PHYS 117 – 2020 Final Assessment
SOLUTIONS

1. - P117-2020-FA-02-v1-SOLN [4633803]
Arterial blockages are described by the reduction in blood flow rate that they cause. Suppose that a blood clot has reduced the flow rate in an artery to 13.3% of its normal value and the average pressure difference per unit length along the artery has increased by 33.0%. Calculate the factor by which the radius of the artery, r_o, has changed. You may assume that the viscosity of the blood does not change.

$r =$ [ ] $0.562r_o$

SOLUTION:

This question involves Poiseuille's Law for flow of a viscous fluid:

$$\frac{\Delta V}{\Delta t} = \frac{\pi R^4 (P_1 - P_2)}{8\eta L}$$

There is no change in viscosity of the fluid or the length over which the flow is occurring. The question asks for the relationship between the new radius and the original radius.

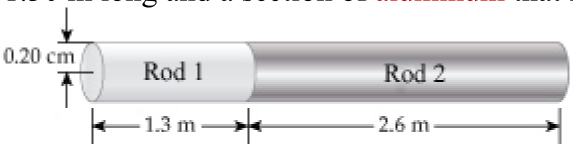
Re-arranging Poiseuille's Law:

$$R^4 = \left(\frac{\Delta V}{\Delta t}\right)\left(\frac{8\eta L}{\pi(P_1 - P_2)}\right)$$

$$\frac{R^4}{R_o^4} = \frac{\left(\frac{\Delta V}{\Delta t}\right)\left(\frac{8\eta L}{\pi(P_1 - P_2)}\right)}{\left(\frac{\Delta V}{\Delta t}\right)_o\left(\frac{8\eta L}{\pi(P_1 - P_2)}\right)_o} = \frac{\left(\frac{\Delta V}{\Delta t}\right)(P_1 - P_2)_o}{\left(\frac{\Delta V}{\Delta t}\right)_o (P_1 - P_2)} = \frac{0.133\left(\frac{\Delta V}{\Delta t}\right)_o (P_1 - P_2)_o}{\left(\frac{\Delta V}{\Delta t}\right)_o 1.33(P_1 - P_2)_o}$$

$$\frac{R^4}{R_o^4} = \frac{0.133}{1.33} \quad \Rightarrow \quad \frac{R}{R_o} = \sqrt[4]{\frac{0.133}{1.33}} \quad \Rightarrow \quad R = 0.562R_o$$

2. - P117-2020-FA-03-v1-SOLN [4633814]
A cylindrical rod with a radius of 0.200 cm consists of two sections (a section of cast iron that is 1.30 m long and a section of aluminum that is 2.60 m long) as shown in the diagram below.



Calculate the change in length of the rod when a tensile force of 7.90×10^3 N is exerted on it. The Young's modulus values are $Y_{\text{cast iron}} = 99.9 \times 10^{10}$ N/m^2 and $Y_{\text{aluminum}} = 7.01 \times 10^{10}$ N/m^2.

2.41 cm

SOLUTION:

This question involves the stress-strain relationship for a tensile stress.

$$\frac{F}{A} = Y\frac{\Delta L}{L_0}$$

Calculate the change in length of each material, then add to obtain the overall change in length.

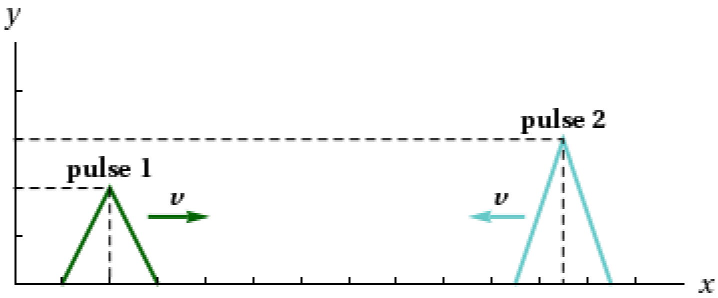
$$\Delta L = \frac{FL_0}{YA}$$

$$\Delta L_{tot} = \Delta L_{Fe} + \Delta L_{Al} = \frac{FL_{0,Fe}}{Y_{Fe}A} + \frac{FL_{0,Al}}{Y_{Al}A}$$

$$\Delta L_{tot} = \frac{F}{A}\left(\frac{L_{0,Fe}}{Y_{Fe}} + \frac{L_{0,Al}}{Y_{Al}}\right) = \frac{7.90\times10^3\,\text{N}}{\pi(0.200\times10^{-2}\,\text{m})^2}\left(\frac{1.30\text{ m}}{101\times10^{10}\,\text{N/m}^2} + \frac{2.60\text{ m}}{7.01\times10^{10}\,\text{N/m}^2}\right)$$

$$\Delta L_{tot} = 2.41\text{ cm}$$

3. - P117-2020-FA-04-v1-SOLN [4633823]
Two pulses are moving toward each other with the same speed v = 18.3 cm/s. The diagram below shows the instantaneous positions of the pulses at time t = 0,



