

## CHAPTER 11 SOLUTIONS

11-1 Identify elements

Given:  ${}_{18}\text{X}$  and  ${}_{7}\text{X}$

Solution:

a. From atomic numbers inside front cover of book

${}_{18}\text{X}$  ---> Argon

b. From atomic numbers inside front cover of book

${}_{7}\text{X}$  ---> Nitrogen

11-2 Identify elements

Given:  ${}_{4}\text{X}$  and  ${}_{92}\text{X}$

Solution:

a. From atomic numbers inside front cover of book

${}_{4}\text{X}$  ---> Beryllium

b. From atomic numbers inside front cover of book

${}_{92}\text{X}$  ---> Uranium

11-3 What particles are emitted in  ${}^{14}\text{C}$  decay?

Given: Carbon-14 decay to Nitrogen-14

Beta particle is emitted because Z increases by 1 and A remains the same.

11-4 What particles are emitted in  ${}^{32}\text{P}$  decay?

Given: Phosphorous-32 decays to Sulfur-32

Solution:

Beta particle is emitted because Z increases by 1 and A remains the same.

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11-5 What particles are emitted in decay chain?

Given: Radium-226 decay to lead-214

Solution:

Alpha particle in each case because Z decreases by 2 and A decreases by 4.

11-6 What particles emitted in decay chain?

Given: Lead-214 decay to Lead-206

Solution:

- a.  ${}_{82}^{214}\text{Pb} \rightarrow {}_{83}^{214}\text{Bi}$                       Beta particle
- b.  ${}_{83}^{214}\text{Bi} \rightarrow {}_{84}^{214}\text{Po}$                       Beta particle
- c.  ${}_{84}^{214}\text{Po} \rightarrow {}_{82}^{210}\text{Pb}$                       Alpha particle
- d.  ${}_{82}^{210}\text{Pb} \rightarrow {}_{83}^{210}\text{Bi}$                       Beta particle
- e.  ${}_{83}^{210}\text{Bi} \rightarrow {}_{84}^{210}\text{Po}$                       Beta particle
- f.  ${}_{84}^{210}\text{Po} \rightarrow {}_{82}^{206}\text{Pb}$                       Alpha particle

11-7 What particles are emitted in  ${}^{238}\text{U}$  decay chain?

Given: Uranium-238 decays to Uranium-234

Solution:

- a.  ${}_{92}^{238}\text{U} \rightarrow {}_{90}^{234}\text{Th}$                       Alpha particle
- b.  ${}_{90}^{234}\text{Th} \rightarrow {}_{91}^{234}\text{Pa}$                       Beta Particle
- c.  ${}_{91}^{234}\text{Pa} \rightarrow {}_{92}^{234}\text{U}$                       Beta Particle

11-8 Show annihilation yields 1.02 MeV

Given: Positron and electron annihilation

Solution:

a. From text discussion in section 11-1 find

Energy equivalent of 1 u = 931.634 MeV

Electron has mass of 0.0005486 u

Positron has mass = electron

b. Assuming annihilation converts all mass to energy

Total mass = 0.0005486 u + 0.0005486 u = 0.001097 u

Energy = (931.634 MeV/u)(0.001097 u) = 1.022 or 1.02 MeV

11-9 Holding time for  $^{32}\text{P}$

Given: 0.5  $\mu\text{Ci/L}$  of  $^{32}\text{P}$  is to be discharged

Solution:

a. Allowable discharge of  $^{32}\text{P}$  =  $9 \times 10^{-5}$   $\mu\text{Ci/mL}$  from Table 11-2

b. Convert original concentration to same units

$$0.5 \mu\text{Ci/L} = 0.5 \times 10^{-3} \mu\text{Ci/mL}$$

c. Calculate decay constant

From Table 11-1,  $T_{1/2} = 14.3$  d

$$\text{Decay Constant} = \frac{0.693}{T_{1/2}} = \frac{0.693}{14.3 \text{ days}} = 0.0485 / \text{day}$$

d. Using log form of Eqn. 11-6

$$\ln\left(\frac{9 \times 10^{-5}}{0.5 \times 10^{-3}}\right) = -0.0485(t)$$

$$t = \frac{-1.715}{-0.0485} = 35.35 \text{ or } 36 \text{ days}$$

#### 11-10 Time to reach tolerance level

Given: Contamination of laboratory with  $^{45}\text{Ca}$  at ten times the tolerance level.

