12.A: Nuclear Physics (Answers)

Check Your Understanding

10.1. eight

10.2. harder

10.3. Half-life is inversely related to decay rate, so the half-life is short. Activity depends on both the number of decaying particles and the decay rate, so the activity can be great or small.

10.4. Neither; it stays the same.

10.5. the same

10.6. the conversion of mass to energy

10.7. power

Conceptual Questions

1. The nucleus of an atom is made of one or more nucleons. A nucleon refers to either a proton or neutron. A nuclide is a stable nucleus.

3. A bound system should have less mass than its components because of energy-mass equivalence $(E=mc^2)$. If the energy of a system is reduced, the total mass of the system is reduced. If two bricks are placed next to one another, the attraction between them is purely gravitational, assuming the bricks are electrically neutral. The gravitational force between the bricks is relatively small (compared to the strong nuclear force), so the mass defect is much too small to be observed. If the bricks are glued together with cement, the mass defect is likewise small because the electrical interactions between the electrons involved in the bonding are still relatively small.

5. Nucleons at the surface of a nucleus interact with fewer nucleons. This reduces the binding energy per nucleon, which is based on an average over all the nucleons in the nucleus.

7. That it is constant.

9. Gamma (**γ**) rays are produced by nuclear interactions and X-rays and light are produced by atomic interactions. Gamma rays are typically shorter wavelength than X-rays, and X-rays are shorter wavelength than light.

11. Assume a rectangular coordinate system with an **xy**-plane that corresponds to the plane of the paper. αα bends into the page (trajectory parabolic in the **xz**-plane); β^+ bends into the page (trajectory parabolic in the xz-plane); and γ is unbent.

13. Yes. An atomic bomb is a fission bomb, and a fission bomb occurs by splitting the **nucleus** of atom.

15. Short-range forces between nucleons in a nucleus are analogous to the forces between water molecules in a water droplet. In particular, the forces between nucleons at the surface of the nucleus produce a surface tension similar to that of a water droplet.

17. The nuclei produced in the fusion process have a larger binding energy per nucleon than the nuclei that are fused. That is, nuclear fusion decreases average energy of the nucleons in the system. The energy difference is carried away as radiation.

19. Alpha particles do not penetrate materials such as skin and clothes easily. (Recall that alpha radiation is barely able to pass through a thin sheet of paper.) However, when produce inside the body, neighboring cells are vulnerable.

Problems

21. Use the rule $A=Z+N$.

	Atomic Number (Z)	**Neutron Number (N)**	**Mass Number (A)**
(a)	29	29	58
(b)	11	13	24
(c)	84	126	210

(d)	20	25	45
(e)	82	124	206

23. a. $r = r_0 A^{1/3}, \rho = \frac{3u}{4\pi r_0^3}$;

b. $\rho = 2.3 \times 10^{17} kg/m^3$

25. side length =$1.6\mu m$

27. 92.4 MeV

29. $8.790 MeV \approx graph' svalue$

31. a. 7.570 MeV;

b. $7.591 MeV$ ≈graph's value

33. The decay constant is equal to the negative value of the slope or $10^{-9} s^{-1}$. The half-life of the nuclei, and thus the material, is $T_{1/2} = 693$ million years.

35. a. The decay constant is $\lambda = 1.99 \times 10^{-5} s^{-1}$

b. Since strontium-91 has an atomic mass of 90.90 g, the number of nuclei in a 1.00-g sample is initially

$N_0 = 6.63 \times 10^{21} nuclei$.

The initial activity for strontium-91 is

$A_0 = \lambda N_0 = 1.32 \times 10^{17} decays/s$

The activity at $t = 15.0\ h = 5.40 \times 10^4 s$ is

$A = 4.51 \times 10^{16} decays/s$.

37. $1.20 \times 10^{-2} mol; 6.00 \times 10^{-3} mol; 3.75 \times 10^{-4} mol$

39. a. 0.988 Ci;

b. The half-life of ^{226}Ra is more precisely known than it was when the Ci unit was established.

41. a. $2.73\mu g$;

b. $9.76 \times 10^4 Bq$

43. a. $7.46 \times 10^5 Bq$;

b. $7.75 \times 10^5 Bq$

45. a. 4.273 MeV;

b. 1.927×10^{-5};

c. Since ^{238}U is a slowly decaying substance, only a very small number of nuclei decay on human timescales; therefore, although those nuclei that decay lose a noticeable fraction of their mass, the change in the total mass of the sample is not detectable for a macroscopic sample.

