2. ***REASONING***

a. The number of protons in a given nucleus ${}^{A}_{Z}X$ is specified by its atomic number Z.

b. The number N of neutrons in a given nucleus ${}^{A}_{Z}X$ is equal to the nucleon number A (the number of protons and neutrons) minus the atomic number Z (the number of protons): $N = A - Z$ (Equation 31.1).

c. In an electrically neutral niobium atom, the number of electrons in orbit about the nucleus is equal to the number of protons in the nucleus.

SOLUTION

a. The number of protons in the uranium ${}^{238}_{92}\text{U}$ nucleus is $Z = \boxed{92}$.

b. The number N of neutrons in the ${}^{202}_{80}\text{Hg}$ nucleus is $N = A - Z = 202 - 80 = \boxed{122}$.

c. The number of electrons that orbit the ${}^{93}_{41}\text{Nb}$ nucleus in the neutral niobium atom is equal to the number of protons in the nucleus, or $\boxed{41}$.

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3. ***REASONING*** For an element whose chemical symbol is X, the symbol for the nucleus is ${}^{A}_{Z}\text{X}$ where A represents the number of protons and neutrons (the nucleon number) and Z represents the number of protons (the atomic number) in the nucleus.

SOLUTION

a. The symbol ${}^{195}_{78}\text{X}$ indicates that the nucleus in question contains $Z = 78$ protons, and $N = A - Z = 195 - 78 = \boxed{117 \text{ neutrons}}$. From the periodic table, we see that $Z = 78$ corresponds to $\boxed{\text{platinum, Pt}}$.

b. Similar reasoning indicates that the nucleus in question is $\boxed{\text{sulfur, S}}$, and the nucleus contains $N = A - Z = 32 - 16 = \boxed{16 \text{ neutrons}}$.

c. Similar reasoning indicates that the nucleus in question is $\boxed{\text{copper, Cu}}$, and the nucleus contains $N = A - Z = 63 - 29 = \boxed{34 \text{ neutrons}}$.

d. Similar reasoning indicates that the nucleus in question is $\boxed{\text{boron, B}}$, and the nucleus contains $N = A - Z = 11 - 5 = \boxed{6 \text{ neutrons}}$.

e. Similar reasoning indicates that the nucleus in question is $\boxed{\text{plutonium, Pu}}$, and the nucleus contains $N = A - Z = 239 - 94 = \boxed{145 \text{ neutrons}}$.

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4. ***REASONING*** According to Coulomb's law, the magnitude of the electrostatic force between two protons is $F = ke^2/r^2$ (Equation 18.1), where e is the magnitude of the charge on each proton and r is the distance between them. The electrostatic force given by Coulomb's law has the least possible magnitude when the two charges are as widely separated as possible, so that the distance r between them is as great as possible. In the nucleus, this means that the two protons in question must be located at opposite ends of the diameter of the nucleus.

SOLUTION To find the magnitude of the least possible electrostatic force that either of two protons can exert on the other, we need to know the diameter of the gold nucleus. The diameter is twice the radius, so that Equation 31.2 indicates that the diameter of the gold nucleus is $d = 2(1.2 \times 10^{-15} \text{ m})\, A^{1/3}$, where A is the nucleon number. For gold ${}^{197}_{79}\text{Au}$ it follows that $A = 197$. Using Coulomb's law with a separation between the protons that equals the diameter d of the nucleus, we find

$$F_{\substack{\text{Least}\\\text{possible}}} = \frac{ke^2}{d^2} = \frac{ke^2}{\left[2\left(1.2\times10^{-15}\text{ m}\right)A^{1/3}\right]^2}$$

$$= \frac{\left(8.99\times10^{9}\text{ N}\cdot\text{m}^2/\text{C}^2\right)\left(1.60\times10^{-19}\text{ C}\right)^2}{\left[2\left(1.2\times10^{-15}\text{ m}\right)(197)^{1/3}\right]^2} = \boxed{1.2 \text{ N}}$$

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5. $\boxed{\text{SSM}}$ $\boxed{\text{WWW}}$ ***REASONING AND SOLUTION*** Equation 31.2 gives for the radius of the ${}^{48}_{22}\text{Ti}$ nucleus that

$$r = (1.2 \times 10^{-15}\text{ m})A^{1/3} = (1.2 \times 10^{-15}\text{ m})(48)^{1/3} = \boxed{4.4\times10^{-15}\text{ m}}$$

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6. ***REASONING*** Assuming that the nuclei are spherical, we will use $\text{Area} = 4\pi r^2$ to find the surface area of a nucleus from its radius r. Under the same assumption, the radius r of a nucleus is given by $r = \left(1.2\times10^{-15}\text{ m}\right)A^{1/3}$ (Equation 31.2), where A is the number of nucleons in the nucleus.

