Mr. Wright's Math
Extravaganza

Physical Sciences

(Chemistry, Physics, Physical Science)

Fission, Fusion, and Radioactive Decay

Unit 13 Radioactivity, Fission, Fusion

Level 2.0: 70% on test, Level 3.0: 80% on test, Level 4.0: level 3.0 and success on mass-energy lab

Score	I Can Statements
4.0	☐ I can investigate the amounts of energy released or mass converted by fission, fusion, and radioactive decay using the mass-energy equivalence formula and given values for either mass or energy.
3.5	In addition to score 3.0 performance, partial success at score 4.0 content
3.0	☐ I can explain how changes in the composition of an atom's nucleus during radioactive decay release energy. ☐ I can explain how changes in the composition of an atom's nucleus during fission release energy. ☐ I can explain how changes in the composition of an atom's nucleus during fusion release energy.
2.5	No major errors or omissions regarding score 2.0 content, and partial success at score 3.0 content
2.0	☐ I can describe the end goal or radioactivity and how the time frame to achieve transmutation differs according to an element's half-life. ☐ I can explain why mass is lost during radioactive decay using the mass-energy equivalence formula. ☐ I can List the types of radiation, the products they produce, and each of the products' strength. ☐ I can use appropriate notation to write balanced chemical equations using the periodic table and knowledge of the products of various types of radiation. ☐ I can state that atoms always prefer a more stable form when possible. ☐ I can explain why elements with larger nuclei are less stable and therefore more fissile. ☐ I can describe the process used to split an unstable nucleus. ☐ I can relate mass defect, nuclear binding energy, and the mass-energy equivalence formula to the energy released when a nucleus undergoes nuclear fission. ☐ I can use appropriate notation to write balanced chemical equations representing the process of nuclear fission. ☐ I can describe the process used to combine multiple nuclei. ☐ I can explain why extreme circumstances (high temperatures or pressure) are needed for nuclear fusion to occur. ☐ I can relate mass defect, nuclear binding energy, and the mass-energy equivalence formula to the energy released when a nucleus undergoes nuclear fusion. ☐ I can use appropriate notation to write balanced chemical equations representing the process of nuclear fusion.
1.5	Partial success at score 2.0 content, and major errors or omissions regarding score 3.0 content.
1.0	With help, partial success at score 2.0 content and score 3.0 content.
0.5	With help, partial success at score 2.0 content but not at score 3.0 content.
0.0	Even with help, no success.

Physics 13-01 Radioactivity **Name:** ______________

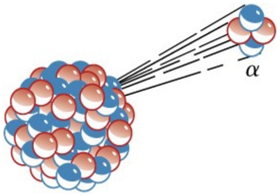
Structure of the atom

- Rutherford's Experiment
  - Shot ___________ at thin ___________foil
  - Expected to pass mostly straight though with ___________scattering
  - Most passed straight through without scattering; Some scattered ___________ – even straight back
  - Showed the nucleus was very ___________and much ___________space around it
  - Planetary model of the atom: Nucleus like _________, Electrons like ___________, Electrical force like ___________
- Nucleus
  - Contains ___________and ___________
- Atomic mass unit (u)
  - Neutral carbon-12 = 12 u
  - C-12 has 6 protons, 6 neutrons
  - Proton and neutrons = ___________
  - 1 u = ___________ MeV/c^2

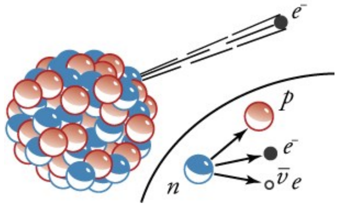
6
C
12.011

- Atomic Number (Z)
  - Number of ___________ in nucleus
  - Determines the ___________
- Mass Number (A)
  - Number of ___________and ___________
- Isotopes
  - Same element can have different number of ___________
  - ${}^{A}_{Z}X$ or ${}^{A}X$
  - Then number of neutrons changes behavior of ___________
- Strong nuclear force
  - Holds ___________together
  - Acts at distance less than ___________
- Electric forces try to ___________nucleus apart
  - When electric forces are more than strong nuclear force, nuclear particles are ejected from nucleus – ___________
- Nucleus wants
  - About ___________number of protons and neutrons
  - Smaller radius than strong ___________force