The scale of the horizontal axis (x) is 4.00 cm per division and the scale of the vertical axis (y) is 2.00 cm per division. (At t = 0, the peak of pulse 2 is exactly on a half-unit of the horizontal axis.)

(a) Calculate the location where the superposition of the two pulses has maximum amplitude.
27.0 cm

(b) Calculate the time when the superposition of the two pulses has maximum amplitude.
1.04 s

(c) Calculate the maximum amplitude of the superposition of the two pulses.
10.0 cm

SOLUTION:
(a) and (b):
At time t = 0, the peaks of the pulses are 9.5 divisions = (9.5)(4.00 cm) = 38.0 cm apart.

The pulses are moving toward each other with the same speed of 18.3 cm/s. Let t be the time when the pulses completely overlap (peaks at the same position)…

$$x_{tot} = x_1 + x_2 = \upsilon_1 t + \upsilon_2 t = 2\upsilon t$$
$$t = \frac{x_{tot}}{2\upsilon} = \frac{38.0 \text{ cm}}{2(18.3 \text{ cm/s})} = 1.04 \text{ s}$$

In time t, pulse 1 has travelled a distance of $x_1 = \upsilon t$ = (18.3 cm/s)(1.04 s) = 19.0 cm. Since pulse 1 was initially at a position of 2 divisions = 8.0 cm, the position when the superposition has maximum amplitude is 8.0 cm + 19.0 cm = 27.0 cm.

Alternative solutions for (a) and (b):
Since the two pulses move toward each other at the same speed, the pulses will meet at the middle point where the superposition of the two pulses has the maximum amplitude.

At $t = 0$, the peak of pulse 1 is at 2 divisions and the peak of pulse 2 is at 11.5 divisions, thus the middle point is at (2+11.5)/2 = 6.75 divisions.

$$x_{mid} = (6.75)(4.00\text{ cm}) = 27.0\text{ cm}$$

Pulse 1 will move 4.75 divisions until it arrives at the middle point:

$$t = \frac{(4.75)(4.00\text{ cm})}{18.3\text{ cm/s}} = 1.04\text{ s}$$

(c) The maximum amplitude of the superposition is 2 vertical divisions + 3 vertical divisions = 5 vertical divisions. 5 vertical divisions × 2.00 cm/division = 10.0 cm

4. - P117-2020-FA-05-v1-SOLN [4633830]
One type of non-invasive blood flow measuring device measures the beat frequency between the original ultrasound wave emitted by the device and the ultrasound wave reflected from the oncoming blood cells.

Suppose that the frequency of the ultrasound emitted by the device is 2.13 MHz, the speed of ultrasound through human tissue is 1540 m/s, and the speed of the oncoming blood is 52.2 cm/s.

Calculate the beat frequency. **Keep as many decimal places as your calculator will allow throughout your calculations, and then round-off your final answer.**

1440 Hz

SOLUTION:

There are two Doppler effects. The blood cells receive a higher frequency, f_{o1}, of ultrasound (observer moving toward a stationary source) and the device receives a still higher frequency, f_{o2}, (cells are now a source moving toward a stationary observer).

$$f_{O1} = \left(\frac{\upsilon + \upsilon_{O1}}{\upsilon - \upsilon_{S1}}\right) f_{S1} = \left(\frac{\upsilon + \upsilon_{O1}}{\upsilon}\right) f_{S1} = \left(\frac{1540 \text{ m/s} + (+0.522 \text{ m/s})}{1540 \text{ m/s}}\right)(2.13 \text{ MHz}) = 2.13072 \text{ MHz}$$

There is no shift in frequency due to reflection, so the blood cells are now sources of ultrasound of frequency 2.13072 MHz.