47. a. $^{90}_{38}Sr_{52} \rightarrow ^{90}_{39} Y_{51} + \beta^{-1} + \bar{v_e}$;

b. 0.546 MeV

49. $^3_1H_2 \rightarrow ^3_2 He_1 + \beta^- + \bar{v_e}$

51. a. $^7_4Be + 3 + e^- \rightarrow ^7_3 Li_4 + v_e$;

b. 0.862 MeV

53. a. $X = ^{208}_{82} Pb_{126}$;

b. 33.05 MeV

55. a. 177.1 MeV;

b. This value is approximately equal to the average BEN for heavy nuclei.

c. $n+^{238}_{92}U_{146} \rightarrow^{96}_{38}Sr_{58}+^{140}_{54}Xe_{86}+3n$,

$A_i=239=A_f$,

$Z_i=92=38+54=Z_f$

57. a. 2.57×10^3MW;

b. 8.04×10^{19} fissions/s;

c. 991 kg

59. i. $^1_1H+^1_1H\rightarrow^2_1H+e^++v_e$

$A+i=1+1=2; A_f=2, Z_i=1+1=2;$

$Z_f=1+1=2$

ii. $^1_1H+^2_1H\rightarrow^3_2H+\gamma$

$A_i=1+2=3; A_f=3+0=3, Z_i=1+1=2$

$Z_E=1+1=2$;

iii. $^3_2H+^3_2H\rightarrow^4_2H+^1_1H+^1_1H$

$A_i=3+3=6; A_f=4+1+1=6, Z_i=2+2=4$

$Z_f=2+1+1=4$

61. 26.73 MeV

63. a. $3\times10^{38}protons/s$;

b. $6\times10^{14}neutrinos/m^2\cdot s$;

This huge number is indicative of how rarely a neutrino interacts, since large detectors observe very few per day.

65. a. The atomic mass of deuterium (^2H) is 2.014102 u, while that of tritium (^3H) is 3.016049 u, for a total of 5.032151 u per reaction. So a mole of reactants has a mass of 5.03 g, and in 1.00 kg, there are $(1000g)/(5.03g/mol)=198.8mol$of reactants. The number of reactions that take place is therefore

$$(198.8mol)(6.02\times10^{23}mol^{-1})=1.20\times10^{26}reactions.$$

The total energy output is the number of reactions times the energy per reaction:

$$E=3.37\times10^{14}J;$$

b. Power is energy per unit time. One year has 3.16×10^7s, so

$$P=10.7MW.$$

We expect nuclear processes to yield large amounts of energy, and this is certainly the case here. The energy output of $3.37\times10^{14}J$ from fusing 1.00 kg of deuterium and tritium is equivalent to 2.6 million gallons of gasoline and about eight times the energy output of the bomb that destroyed Hiroshima. Yet the average backyard swimming pool has about 6 kg of deuterium in it, so that fuel is plentiful if it can be utilized in a controlled manner.

67. \(\displaystyle G_y=\frac{Sv}{RBE}:

a. 0.01 Gy;

b. 0.0025 Gy;

c. 0.16 Gy

69. 1.24 MeV

71. 1.69 mm

73. For cancer: $(3rem)(\frac{10}{10^6 rem \cdot y}) = \frac{30}{10^6 y}$, The risk each year of dying from induced cancer is 30 in a million. For genetic defect: $(3rem)(\frac{3.3}{10^6 rem \cdot y}) = \frac{9.9}{10^6 y}$, The chance each year of an induced genetic defect is 10 in a million.

Additional Problems

75. atomic mass(Cl)=35.5g/mol

77. a. $1.71 \times 10^{58} kg$;

b. This mass is impossibly large; it is greater than the mass of the entire Milky Way galaxy.

c. ^{236}U is not produced through natural processes operating over long times on Earth, but through artificial processes in a nuclear reactor.

79. If 10 of rays are left after 2.00 cm, then only $(0.100)^2 = 0.01 = 1$ are left after 4.00 cm. This is much smaller than your lab partner's result (5).

81. a. $1.68 \times 10^{-5} Ci$;

(b) From Appendix B, the energy released per decay is 4.27 MeV, so $8.65 \times 10^{10} J$;

(c) The monetary value of the energy is $\$2.9 \times 10^3$

83. We know that $\lambda = 3.84 \times 10^{-12} s^{-1}$ and $A_0 = 0.25 decays/s \cdot g = 15 decays/min \cdot g$.

Thus, the age of the tomb is

$$t = -\frac{1}{3.84 \times 10^{-12} s^{-1}} ln \frac{10 decays/min \cdot g}{15 decays/min \cdot g} = 1.06 \times 10^{11} s \approx 3350 y .$$

Challenge Problems

85. a. $6.97 \times 10^{15} Bq$;

b. 6.24 kW;

c. 5.67 kW

87. a. Due to the leak, the pressure in the turbine chamber has dropped significantly. The pressure difference between the turbine chamber and steam condenser is now very low.

b. A large pressure difference is required for steam to pass through the turbine chamber and turn the turbine.

89. The energies are

$$E_\gamma = 20.6 MeV$$

$$E_{^4He} = 5.68 \times 10^{-2} MeV .$$

Notice that most of the energy goes to the γγ ray.