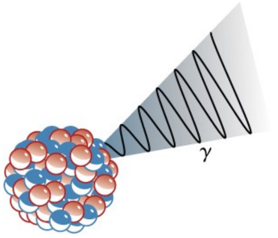
Types of Radioactivity



- Alpha Decay (α)
  - Most ___________decay type
  - Happens when too many ___________in nucleus
  - Nucleus ejects ___________ and ___________ (___________nucleus)
  - ${}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}\text{He} \quad \rightarrow \quad {}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^{4}_{2}\text{He}$
  - During α-decay, the atomic number changes and one element ___________into another
    - The α-particle quickly gains two electrons and becomes a stable ___________atom
    - The total number of ___________stays the same
      - Law of Conservation of ___________and ___________
        - Any change in mass is converted to energy by _______
      - Law of Conservation of ___________



- Beta decay (β)
  - Imbalance of ___________and ___________
  - A neutron ___________into a ___________and ___________or vice versa
  - ${}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + e^- + \nu \quad \rightarrow \quad {}^{14}_{6}C \rightarrow {}^{14}_{7}N + \nu + e^-$
    - e is ___________, ν is ___________



- Gamma decay (γ)
  - Occurs when nucleus drops from ___________state to ground state releasing energy as a photon
  - ${}^{A}_{Z}X \rightarrow {}^{A}_{Z}X + \gamma \quad \rightarrow \quad {}^{137}_{56}Ba \rightarrow {}^{137}_{56}Ba + \gamma$

Physics 13-01 Radioactivity **Name: ______________**

- α-particles are massive (4 u) and have +2 charge, so they quickly interact with matter and can be stopped quickly
    - ________________________, ____________ of air, ________________________ of tissue
- β-particles are smaller (mass of e) and −1 charge, so they penetrate farther
    - ________________________ plate, _______________ of tissue
- γ-particles have no mass or charge and barely interact with matter, so they penetrate very far
    - ________________ of lead, ____________of concrete

Write the complete decay equation in $^{A}_{Z}X$ notation for beta decay producing $^{60}_{28}\text{Ni}$. Refer to the periodic table for values of Z.

Find the energy emitted in the α decay of $^{226}_{\square}\text{Ra}$.

Practice Work

1. What leads scientists to infer that the nuclear strong force exists? (HSP C22.2)
2. What influence does the strong nuclear force have on the electrons in an atom? (HSP 22.10)
3. What is the source of the energy emitted in radioactive decay? Identify an earlier conservation law, and describe how it was modified to take such processes into account. (OpenStax C31.5)
4. Explain why an alpha particle can have a greater range in air than a beta particle in lead. (OpenStax C31.7)
5. Arrange the following according to their ability to act as radiation shields, with the best first and worst last. Explain your ordering in terms of how radiation loses its energy in matter.
   (a) A solid material with low density composed of low-mass atoms.
   (b) A gas composed of high-mass atoms.
   (c) A gas composed of low-mass atoms.
   (d) A solid with high density composed of high-mass atoms. (OpenStax C31.8)
6. Often, when people have to work around radioactive materials spills, we see them wearing white coveralls (usually a plastic material). What types of radiation (if any) do you think these suits protect the worker from, and how? (OpenStax C31.9)
7. The weak and strong nuclear forces are basic to the structure of matter. Why do we not experience them directly? (OpenStax C31.11)
8. What are isotopes? Why do different isotopes of the same element have similar chemistries? (OpenStax C31.13)

In the following eight problems, write the complete decay equation for the given nuclide in the complete $^{A}_{Z}X$ notation. Refer to the periodic table for values of Z.

9. β^{-} decay of $^{3}_{\square}H$ (tritium), a manufactured isotope of hydrogen used in some digital watch displays and manufactured primarily for use in hydrogen bombs. (OpenStax 31.17) $\boldsymbol{^{3}_{1}H \rightarrow {}^{3}_{2}He + e^{-} + \nu}$
10. β^{-} decay of $^{40}_{\square}K$, a naturally occurring rare isotope of potassium responsible for some of our exposure to background radiation. (OpenStax 31.18) $\boldsymbol{^{40}_{19}K \rightarrow {}^{40}_{20}Ca + e^{-} + \nu}$
11. α decay of $^{210}_{\square}Po$, the isotope of polonium in the decay series of $^{238}_{\square}U$ that was discovered by the Curies. A favorite isotope in physics labs, since it has a short half-life and decays to a stable nuclide. (OpenStax 31.23) $\boldsymbol{^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He}$
12. α decay of $^{226}_{\square}Ra$, another isotope in the decay series of $^{238}_{\square}U$, first recognized as a new element by the Curies. Poses special problems because its daughter is a radioactive noble gas. (OpenStax 31.24) $\boldsymbol{^{226}_{88}Ra \rightarrow {}^{222}_{86}Rn + {}^{4}_{2}He}$

Physics 13-01 Radioactivity *Name:* ______________

In the following four problems, identify the parent nuclide and write the complete decay equation in the ${}^{A}_{Z}X$notation. Refer to the periodic table for values of Z.