SOLUTION The ratio of the surface area Area_{209} of the largest nucleus ($A_{209} = 209$) to the surface area Area_1 of the smallest nucleus ($A_1 = 1$) is

12. ***REASONING*** The mass defect is the total mass of the stationary separated nucleons (protons and neutrons) minus the mass of the intact nucleus. The given atomic masses are for the electrical neutral atoms and, therefore, include the mass of the electrons. This will cause no problem, provided that we use the atomic mass of the hydrogen atom (including its electron) when determining the mass of the separated nucleons. Referring to Table 31.1 we find that the mass of a neutron is 1.008 665 u and the mass of a hydrogen atom is 1.007 825 u.

SOLUTION

a. The helium ${}^{3}_{2}\text{He}$ nucleus contains 2 protons and 3 − 2 = 1 neutron. Thus, the mass defect Δm is

$$\Delta m = \underbrace{2(1.007\ 825\ \text{u}) + 1(1.008\ 665\ \text{u})}_{\text{Separated nucleons: 2 protons and 1 neutron}} - \underbrace{3.016\ 030\ \text{u}}_{\text{Intact nucleus}} = \boxed{0.008\ 285\ \text{u}}$$

b. The tritium ${}^{3}_{1}\text{T}$ nucleus contains 1 proton and 3 − 1 = 2 neutrons. Thus, the mass defect Δm is

$$\Delta m = \underbrace{1(1.007\ 825\ \text{u}) + 2(1.008\ 665\ \text{u})}_{\text{Separated nucleons: 1 proton and 2 neutrons}} - \underbrace{3.016\ 050\ \text{u}}_{\text{Intact nucleus}} = \boxed{0.009\ 105\ \text{u}}$$

c. The mass defect for tritium ${}^{3}_{1}\text{T}$ is greater than that for helium ${}^{3}_{2}\text{He}$. The mass defect is related to the binding energy as follows:

$$\text{Binding energy} = (\Delta m)c^2 \qquad (31.3)$$

The binding energy is the energy that must be supplied to the intact nucleus in order to separate it into its constituent nucleons. Thus,

$$\boxed{\text{more energy must be supplied to tritium } {}^{3}_{1}\text{T than to helium } {}^{3}_{2}\text{He}}.$$

13. ***REASONING AND SOLUTION*** For ${}^{202}_{80}\text{Hg}$ the mass of the separated nucleons is

$$m = 80(1.007\ 825\ \text{u}) + 122(1.008\ 665\ \text{u}) = 203.683\ 130\ \text{u}$$

The mass defect is then $\Delta m = 203.683\ 130\ \text{u} - 201.970\ 617\ \text{u} = 1.712\ 513\ \text{u}$.

This corresponds to a total binding energy of $(1.712\ 513\ \text{u})\left(\dfrac{931.5\ \text{MeV}}{1\ \text{u}}\right) = 1595\ \text{MeV}$ and a binding energy per nucleon of $\dfrac{1595\ \text{MeV}}{202\ \text{nucleons}} = \boxed{7.90\ \text{MeV/nucleon}}$.

14. ***REASONING***

a. The gravitational potential energy of the earth-boulder system is given by $\text{PE} = mgh$ (Equation 6.5), where m is the boulder's mass, $g = 9.8\ \text{m/s}^2$ is the acceleration due to gravity, and h is the height of the shaft. Equation 6.5 gives the amount of gravitational potential energy the system loses as the boulder falls to the bottom, which is the binding energy when the boulder is at the bottom of the shaft.

b. The earth-boulder system loses energy as it falls, so it also loses mass. The binding energy is proportional to the change Δm in the system's mass, according to Equation 31.3: $\text{Binding energy} = (\Delta m)c^2$. Here, $c = 3.00\times10^8\ \text{m/s}$ is the speed of light in a vacuum.

SOLUTION

a. The binding energy is equal to the potential energy the earth-boulder system loses when the boulder falls down the mineshaft. Therefore, we have that

$$\text{Binding energy} = \text{PE} = mgh = (245\ \text{kg})(9.8\ \text{m/s}^2)(3.0\times10^3\ \text{m}) = \boxed{7.2\times10^6\ \text{J}}$$

b. Solving the expression $\text{Binding energy} = (\Delta m)c^2$ (Equation 31.3) for Δm, we obtain

$$\Delta m = \frac{\text{Binding energy}}{c^2} = \frac{7.2\times10^6\ \text{J}}{(3.00\times10^8\ \text{m/s})^2} = \boxed{8.0\times10^{-11}\ \text{kg}}$$

15. ***REASONING*** The mass defect Δm is related to the total binding energy and the square of the speed c of light. Thus, to determine Δm we will use Figure 31.5 to obtain the binding energy per nucleon for the oxygen ${}^{16}_{8}\text{O}$ nucleus and multiply this value by the total number of nucleons (16) to find the total binding energy. Note that the data in Figure 31.5 is given in MeV per nucleon and that an MeV is not an SI unit compatible with kilograms. Thus, we will need to convert MeV to joules (J).