Solution:

a. Calculate decay constant

From Table 11-1,  $T_{1/2} = 165 \text{ d}$

$$\text{Decay Constant} = \frac{0.693}{T_{1/2}} = \frac{0.693}{165 \text{ days}} = 0.0042 / \text{day}$$

b. Calculate time using log form of Eqn. 11-6

$$\ln\left(\frac{1}{10}\right) = -0.0042(t)$$

$$t = \frac{-2.3025}{-0.0042} = 548.23 \text{ or } 549 \text{ days}$$

#### 11-11 Time to reach allowable discharge activity for $^{131}\text{I}$

Given:  $100 \mu\text{Ci/L}$  of  $^{131}\text{I}$

Solution:

a. allowable discharge activity from table 11-2 is  $1 \times 10^{-5} \mu\text{Ci/mL}$

For I the allowable discharge activity is then  $1 \times 10^{-5} \mu\text{Ci/L}$

b. Calculate decay constant

From table 11-1,  $T_{1/2} = 8.06 \text{ d}$

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$$\text{Decay Constant} = \frac{0.693}{T_{1/2}} = \frac{0.693}{8.06 \text{ days}} = 0.086 / \text{day}$$

c. Calculate time using log form of eqn 11-6

$$\ln\left(\frac{1 \times 10^{-5}}{100}\right) = -0.086(t)$$

$$t = \frac{-16.118}{-0.086} = 187.42 \text{ or } 188 \text{ days}$$

### 11-12 Radium content in 2010

Given 20.0 mg of  $\text{RaCl}_2$  prepared in 1911

Solution:

a. Calculate fraction of  $\text{RaCl}_2$  that is radium

Gram molecular weight of Ra: 226

GMW of 2 Cl:  $2(35.45) = 70.90$

GMW of  $\text{RaCl}_2$ :  $226 + 70.90 = 296.90$

$$\text{Mass of Ra} = \frac{226}{296.90}(20 \text{ mg}) = 15.22 \text{ mg}$$

b. Calculate decay constant

From table 11-1  $T_{1/2} = 1622 \text{ yr}$

$$\text{Decay Constant} = \frac{0.693}{1622} = 4.27 \times 10^{-4} \text{ 1/yr}$$

c. Calculate number of years

$$2010 - 1911 = 99 \text{ yr}$$

d. calculate mg of Ra remaining using eqn 11-6

$$N = (15.22\text{mg})e^{-4.27 \times 10^{-4}(99)} = 14.59\text{mg}$$

11-13 Mass of 50  $\mu\text{Ci}$  of  $^{131}\text{I}$ 

Given: 50  $\mu\text{Ci}$  of  $^{131}\text{I}$ , pure sample

Solution:

a. Compute decay constant in seconds

From Table 11-1,  $T_{1/2} = 8.06 \text{ d}$

$$\text{Decay constant} = \frac{0.693}{8.06\text{d}(86400\text{s/d})} = 9.95 \times 10^{-7} / \text{s}$$

b. Compute specific activity using Eqn. 11-9 (NOTE: dps/g = disintegrations per second per gram)

$$S = \frac{9.95 \times 10^{-7} (6.028 \times 10^{23})}{131} = 4.57 \times 10^{15} \text{ dps/g}$$

c. Compute dps for 50  $\mu\text{Ci}$

$$(50 \times 10^{-6} \text{ Ci})(3.7 \times 10^{10} \text{ dps/Ci}) = 1.85 \times 10^6 \text{ dps}$$

d. Compute mass of  $^{131}\text{I}$

$$\text{Mass} = \frac{1.85 \times 10^6 \text{ dps}}{4.57 \times 10^{15} \text{ dps/g}} = 4.04 \times 10^{-10} \text{ g}$$

11-14 Volume of  $^4\text{He}$  produced from decay

Given: Decay of  $^{210}\text{Po}$  to  $^{206}\text{Pb}$  for one year,  $^{210}\text{Po}$  half life of 138.4 d, 50 Ci of  $^{210}\text{Po}$  initially, gas at STP

Solution:

a. Compute decay constant in seconds

$$T_{1/2} = 138.4 \text{ d}$$

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$$\text{Decay constant} = \frac{0.693}{138.4\text{d}(86,400\text{s/d})} = 5.795 \times 10^{-8} / \text{s}$$

b. Assuming each disintegration yields an alpha particle, calculate the number of disintegrations that occur by integrating Eqn.11-6 from  $t = 0$  to  $t = 365$  days (31,536,000 s)

$$\text{Total No. of Disintegration (TND)} = \int_{0\text{days}}^{365\text{days}} N_0 e^{-\lambda t}$$

$$\text{TND} = N_0 \left[ \left( \frac{e^{-\lambda t}}{\lambda} \right)_{t=0} - \left( \frac{e^{-\lambda t}}{\lambda} \right)_{t=365} \right]$$

$$\text{TND} = N_0 \left[ \left( \frac{e^{-5.79 \times 10^{-8}(0)}}{5.79 \times 10^{-8}} \right) - \left( \frac{e^{-5.79 \times 10^{-8}(3.1536 \times 10^7)}}{5.79 \times 10^{-8}} \right) \right]$$

$$\text{TND} = N_0 [1.726 \times 10^7 - 2.776 \times 10^6] = N_0 [1.448 \times 10^7]$$

$$\text{TND} = (50 \text{ Ci})(3.7 \times 10^{10} \text{ dps/Ci})(1.448 \times 10^7 \text{ s})$$

$$\text{TND} = 2.6789 \times 10^{19} \text{ disintegrations (atoms)}$$

c. Calculate moles of Helium

$$\frac{2.6789 \times 10^{19} \text{ atoms}}{6.0248 \times 10^{23} \text{ atoms/mole}} = 4.45 \times 10^{-5} \text{ mole}$$

d. Calculate volume of gas (NOTE: 1 mole = 22.414 L @ STP)

$$(4.446 \times 10^{-5} \text{ mole})(22,414 \text{ mL/mole}) = 0.997 \text{ mL}$$

### 11-15 Growth curve of $^{222}\text{Rn}$

Given: Initial conditions = pure  $^{226}\text{Ra}$ , no  $^{222}\text{Rn}$  present

Solution:

a. Calculate decay constants

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For Radium, from Table 11-1,  $T_{1/2} = 1,622 \text{ y}$

$$\text{Decay constant} = \frac{0.693}{1,622\text{y}(365\text{d}/\text{y})} = 1.171 \times 10^{-6} / \text{d}$$

For Radon, from Table 11-1,  $T_{1/2} = 3.825 \text{ d}$

$$\text{Decay constant} = \frac{0.693}{3.852\text{d}} = 0.181 / \text{d}$$

b. Solving Eqn. 11-16 for  $N_2/N_1$

$$\frac{N_2}{N_1} = \frac{\lambda_1}{\lambda_2 - \lambda_1} \left[ e^{-\lambda_1 t} - e^{-\lambda_2 t} \right]$$

$$\frac{N_2}{N_1} = \frac{1.171 \times 10^{-6}}{0.181 - 1.171 \times 10^{-6}} \left[ e^{-1.171 \times 10^{-6} t} - e^{-0.181 t} \right]$$

Time [day]	$N_2/N_1$
1	1.07063E-06
2	1.96385E-06
4	3.33076E-06
8	4.94438E-06
16	6.10483E-06
32	6.44101E-06
64	6.46032E-06
1,000	6.4533E-06
10,000	6.38568E-06
100,000	5.74717E-06

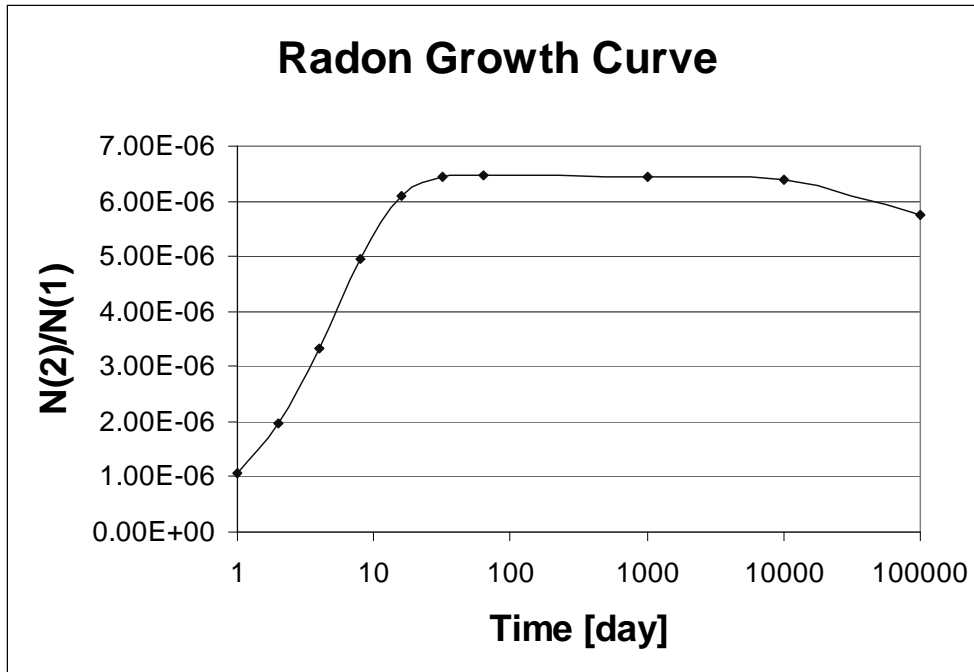


Figure S-11-15: Radon growth curve

## 11-16 X-ray intensity 2 m from source

Given: X-ray unit operated at 70 kVp and 5 mA produces intensity of D R/min at 1.0 m from source

Solution:

Apply Eqn. 11-22

$$\frac{I_1}{I_2} = \frac{(R_2)^2}{(R_1)^2}$$

$$\frac{D}{I_2} = \frac{(2.0)^2}{(1.0)^2}$$

$$I_2 = \frac{1.0}{4.0} D$$

## 11-17 X-ray intensity at 2.0 with increased current

Given: Problem 11-16, current is increased to 15 mA

Solution:

a. Radiated power is directly proportional to current so

$$\text{Current increase} = 15\text{mA}/5\text{mA} = 3$$

b. New intensity

$$I_2 = \frac{3}{4} D$$

## 11-18 Thickness of lead

Given:  $^{60}\text{Co}$  source, transmission reduction of 99.6 % required using lead shield

Solution:

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- a. Compute transmission allowed

$$1.000 - 0.996 = 0.004$$

- b. From Figure 11-6 using  $^{60}\text{Co}$  line

$$\text{Lead thickness required} = 6 \text{ cm}$$

(Allow some tolerance for graph reading)

#### 11-19 Equivalent thickness of concrete

Given: Problem 11-18

Solution:

- a. Using a transmission of 0.004 from Problem 11-18 and  $^{60}\text{Co}$  line in Figure 11-6

$$\text{Concrete thickness} = 43 \text{ cm}$$

(Allow some tolerance for graph reading)

