Physics Unit 13: Fission, Fusion, and Radioactivity Review

1. Know about the three types of radiation, half-life, fission, fusion, nuclear reactors
2. Be able to write chemical equations for radioactivity (α, β^-, and γ), fission, and fusion.
3. Know the three types of radiation, what daughter products they make, and what is needed to block them.
4. What makes a nucleus radioactively stable?
5. Why is mass lost during radioactive decay?
6. Why does radioactivity happen?
7. How much energy is released in the α-decay of ^{242}Cm?
   Possible needed masses ^{242}Cm = 242.058829 u, ^{242}Am = 242.059547 u, ^{242}Bk = 242.061981 u, ^{238}Pu = 238.049553 u, ^{4}He = 4.002602 u, e^- = 0.000548 u, $\nu \approx 0$ u
8. How much energy is released in the β^-decay of ^{131}I?
   Possible needed masses ^{131}I = 130.906124 u, ^{131}Xe = 130.905082 u, ^{4}He = 4.002602 u, e^- = 0.000548 u, ν = 0 u.
9. An unknown element has a measured half-life of 5.00 hours. What is its decay constant?
10. If 11.0% of a radioactive element decays in 2.00 minutes. What is the half-live of the element?
11. What is the process of fission?
12. How does a fission reactor work?
13. Calculate the energy released in the fission reaction $n + {}^{233}_{92}U \rightarrow {}^{137}_{54}Xe + {}^{94}_{38}Sr + 3n$
    Masses: ^{233}U = 233.039628 u, ^{137}Xe = 136.911562 u, ^{94}Sr = 93.915359 u, n = 1.008664 u
14. How does a fusion reactor work?
15. What are the advantages of generating electricity from fusion vs fission?
16. Calculate the energy released in the fusion reaction ${}^{3}H3 + {}^{3}He \rightarrow {}^{4}He + {}^{1}H + {}^{1}H$
    Masses: ^{1}H = 1.007825 u, ^{2}H = 2.014102 u, ^{3}He = 3.01603 u, ^{4}He = 4.002602 u, me = 0.00054858 u, m$\nu \approx 0$ u.

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Answers

4. About the same number of neutrons as protons and a nucleus smaller than the effective range of the strong nuclear force.

5. Some of the mass is converted to energy by E = mc^2.

6. Radioactivity occurs to get a stable nucleus that is held together by the strong nuclear force.

7. ${}^{242}_{96}Cm \rightarrow {}^{238}_{94}Pu + {}^{4}_{2}He$

   $\Delta m = (242.058829\,u) - (238.049553\,u + 4.002602\,u) = 0.006674\,u$

   $$0.006674\,n\left(\frac{931.5\frac{MeV}{c^2}}{1\,u}\right) = 6.2168\frac{MeV}{c^2}$$

   $$E = mc^2 \rightarrow E = \left(6.2168\frac{MeV}{c^2}\right)c^2 \rightarrow E = \mathbf{6.22\ MeV}$$

8. ${}^{131}_{53}I \rightarrow {}^{131}_{54}Xe + \mathrm{e}^- + \nu$

   The mass of Xe has one more electron (54) in it than I (53), so subtract that out.

   $\Delta m = (130.906124\,u) - (130.905082\,u - 0.000548\,u + 0.000548\,u) = 0.001042\,u$

   $$0.001042\,n\left(\frac{931.5\frac{MeV}{c^2}}{1\,u}\right) = 0.970623\frac{MeV}{c^2}$$

   $$E = mc^2 \rightarrow E = \left(0.970623\frac{MeV}{c^2}\right)c^2 \rightarrow E = \mathbf{0.971\ MeV}$$

9. $\lambda = \frac{\ln(2)}{t_{\frac{1}{2}}} \rightarrow \lambda = \frac{\ln(2)}{5\,h} \rightarrow \lambda = \mathbf{0.138\frac{}{h}}$

10. If 11% decayed, then 100% − 11% = 89% is left

    $$N = N_0 e^{-\lambda t} \rightarrow \frac{N}{N_0} = e^{-\lambda t} \rightarrow 0.89 = e^{-\lambda(2.00\,min.)} \rightarrow \ln(0.89) = -\lambda(2.00\,min.) \rightarrow \lambda = 0.05827\frac{}{min}$$

    $$\lambda = \frac{\ln(2)}{t_{\frac{1}{2}}} \rightarrow t_{\frac{1}{2}} = \frac{\ln(2)}{\lambda} \rightarrow t_{\frac{1}{2}} = \frac{\ln(2)}{0.05827\frac{}{min}} \rightarrow t_{\frac{1}{2}} = \mathbf{11.9\ min}$$

11. Hit a large nucleus with a neutron (from a β⁻ decay). That splits the nucleus into two smaller pieces and releases several more neutrons. Those hit more large nuclei splitting those and releasing more neutrons.

12. The fissible material (usually uranium) is in the reactor and forms a fission chain reaction. This is slowed by control rods and water absorbing the excess neutrons formed from the fission. The energy released heat water into steam which turns turbines and makes electricity.

13. $n + {}^{233}_{92}U \rightarrow {}^{137}_{54}Xe + {}^{94}_{38}Sr + 3n$

    $\Delta m = (1.008664\,u + 233.039628\,u) - \big(136.911562\,u + 93.915359\,u + 3(1.008664\,u)\big) = 0.195379\,u$

    $$0.195379\,n\left(\frac{931.5\frac{MeV}{c^2}}{1\,u}\right) = 181.996\frac{MeV}{c^2}$$

    $$E = mc^2 \rightarrow E = \left(181.996\frac{MeV}{c^2}\right)c^2 \rightarrow E = \mathbf{182\ MeV}$$

14. Deuterium and tritium injected into vessel with high temperature and pressure. EM field turns hydrogen into plasma. Hydrogen fuses into helium releasing neutrons. They strike the sides of the vessel creating heat. The heat turns water into steam. The steam turns a turbine to generate electricity.

15. Fusion has plentiful fuel, products are safe, and more energy is released.

16. ${}^{3}_{}H3 + {}^{3}_{}He \rightarrow {}^{4}_{}He + {}^{1}_{}H + {}^{1}_{}H$

    $\Delta m = (3.01603\,u + 3.01603\,u) - (4.002602\,u + 1.007825\,u + 1.007825) = 0.013808\,u$

    $$0.013808\,n\left(\frac{931.5\frac{MeV}{c^2}}{1\,u}\right) = 12.9\ \frac{MeV}{c^2}$$

    $$E = mc^2 \rightarrow E = \left(12.9\frac{MeV}{c^2}\right)c^2 \rightarrow E = \mathbf{12.9\ MeV}$$