13. β^- decay producing ${}^{137}_{\square}Ba$. The parent nuclide is a major waste product of reactors and has chemistry similar to potassium and sodium, resulting in its concentration in your cells if ingested. (OpenStax 31.25) $\boldsymbol{{}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + e^- + \nu}$

14. β^- decay producing ${}^{90}_{\square}Y$. The parent nuclide is a major waste product of reactors and has chemistry similar to calcium, so that it is concentrated in bones if ingested (${}^{90}_{\square}Y$ is also radioactive.) (OpenStax 31.26) $\boldsymbol{{}^{90}_{38}Sr \rightarrow {}^{90}_{39}Y + e^- + \nu}$

15. α decay producing ${}^{228}_{\square}Ra$. The parent nuclide is nearly 100% of the natural element and is found in gas lantern mantles and in metal alloys used in jets (${}^{228}_{\square}Ra$ is also radioactive). (OpenStax 31.27) $\boldsymbol{{}^{232}_{90}Th \rightarrow {}^{228}_{88}Ra + {}^{4}_{2}He}$

16. α decay producing ${}^{208}_{\square}Pb$. The parent nuclide is in the decay series produced by ${}^{232}_{\square}Th$, the only naturally occurring isotope of thorium. (OpenStax 31.28) $\boldsymbol{{}^{212}_{84}Pa \rightarrow {}^{208}_{82}Pb + {}^{4}_{2}He}$

17. (a) Write the complete α decay equation for ${}^{226}_{\square}Ra$. (b) Find the energy released in the decay. (${}^{226}_{88}Ra = 226.025402\ u$, ${}^{222}_{86}Rn = 222.0175763\ u$, ${}^{4}_{2}He = 4.002602\ u$(OpenStax 31.35) **4.87 MeV**

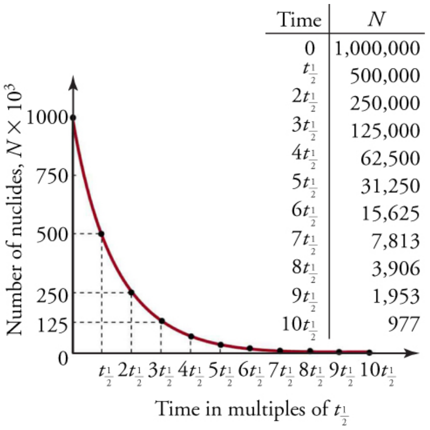
18. (a) Write the complete α decay equation for ${}^{249}_{\square}Cf$. (b) Find the energy released in the decay. (${}^{249}_{98}Cf = 249.074844\ u$, ${}^{245}_{96}Cm = 245.058830\ u$, ${}^{4}_{2}He = 4.002602\ u$)(OpenStax 31.36) **12.5 MeV**

19. (a) Write the complete β^- decay equation for the neutron. (b) Find the energy released in the decay. (${}^{1}_{0}n = 1.008664915\ u$, ${}^{1}_{1}H = 1.007276466\ u$, $e^- = 0.000548579\ u$, $\nu \approx 0\ u$) (OpenStax 31.37) **0.7823 MeV**

20. (a) Write the complete β^- decay equation for ${}^{90}_{\square}Sr$, a major waste product of nuclear reactors. (b) Find the energy released in the decay. (${}^{90}_{38}Sr = 89.9077279\ u$, ${}^{90}_{39}Y = 89.9071519\ u$, e^- =included in the mass of Y, $\nu \approx 0\ u$) (OpenStax 31.38) **0.537 MeV**

Physics 13-02 Radiometric Dating **Name:** _______________

Half-Life



Time	N
0	1,000,000
$t_{\frac{1}{2}}$	500,000
$2t_{\frac{1}{2}}$	250,000
$3t_{\frac{1}{2}}$	125,000
$4t_{\frac{1}{2}}$	62,500
$5t_{\frac{1}{2}}$	31,250
$6t_{\frac{1}{2}}$	15,625
$7t_{\frac{1}{2}}$	7,813
$8t_{\frac{1}{2}}$	3,906
$9t_{\frac{1}{2}}$	1,953
$10t_{\frac{1}{2}}$	977