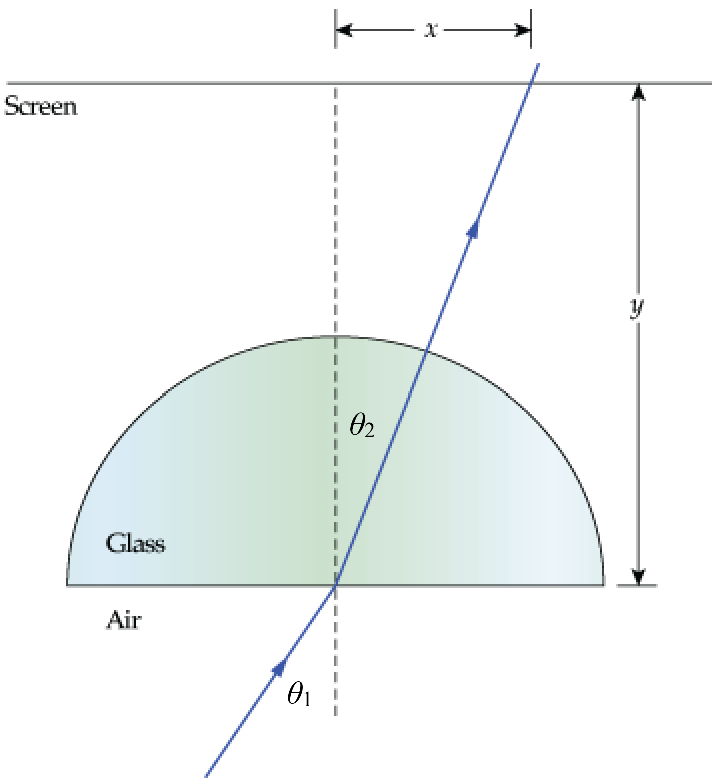
$$f_{O2} = \left(\frac{\upsilon}{\upsilon - \upsilon_{S2}}\right) f_{S2} = \left(\frac{1540 \text{ m/s}}{1540 \text{ m/s} - (+0.522 \text{ m/s})}\right)(2.13072 \text{ MHz}) = 2.13144 \text{ MHz}$$

and the beat frequency that the device measures is the difference between its source frequency and the frequency of the reflected ultrasound that it detects.

$$f_{beat} = f_{O2} - f_{S1} = 0.00144 \text{ MHz} = 1.44 \text{ kHz} = 1440 \text{ Hz}$$

5. - P117-2020-FA-06-v1-SOLN [4633838]
The refractive index of a semicircular glass disk is $n_g = 1.66$. A light ray enters the glass at the midpoint of the flat side, as shown in the diagram. Calculate the angle of incidence in air so that the ray will be perpendicular to the semicircular surface when it leaves the glass and will strike the screen at $x = 4.70$ cm and $y = 19.0$ cm.

23.5°



SOLUTION:
As seen in the diagram, since the outgoing ray from the glass is perpendicular to the disk surface when it leaves, it will not refract (angle of incidence is zero).

Therefore, θ_2 can be calculated from the values of x and y, and θ_1 can be calculated from Snell's Law.

$$\tan\theta_2 = \frac{x}{y} = \frac{4.70 \text{ cm}}{19.0 \text{ cm}} \Rightarrow \theta_2 = \arctan\left(\frac{4.70}{19.0}\right) = 13.894^\circ$$

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \Rightarrow \theta_1 = \arcsin\left(\frac{n_2 \sin\theta_2}{n_1}\right) = \arcsin\left(\frac{1.66 \sin(13.894^\circ)}{1.00}\right) = 23.5^\circ$$

6. - P117-2020-FA-07-v1-SOLN [4633851]
Two lenses, one converging and the other diverging, have the same magnitude of focal length, 32.3 cm. A light bulb is used as an object.

(a) Which lens should be used to produce a focussed image of the light bulb on a screen several meters away.
○ converging ○ diverging

(b) Calculate the distance from the lens at which the screen should be placed so that the image of the light bulb on the screen is a factor of 2.70 larger than the light bulb.

1.2 m

SOLUTION:

(a) Only converging lenses produces real images – images that can be projected and focussed on a screen.