18. ***REASONING AND SOLUTION***

a. The mass defect is

$$\Delta m = 13.005\ 738\ \text{u} + 1.008\ 665\ \text{u} - 14.003\ 074\ \text{u} = 0.011\ 329\ \text{u}$$

The binding energy of the neutron is then

$$(0.011\,329\ \text{u})\left(\frac{931.5\ \text{MeV}}{1\ \text{u}}\right) = \boxed{10.55\ \text{MeV}}$$

b. The mass defect is

$$\Delta m = 13.003\ 355\ \text{u} + 1.007\ 825\ \text{u} - 14.003\ 074\ \text{u} = 0.008\ 106\ \text{u}$$

The binding energy of the proton is then

$$(0.008\,106\ \text{u})\left(\frac{931.5\ \text{MeV}}{1\ \text{u}}\right) = \boxed{7.55\ \text{MeV}}$$

c. The $\boxed{\text{neutron}}$ is more tightly bound, since it has the larger binding energy.

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19. $\boxed{\text{SSM}}$ $\boxed{\text{WWW}}$ ***REASONING AND SOLUTION*** The general form for β^+ decay is

$$\underbrace{{}^{A}_{Z}\text{P}}_{\substack{\text{Parent}\\ \text{nucleus}}} \rightarrow \underbrace{{}^{A}_{Z-1}\text{D}}_{\substack{\text{Daughter}\\ \text{nucleus}}} + \underbrace{{}^{0}_{+1}\text{e}}_{\substack{\beta^+\ \text{particle}\\ \text{(positron)}}}$$

a. Therefore, the β^+ decay process for ${}^{18}_{9}\text{F}$ is $\boxed{{}^{18}_{9}\text{F} \rightarrow {}^{18}_{8}\text{O} + {}^{0}_{+1}\text{e}}$.

b. Similarly, the β^+ decay process for ${}^{15}_{8}\text{O}$ is $\boxed{{}^{15}_{8}\text{O} \rightarrow {}^{15}_{7}\text{N} + {}^{0}_{+1}\text{e}}$.

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20. ***REASONING*** The reaction and the atomic masses are:

$$\underbrace{{}^{191}_{76}\text{Os}}_{190.960\ 920\ \text{u}} \rightarrow \underbrace{{}^{191}_{77}\text{Ir} + {}^{0}_{-1}\text{e}}_{190.960\ 584\ \text{u}}$$

When the ${}^{191}_{76}\text{Os}$ nucleus is converted into an iridium ${}^{191}_{77}\text{Ir}$ nucleus, the number of orbital electrons remains the same, so the resulting iridium atom is missing one orbital electron. However, the given mass includes all 77 electrons of a neutral iridium atom. In effect, then, the value of 190.960 584 u for ${}^{191}_{77}\text{Ir}$ already includes the mass of the β^- particle. Since energy is released during the decay, the combined mass of the iridium ${}^{191}_{77}\text{Ir}$ daughter nucleus and the β^- particle is less than the mass of the osmium ${}^{191}_{76}\text{Os}$ parent nucleus. The difference in mass is equivalent to the energy released. To obtain the energy released in MeV, we will use the fact that 1 u is equivalent to 931.5 MeV.

SOLUTION The mass decrease that accompanies the β^- decay of osmium ${}^{191}_{76}\text{Os}$ is 190.960 920 u − 190. 960 584 u = 3.36×10^{-4} u. Since 1 u is equivalent to 931.5 MeV, the energy released is

$$\text{Energy released} = \left(3.36\times10^{-4}\ \text{u}\right)\left(\frac{931.5\ \text{MeV}}{1\ \text{u}}\right) = \boxed{0.313\ \text{MeV}}$$

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21. $\boxed{\text{SSM}}$ ***REASONING AND SOLUTION*** The general form for β^- decay is

$$\underbrace{{}^{A}_{Z}\text{P}}_{\substack{\text{Parent}\\ \text{nucleus}}} \rightarrow \underbrace{{}^{A}_{Z+1}\text{D}}_{\substack{\text{Daughter}\\ \text{nucleus}}} + \underbrace{{}^{0}_{-1}\text{e}}_{\substack{\beta^-\ \text{particle}\\ \text{(electron)}}}$$

Therefore, the β^- decay process for ${}^{35}_{16}\text{S}$ is $\boxed{{}^{35}_{16}\text{S} \rightarrow {}^{35}_{17}\text{Cl} + {}^{0}_{-1}\text{e}}$.

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22. ***REASONING*** Since the released energy E is shared among the three particles, we know that

$$E = E_{\text{Daughter}} + E_{\text{Beta particle}} + E_{\text{Antineutrino}}$$

or

$$E_{\text{Antineutrino}} = E - E_{\text{Daughter}} - E_{\text{Beta particle}} \tag{1}$$

The value for $E_{\text{Beta particle}}$ is known. For a given value of E, $E_{\text{Antineutrino}}$ will have its maximum possible value when E_{Daughter} is zero.

The energy E released during the decay is related to the mass decrease Δm by $E = (\Delta m)c^2$ (Equation 28.5), where c is the speed of light in a vacuum. A mass decrease of one atomic mass unit (Δm = 1 u) corresponds to a released energy of 931.5 MeV.

SOLUTION We begin by calculating the decrease in mass for the decay process, which is shown as follows, along with the given atomic mass values: