protection (EPA), "Any radon exposure has some risk of causing lung cancer. The lower the radon level in your home, the lower your family's risk of lung cancer." The average person exposure to radon gas comes from their homes and the average person receives a higher dose of radiation from the radon levels in their home than from their combined exposure to all other radiation sources, natural or man-made.

1. Suppose that radon decays to an isotope of polonium according the decay scheme ${}^{220}_{86}Rn \longrightarrow {}^{216}_{84}Po + {}^{A}_{Z}X$. In the radioactive decay of radon, which of the follwing particles was emitted?
   a. ${}^{A}_{Z}X = {}^{1}_{1}p$
   b. ${}^{A}_{Z}X = {}^{0}_{+1}e$
   c. ${}^{A}_{Z}X = {}^{0}_{-1}e$
   d. ${}^{A}_{Z}X = {}^{1}_{0}n$
   e. ${}^{A}_{Z}X = {}^{4}_{2}He$

Particle	Mass (u)
${}^{1}_{0}n$	1.008665
${}^{1}_{1}p$	1.007825
${}^{0}_{\pm1}e$	0.000549
${}^{4}_{2}He$	4.00260
${}^{220}_{86}Rn$	220.011394
${}^{216}_{84}Po$	216.001915

2. For the above decay of radon into polonium, assuming that radon is at rest when the decay takes place and taking into account the recoil of the polonium nucleus, what is the maximum kinetic energy of the emitted particle? Use the table of masses to answer this question.

   Using conservation of energy we have:

$$Q = \left(m_{Rn} - m_{\alpha} - m_{Po}\right)c^2 = K_{\alpha} + K_{Po} = K_{\alpha}\left(1 + \frac{m_{\alpha}}{m_{Po}}\right)$$

$$\therefore K_{\alpha} = \frac{Q}{\left(1 + \frac{m_{\alpha}}{m_{Po}}\right)} = \frac{\left(220.0011394u - 4.0026u - 216.001915u\right)\times\left(\frac{931.5\ {}^{MeV}\!/_{c^2}}{1u}\right)c^2}{\left(1 + \frac{4.0026u}{216.001915u}\right)}$$

$$K_{\alpha} = 6.2912\,MeV$$

   Where the speed of the speed of the recoiling polonium nucleus is determined from conservation of momentum. Thus we have:

$$p_i = p_f \rightarrow 0 = -p_{\alpha} + p_{Po} \rightarrow p_{\alpha} = p_{Po} \rightarrow m_{\alpha}v_{\alpha} = m_{Po}v_{Po} \rightarrow v_{Po} = \frac{m_{\alpha}}{m_{Po}}v_{\alpha}$$

$$\therefore K_{Po} = \tfrac{1}{2}m_{Po}v_{Po}^2 = \tfrac{1}{2}m_{Po}\left(\frac{m_{\alpha}}{m_{Po}}v_{\alpha}\right)^2 = \tfrac{1}{2}m_{\alpha}v_{\alpha}^2\left(\frac{m_{\alpha}}{m_{Po}}\right) = \left(\frac{m_{\alpha}}{m_{Po}}\right)K_{\alpha}$$

3. What is the speed of the emitted particle expresssed as a fraction of the speed of light?

$$K_\alpha = \tfrac{1}{2} m_\alpha v_\alpha^2 \rightarrow v_\alpha = \sqrt{\frac{2K_\alpha}{m_\alpha}} = \sqrt{\frac{2 \times 6.2912 MeV}{4.00260u \times \left(\frac{931.5 \, {}^{MeV}\!/\!_{c^2}}{1u} \right)}} = 0.0581c$$

4. The Indoor Radon Abatement Act passed by Congress in 1988 set the natural outdoor level of radon gas at four picocuries (pCi) per liter of air ($4 \frac{pCi}{L}$) as the target radon level for indoor radon levels. Most homes in the US are at or above this level and at or above this level of radon, the EPA recommends you take corrective measures to reduce your exposure to radon gas. It is estimated that a reduction of radon levels to below $2 \frac{pCi}{L}$ nationwide would likely reduce the yearly lung cancer deaths attributed to radon by 50%. However, even at the $2 \frac{pCi}{L}$ level, the cancer risk presented by radon gas is still hundreds of times greater than the risks allowed for carcinogens in our food and water. Assuming that when a person is resting, the volume of air that enters the lungs every breath is $0.5L$. If this were the only exposure to radon and if all of the radon gas in the breath of air stays trapped in your lungs, after 30 days, what would be the activity (in $\frac{pCi}{L}$)? Assume that the air that you are breathing has a uniform radon content at the threshold level of $4 \frac{pCi}{L}$? Hints: The half-life of radon is 3.8 days and the following information may be useful in answering the question. $1pCi = 1 \times 10^{-12} Ci$ and $1Ci = 3.7 \times 10^{10} \frac{decays}{s}$.

$$A = A_0 e^{-\lambda t} = 4 \tfrac{pCi}{L} e^{-\left(\frac{0.693}{3.8d}\right)30d} = 0.017 \tfrac{pCi}{L}$$

This of course assumes that you only take one breath. If you continually breathe you keep the radon level approximately constant in your lungs and this in turn provides a continuous supply of alpha particles to damage your lungs. Also, I left the “activity” in $\frac{pCi}{L}$ to make the calculation easier. You could actually convert this to an activity by converting the pCi to decays per second and then multiplying by the volume intake of the lung. Then you’d have to convert this answer back to $\frac{pCi}{L}$. You will get the same answer either way.

Physics 111 Equation Sheet

Electric Forces, Fields and Potentials

$$\vec{F} = k\frac{Q_1Q_2}{r^2}\hat{r}$$
$$\vec{E} = \frac{\vec{F}}{q}$$
$$\vec{E}_Q = k\frac{Q}{r^2}\hat{r}$$
$$PE = k\frac{Q_1Q_2}{r}$$
$$V(r) = k\frac{Q}{r}$$
$$E_x = -\frac{\Delta V}{\Delta x}$$
$$W = -q\Delta V_{f,i}$$

Magnetic Forces and Fields

$$F = qvB\sin\theta$$
$$F = IlB\sin\theta$$
$$I = nAv_dq$$
$$\tau = NIAB\sin\theta = \mu B\sin\theta$$
$$PE = -\mu B\cos\theta$$
$$B = \frac{\mu_0 I}{2\pi r}$$
$$\varepsilon_{induced} = -N\frac{\Delta\phi_B}{\Delta t} = -N\frac{\Delta(BA\cos\theta)}{\Delta t}$$

Constants

$g = 9.8\,\frac{m}{s^2}$

$1e = 1.6\times10^{-19}C$

$k = \frac{1}{4\pi\varepsilon_o} = 9\times10^9\,\frac{C^2}{Nm^2}$

$\varepsilon_o = 8.85\times10^{-12}\,\frac{Nm^2}{C^2}$

$1eV = 1.6\times10^{-19}J$

$\mu_o = 4\pi\times10^{-7}\,\frac{Tm}{A}$

$c = 3\times10^8\,\frac{m}{s}$

$h = 6.63\times10^{-34}Js$

$m_e = 9.11\times10^{-31}kg = \frac{0.511MeV}{c^2}$

$m_p = 1.67\times10^{-27}kg = \frac{937.1MeV}{c^2}$

$m_n = 1.69\times10^{-27}kg = \frac{948.3MeV}{c^2}$

$1amu = 1.66\times10^{-27}kg = \frac{931.5MeV}{c^2}$

$N_A = 6.02\times10^{23}$

$Ax^2 + Bx + C = 0 \rightarrow x = \frac{-B\pm\sqrt{B^2-4AC}}{2A}$

Electric Circuits

$$I = \frac{\Delta Q}{\Delta t} = nAv_dq$$
$$V = IR = I\left(\frac{\rho L}{A}\right)$$
$$R_{series} = \sum_{i=1}^{N} R_i$$
$$\frac{1}{R_{parallel}} = \sum_{i=1}^{N}\frac{1}{R_i}$$
$$P = IV = I^2R = \frac{V^2}{R}$$
$$Q = CV = \left(\frac{\kappa\varepsilon_0 A}{d}\right)V = (\kappa C_0)V$$
$$PE = \tfrac{1}{2}QV = \tfrac{1}{2}CV^2 = \frac{Q^2}{2C}$$
$$Q_{\text{charge}}(t) = Q_{\max}\left(1-e^{-\frac{t}{RC}}\right)$$
$$Q_{\text{discharge}}(t) = Q_{\max}e^{-\frac{t}{RC}}$$
$$C_{parallel} = \sum_{i=1}^{N} C_i$$
$$\frac{1}{C_{series}} = \sum_{i=1}^{N}\frac{1}{C_i}$$

Light as a Particle & Relativity

$$E = hf = \frac{hc}{\lambda} = pc$$
$$K_{\max} = hf - \varphi = eV_{stop}$$
$$\Delta\lambda = \frac{h}{m_ec}(1-\cos\varphi)$$
$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$
$$p = \gamma mv$$
$$E_{total} = K + E_{rest} = \gamma mc^2$$
$$E_{total}^2 = p^2c^2 + m^2c^4$$
$$E_{rest} = mc^2$$
$$K = (\gamma-1)mc^2$$

Geometry

$Circles:\quad C = 2\pi r = \pi D \qquad A = \pi r^2$

$Triangles:\quad A = \tfrac{1}{2}bh$

$Spheres:\quad A = 4\pi r^2 \qquad V = \tfrac{4}{3}\pi r^3$

Light as a Wave

$$c = f\lambda = \frac{1}{\sqrt{\varepsilon_o\mu_o}}$$
$$S(t) = \frac{energy}{time\times area} = \frac{Power}{area} = c\varepsilon_oE^2(t) = c\frac{B^2(t)}{\mu_0}$$
$$I = S_{avg} = \tfrac{1}{2}c\varepsilon_oE_{\max}^2 = c\frac{B_{\max}^2}{2\mu_0}$$
$$P = \begin{cases} S/c \\ 2S/c \end{cases} = \frac{Force}{Area}$$
$$S = S_o\cos^2\theta$$
$$v = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{c}{n}$$
$$\theta_{inc} = \theta_{refl}$$
$$n_1\sin\theta_1 = n_2\sin\theta_2$$
$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$
$$M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$$
$$M_{total} = \prod_{i=1}^{N} M_i$$
$$S_{out} = S_{in}e^{-\sum_i \mu_i x_i}$$
$$HU = \frac{\mu_{material}-\mu_{water}}{\mu_{water}-\mu_{air}}$$

Nuclear Physics

$$E_{binding} = (Zm_p + Nm_n - m_{rest})c^2$$
$$\frac{\Delta N}{\Delta t} = -\lambda N_o \rightarrow N(t) = N_oe^{-\lambda t}$$
$$A(t) = A_oe^{-\lambda t}$$
$$m(t) = m_oe^{-\lambda t}$$
$$t_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$$

Misc. Physics 110 Formulae

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t} = \frac{\Delta(m\vec{v})}{\Delta t} = m\vec{a}$$
$$\vec{F} = -k\vec{y}$$
$$\vec{F}_C = m\frac{v^2}{R}\hat{r}$$
$$W = \Delta KE = \tfrac{1}{2}m\left(v_f^2 - v_i^2\right) = -\Delta PE$$
$$PE_{gravity} = mgy$$
$$PE_{spring} = \tfrac{1}{2}ky^2$$
$$|\vec{A}| = \sqrt{A_x^2 + A_y^2}$$
$$\phi = \tan^{-1}\left(\frac{A_y}{A_x}\right)$$
$$\vec{v}_f = \vec{v}_i + \vec{a}t$$
$$v_f^2 = v_i^2 + 2a\Delta x$$
$$\vec{x}_f = \vec{x}_i + \vec{v}_it + \tfrac{1}{2}\vec{a}t^2$$