(b) Use the magnification equation to obtain a relationship between p and q, then use the thin lens equation to solve for q.

$$M = \frac{h'}{h} = -\frac{q}{p} \Rightarrow p = -\frac{q}{M}$$

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f} \Rightarrow \frac{1}{q} = \frac{1}{f} - \frac{1}{p} = \frac{1}{f} - \frac{1}{-\left(q/M\right)} = \frac{1}{f} + \frac{M}{q}$$

$$\frac{1}{q} - \frac{M}{q} = \frac{1}{f} \Rightarrow \frac{1}{q}(1-M) = \frac{1}{f} \Rightarrow q = f(1-M)$$

Remembering that a real image formed by a converging lens is inverted (and therefore M is negative):

$$q = f(1 - M) = (32.3 \text{ cm})(1 - (-2.70)) = 120 \text{ cm} = 1.20 \text{ m}$$

7. - P117-2020-FA-08-v1-SOLN [4633865]
Light with a wavelength of 601 nm is incident on a pair of slits. Calculate the required distance between the two slits so that the interference pattern has its first **minimum** at an angle of 0.308°, as measured from the direction of the incident light.

5.59e-05 m

SOLUTION:

The first minimum (m = 0) occurs when the path length difference from the slits is half of the wavelength.

$$d \sin\theta_{dark} = (m + \tfrac{1}{2})\lambda$$

$$d = \frac{(\frac{1}{2})\lambda}{\sin\theta_{dark}} = \frac{(\frac{1}{2})(601 \text{ nm})}{\sin(0.308^\circ)} = 5.59\times10^{4} \text{ nm} = 5.59\times10^{-5} \text{ m}$$

8. - P117-2020-FA-09-v1-SOLN [4633872]
The distance from the eye lens (i.e. lens-cornea system) to the retina of a particular eye is 1.96 cm. The power of the eye lens when it is relaxed is 54.4 D.

(a) Calculate the far point of the eye.

0.296 m

(b) If a corrective lens is to be placed 1.80 cm from the eye, calculate the power of the corrective lens that will allow the eye to focus on distant objects.

-3.6 D

SOLUTION:

When the eye is relaxed (viewing a distant object), it has a focal length of $f = 1/P$ where P is the power.

The thin lens equation, applied to the eye, can be used to calculate the maximum distance at which the eye can focus. When the eye is focussed, the image distance, q, is the lens to retina distance.

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f} \quad \Rightarrow \quad p=\left(\frac{1}{f}-\frac{1}{q}\right)^{-1}=\left(P-\frac{1}{q}\right)^{-1}=\left(54.4\text{ m}^{-1}-\frac{1}{0.0196\text{ m}}\right)^{-1}=0.296\text{ m}$$

This is an extremely short far point. The person can only clearly focus out to a distance of 29.6 cm!

To correct the person's far vision, want to use a corrective lens so that an object at infinity results in a focussed image on the retina. That is, the corrective lens must form an image that is a distance of 29.6 cm from the person's eye. Given that the corrective lens is to be placed 1.80 cm from the eye, the corrective lens must form its image at a distance of 29.6 cm – 1.80 cm = 27.8 cm from the lens. This is a virtual image, so q for the corrective lens is –27.8 cm = –0.278 m

The required power of the corrective lens is:

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f} \quad \Rightarrow \quad \frac{1}{p}+\frac{1}{q}=P_{corr}=\frac{1}{\infty}+\frac{1}{-0.278\text{ m}}=-3.60\text{ D}$$

9. - P117-2020-FA-10-v1-SOLN [4633878]
Cars have a reservoir to catch radiator fluid that may overflow when the engine is hot. A radiator is made of copper and is filled to its 19.5-L capacity when at 16.0°C. Calculate the volume of radiator fluid that will overflow when the radiator and fluid reach a temperature 95.0°C. The fluid's volume coefficient of expansion is 401×10^{-6}/°C and the volume coefficient of expansion of copper is 51.0×10^{-6}/°C.

0.539 L

SOLUTION:

The amount of fluid that overflows is calculated by subtracting the new volume of fluid from the new volume of the radiator. The initial volumes are the same, because the radiator is initially filled to capacity.