- Measures _____________of radioactive decay
- One half-life is time it takes for _____________ of the nuclei to _____________
- Assumed to be _____________for each isotope

$$N = N_0 e^{-\lambda t}$$

- Where N is number of _____________at time _____________, N_0 is # of nuclei at time _____________, λ is the _____________constant

$$\lambda = \frac{\ln(2)}{t_{1/2}}$$

Radioactive Dating

- Method used to date _____________
- Assumptions
    - Amount of _____________material known
    - No radioactive material _____________or _____________the mineral
    - No new radioactive material _____________by other sources such as _____________rays or other radioactive reactions
    - Decay rate is _____________

Carbon-14 has a half-life of 5730 years. If there was originally 20 grams, but only 15 grams remains. How much time elapsed?

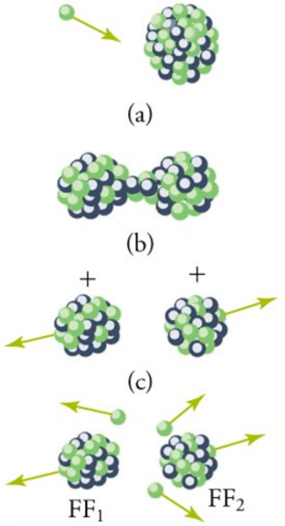
What is the half-life of technetium-99 if 20% decays in about 488000 years?

Physics 13-02 Radiometric Dating	***Name:*** ______________
Practice Work	

1. Radioactivity depends on the nucleus and not the atom or its chemical state. Why, then, is one kilogram of uranium more radioactive than one kilogram of uranium hexafluoride? (OpenStax C31.20)A sample of radioactive material has a decay constant of 0.05 s^{-1}. Why is it wrong to presume that the sample will take just 20 seconds to fully decay? (HSP 22.12)
3. How would some of the daughter products being removed from a mineral change the apparent age with radiometric dating? (RW)
4. How would extra parent isotopes being created affect the apparent age with radiometric dating? (RW)
5. If the decay rate used to be faster than it is today, how would that affect the apparent age with radiometric dating? (RW)
6. Americium-241 is used in smoke detectors and has a half life of 432.2 years. If a new smoke detector has $2.00 \times 10^{-4}\ g$ of Americium-241, how much will it still have 100 years later? (RW) $\mathbf{1.71 \times 10^{-4}\ g}$
7. Technetium-99m is used in imaging in medicine and has a half life of 6.02 hours. If 0.100 μg were injected into a person, how much is left after 24 hours? (RW) $\mathbf{6.31 \times 10^{-9}\ g}$
8. Carbon-14 is used in radiocarbon dating and has a half life of 5730 years. What percentage of C-14 should be left after 2000 years? (RW) **78.5%**
9. Potassium-40 is sometimes used to date rocks. It is assumed to have a half-life of 1.25 billion years. What percentage of will be left after 1 million years? (RW) **99.9%**
10. What is the half-life of an unknown isotope if 0.015% of it decays in 2.0 years? (RW) **9240 y**
11. What is the half life of Indium-113m if 28.5% of it remains after 3.0 hours? (RW) **1.66 h**
12. What is the half life of Iodine-131 if 28.5% of it remains after 1.2 days? (RW) **8.06 d**

Physics 13-03 Nuclear Fission — *Name:* ______________

Fission

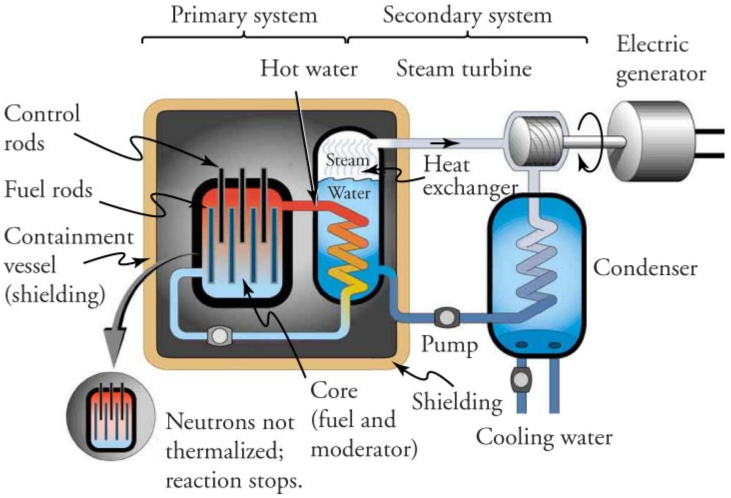


- ____________of a nucleus
- Releases a lot of ____________
- An unstable nucleus can naturally decay with α or β radiation, but can take a long time
- ____________done by hitting a large nucleus with a ____________(β radiation)