#### 11-20 Additional thickness of lead to achieve 99.6% reduction

Given:  $^{60}\text{Co}$  source, 25cm of concrete

Solution:

- a. Compute transmission allowed

$$1.0000 - 0.9960 = 0.0040$$

- b. From figure 11-7 estimate transmission for 25cm of concrete

$$T \approx 0.12$$

- c. The reduction from the concrete is approximately

$$R \approx 1.000 - 0.12 \approx 0.880$$

- d. the additional reduction required is

$$0.996 - 0.880 = 0.116$$

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e. the allowable transmission is

$$T = 1.000 - 0.116 = 0.884$$

From figure 11-6 we can see that an additional thickness of 1cm is needed.

#### 11-21 Proportionality constant for lead

Given: Lead shielding for  $^{137}\text{Cs}$

Solution:

Using Eqn. 11-24 assume a thickness and select a transmission from Figure 11-6

For example @ 10 cm thickness,  $I/I_0 = 0.00002$

$$0.00002 = e^{-u(10 \text{ cm})}$$

$$\ln(0.00002) = \ln(e^{-u(10 \text{ cm})}) = -u(10 \text{ cm})$$

$$u = \frac{-10.82}{-10} = 1.082$$

#### 11-22 Proportionality constant for iron

Given: Iron shielding for  $^{137}\text{Cs}$

Solution:

a. Using Eqn. 11-24, assume a thickness and select a transmission from Figure 11-6

For example @ 10 cm thickness,  $I/I_0 = 0.02$

$$0.02 = e^{-u(10 \text{ cm})}$$

$$\ln(0.02) = \ln(e^{-u(10 \text{ cm})}) = -u(10 \text{ cm})$$

$$u = \frac{-3.912}{-10} = 0.391$$

## DISCUSSION QUESTIONS

### 11-1 Carbon dating

Given: archaeological bone artifact

Solution:

Carbon-14 is a naturally occurring radioisotope produced by cosmic rays bombarding  $\text{CO}_2$  in the atmosphere. This carbon is incorporated into bone along with other carbon used to build bone. Because the carbon-14 decays at a fixed rate over time, the current activity can be used to estimate the age since when the animal dies it no longer incorporates new carbon-14.

### 11-2 Weighting factor

Given:  $W_T$  for big toe larger or smaller than for thyroid?

Solution:

The weighting factor for x-rays to the big toe will be less than that for radioiodine to the thyroid because the iodine is readily incorporated in the thyroid while the toe is not very sensitive to x-rays.

### 11-3 Internal emitter hazard

Given: alpha, beta, gamma, or x-rays

Solution:

Alpha and beta emitters are the most dangerous internal radiation hazards because their specific ionization is very high.

### 11-4 Shielding recommendation

Given: high energy beta

Solution:

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Plexiglas® or Lucite® is recommended.

#### 11-5 Measures to limit radon

Given: older home with floor drain

Solution:

If radon measurements show excessive levels, the following techniques may be employed: seal the floor drain, provide proprietary epoxy coating to floor and walls, provide exterior air supply for furnace and other combustion appliances, place exterior footing tiles around foundation and use vacuum source to keep under negative pressure.

#### 11-6 Yucca Mountain

The Information on Yucca Mountain may vary yearly, and maybe monthly, due to the fact that it's still under construction. For information on the site you may visit the following websites:

Department of Energy

[http://www.ocrwm.doe.gov/ym\\_repository/index.shtml](http://www.ocrwm.doe.gov/ym_repository/index.shtml)

The State on Nevada website:

<http://www.state.nv.us/nucwaste/>

and of 2006:

(<http://www.state.nv.us/nucwaste/news2006/pdf/stanford060307gilinsky.pdf>)

Yucca Mountain has its own website and offers some information:

<http://www.yuccamountain.org/>