$$\Delta V = \beta V_o \Delta T$$

$$V_{overflow} = \Delta V_{fluid} - \Delta V_{radiator} = \beta_{fluid} V_o \Delta T - \beta_{copper} V_o \Delta T$$

$$V_{overflow} = (\beta_{fluid} - \beta_{copper}) V_o \Delta T$$

$$V_{overflow} = (401 \times 10^{-6}\,/^{\circ}\mathrm{C} - 51.0 \times 10^{-6}\,/^{\circ}\mathrm{C})(19.5\ \mathrm{L})(95.0^{\circ}\mathrm{C} - 16.0^{\circ}\mathrm{C})$$

$$V_{overflow} = 0.539\ \mathrm{L}$$

10. - P117-2020-FA-11-v1-SOLN [4633879]
162 g of hot coffee at 78.7°C and some cold cream at 7.50°C are poured into a 115-g cup that is initially at a temperature of 22.0°C. The cup, coffee, and cream reach an equilibrium temperature of 58.0°C. The material of the cup has a specific heat of 0.2604 kcal/(kg·°C) and the specific heat of both the coffee and cream is 1.00 kcal/(kg·°C). Assuming that no heat is lost to or gained from the surroundings, calculate the mass of cream that was added.

45.1 g

SOLUTION:

This is a calorimetry problem. There is no net transfer of energy from the system. The system is the coffee, cream, and cup.

$$\sum Q = 0 \quad \Rightarrow \quad Q_{coffee} + Q_{cream} + Q_{cup} = 0$$

$$m_{coffee} c_{coffee} \Delta T_{coffee} + m_{cream} c_{cream} \Delta T_{cream} + m_{cup} c_{cup} \Delta T_{cup} = 0$$

$$m_{cream} = \frac{-m_{coffee} c_{coffee} \Delta T_{coffee} - m_{cup} c_{cup} \Delta T_{cup}}{c_{cream} \Delta T_{cream}}$$

$$m_{cream} = \frac{-(162\text{ g})(1.00\text{ kcal/kg}^\circ\text{C})(58.0^\circ\text{C} - 78.7^\circ\text{C}) - (115\text{ g})(0.2604\text{ kcal/kg}^\circ\text{C})(58.0^\circ\text{C} - 22.0^\circ\text{C})}{(1.00\text{ kcal/kg}^\circ\text{C})(58.0^\circ\text{C} - 7.50^\circ\text{C})}$$

$$m_{cream} = 45.1\text{ g}$$

11. - P117-2020-FA-12-v1-SOLN [4633881]
The surface area of the human body is 1.40 m^2 and the average thickness of the tissue between the core and the outside of the skin is 1.00 cm. The thermal conductivity of tissue is 0.200 J/(s · m · °C). For a core internal temperature of 37.0°C and an outside-of-skin temperature of 33.8°C, calculate the rate of heat conduction out of the human body.

89.6 W

SOLUTION:

$$P = \kappa A \frac{(T_h - T_c)}{L} = (0.200 \text{ J/s.m.}^{\circ}\text{C})(1.40 \text{ m}^2)\frac{(37.0^{\circ}\text{C} - 33.8^{\circ}\text{C})}{0.0100 \text{ m}} = 89.6 \text{ W}$$

12. - P117-2020-FA-13-v1-SOLN [4633891]
Electrons from a material whose work function is 2.37 eV are ejected by 497-nm photons. Once ejected, calculate the time it takes these electrons (in ns) to travel 3.35 cm.

160 ns

SOLUTION:

This question involves the photoelectric effect.

Calculate the maximum kinetic energy of the ejected electrons, then the maximum speed of the electrons, and then the time to travel the specified distance.

$$KE_{\max} = hf - \phi = \frac{hc}{\lambda} - \phi$$

$$\tfrac{1}{2} m_e \upsilon_{\max}^2 = hf - \phi$$

$$\upsilon_{\max} = \sqrt{\frac{2\left(\frac{hc}{\lambda} - \phi\right)}{m_e}}$$

$$\upsilon_{\max} = \sqrt{\frac{2\left(\left(\frac{(6.626\times10^{-34}\,\text{J.s})(2.998\times10^{8}\,\text{m/s})}{(497\times10^{-9}\,\text{m})}\right) - (2.37\text{ eV})(1.602\times10^{-19}\,\text{C})\right)}{(9.109\times10^{-31}\,\text{kg})}}$$

$$\upsilon_{\max} = 2.097\times10^{5}\ \text{m/s}$$

$$\upsilon = \frac{d}{t} \quad\Rightarrow\quad t_{\min} = \frac{d}{\upsilon_{\max}} = \frac{3.35\times10^{-2}\ \text{m}}{2.76\times10^{5}\ \text{m/s}} = 1.60\times10^{-7}\ \text{s} = 160\ \text{ns}$$

13. - P117-2020-FA-14-v1-SOLN [4633899]
The accelerating electric potential (i.e. voltage) applied to a particular x-ray tube is 17.9 kV. Calculate the shortest wavelength (in nm) of x-rays that can be produced.

0.0693 nm

SOLUTION:

The maximum energy of x-ray is produced when an incident electron loses all of its kinetic energy in a single interaction with the target and produces one photon. Energy conservation allows calculation of the wavelength of this photon.

$$E_{photon} = KE_e$$

$$\frac{hc}{\lambda_{\min}} = e\Delta V$$

$$\lambda_{\min} = \frac{hc}{e\Delta V} = \frac{1240\ \text{eV.nm}}{e(17.9\times 10^3\ \text{V})} = 0.0693\ \text{nm}$$

14. - P117-2020-FA-15-v1-SOLN [4633903]
Calculate the number of neutrons in a bromine nucleus, which has a radius of approximately 5.15×10^{-15} m. The atomic number of carbon is 6, the atomic number of chlorine is 17, and the atomic number of bromine is 35.

44 neutrons

SOLUTION:

The number of nucleons, A, can be calculated from the radius. The number of neutrons is given by $N = A - Z$.

$$r = r_0 A^{1/3} \quad \Rightarrow \quad \frac{r}{r_0} = A^{1/3} \quad \Rightarrow \quad A = \left(\frac{r}{r_0}\right)^3$$

$$N = A - Z = \left(\frac{r}{r_0}\right)^3 - Z = \left(\frac{5.15\times10^{-15}\ \text{m}}{1.2\times10^{-15}\ \text{m}}\right)^3 - 35 = 44$$

15. - P117-2020-FA-16-v1-SOLN [4633907]

(a) For the nuclei ${}^{14}_{7}N$ and ${}^{14}_{8}O$, calculate the difference in binding energy per nucleon (in MeV). The atomic mass of ${}^{14}_{7}N$ is 14.003074 u and the atomic mass of ${}^{14}_{8}O$ is 14.008596 u.)

0.423 MeV

(b) This difference in binding energy is due to which of the following?

- ( ) Greater electron attraction for the ${}^{14}_{8}O$ atom
- (•) Greater proton repulsion for the ${}^{14}_{8}O$ nucleus
- ( ) Greater neutron attraction for the ${}^{14}_{8}O$ nucleus
- ( ) Greater proton attraction for the ${}^{14}_{8}O$ nucleus
- ( ) Greater neutron repulsion for the ${}^{14}_{8}O$ nucleus
- ( ) Greater electron repulsion for the ${}^{14}_{8}O$ atom

SOLUTION:

$$BE = (Zm_H + Nm_n - M_{atomic})c^2$$

$$\Delta BE = BE_{Nitrogen} - BE_{Oxygen} = (Z_N m_H + N_N m_n - M_{N\,atomic})c^2 - (Z_O m_H + N_O m_n - M_{O\,atomic})c^2$$

$$\Delta BE = \left((Z_N - Z_O)m_H + (N_N - N_O)m_n - M_{N\,atomic} + M_{O\,atomic}\right)c^2$$

$$\Delta BE = \left((7-8)m_H + (7-6)m_n - M_{N\,atomic} + M_{O\,atomic}\right)c^2$$

$$\Delta BE = (M_{O\,atomic} + m_n - M_{N\,atomic} - m_H)c^2$$

$$\Delta BE = (14.008596\text{ u} + 1.008665\text{ u} - 14.003074\text{ u} - 1.007825\text{ u})(931.494\text{ MeV/u})$$

$$\Delta BE = 5.92616\text{ MeV}$$

$$\Delta BE\text{ / nucleon} = 5.92616\text{ MeV / 14 nucleons} = 0.423\text{ MeV/nucleon}$$

The Nitrogen nucleus is more-tightly bound because there is less proton repulsion. Oxygen has one more proton, and therefore has more electrostatic repulsion.

16. - P117-2020-FA-17-v1-SOLN [4633920]
In the radioactive decay ${}^{234}_{90}Th \rightarrow {}^{A}_{Z}Ra + {}^{4}_{2}He$ identify the mass number and the atomic number of the Ra nucleus.

(a) the mass number
230

(b) the atomic number
88

SOLUTION:

The mass number is calculated by balancing the superscripts in the decay equation:

$A + 4 = 234$, so $A = 230$

The atomic number is calculated by balancing the subscripts in the decay equation:

$Z + 2 = 90$, so $Z = 88$