Chain reaction

- When the nucleus splits it releases free ____________
- Those can ____________other nuclei and ____________them
- Critical mass – Minimum amount of ____________material necessary to sustain fission ____________reaction
- Number of fission reactions increases ____________

Nuclear Reactor



- To keep a nuclear fission reaction from becoming a __________, slow down the neutrons with _________
- Fuel rods contain ____________
- Control rods ____________neutrons
  - Insert control rods to ____________reaction
- Fission reaction ____________water
- Steam turns turbines to make ____________
- ____________water goes back to be heated

Energy from Fission

- The mass of the products of fission is ____________ than parent nucleus
- That mass is converted to ____________by $E = mc^2$
- Average fission reaction produces about ____________MeV of energy

Find the energy released in the fission of uranium-235 given in the equation

$$^{1}_{0}n + ^{235}_{92}U \rightarrow ^{141}_{56}Ba + ^{92}_{36}Kr + 3\ ^{1}_{0}n$$

Neutron: 1.008665 u, ^{235}U: 235.0439299 u, ^{141}Ba: 140.9144035 u, ^{92}Kr: 91.926173094 u

Physics 13-03 Nuclear Fission *Name:* ______________

Calculate the amount of energy produced by the fission of 1.00 kg of 239Pu, given the average fission reaction of ^{239}Pu produces 211.5 MeV. The atomic mass of ^{239}Pu is 239.05 u.

Practice Work

1. How can a nuclear reactor contain many critical masses and not go supercritical? What methods are used to control the fission in the reactor? (OpenStax C32.23)
2. If a nucleus elongates due to a neutron strike, which of the following forces will decrease? (HSP 22.20)
   (a) Nuclear force between neutrons only
   (b) Coulomb force between protons only
   (c) Strong nuclear force between all nucleons and Coulomb force between protons, but the strong force will decrease more
   (d) Strong nuclear force between neutrons and Coulomb force between protons, but Coulomb force will decrease more
3. (a) Calculate the energy released in the neutron-induced fission (similar to the spontaneous fission in Example 32.3) $n + {}^{238}U \rightarrow {}^{96}Sr + {}^{140}Xe + 3n$, given $m({}^{238}U) = 238.050783\ u$, $m({}^{96}Sr) = 95.921750\ u$ and $m({}^{140}Xe) = 139.92164\ u$. (b) This result is about 6 MeV greater than the result for spontaneous fission. Why? (c) Confirm that the total number of nucleons and total charge are conserved in this reaction. (OpenStax 32.43) **177.0 MeV; 239 nucleons, 92 + charges**
4. (a) Calculate the energy released in the neutron-induced fission reaction $n + {}^{235}U \rightarrow {}^{92}Kr + {}^{142}Ba + 2n$, given $m({}^{235}U) = 235.043923\ u$, $m({}^{92}Kr) = 91.926269\ u$ and $m({}^{142}Ba) = 141.916361\ u$. (b) Confirm that the total number of nucleons and total charge are conserved in this reaction. (OpenStax 32.44) **179.4 MeV; 236 nucleons, 92 + charges**
5. (a) Calculate the energy released in the neutron-induced fission reaction $n + {}^{239}Pu \rightarrow {}^{96}Sr + {}^{140}Ba + 4n$, given $m({}^{239}Pu) = 239.0521634\ u$, $m({}^{96}Sr) = 95.921750\ u$ and $m({}^{140}Ba) = 139.910581\ u$. (b) Confirm that the total number of nucleons and total charge are conserved in this reaction. (OpenStax 32.45) **180.6 MeV; 240 nucleons, 94 + charges**
6. The naturally occurring radioactive isotope ${}^{232}Th$ does not make good fission fuel, because it has an even number of neutrons; however, it can be bred into a suitable fuel (much as is bred into ${}^{239}U$). (a) What are Z and N for ${}^{232}Th$? (b) Write the reaction equation for neutron captured by ${}^{232}Th$ and identify the nuclide ${}^{A}X$ produced in $n + {}^{232}Th \rightarrow {}^{A}X + \gamma$. (c) The product nucleus β^- decays, as does its daughter. Write the decay equations for each, and identify the final nucleus. (d) Confirm that the final nucleus has an odd number of neutrons, making it a better fission fuel. (e) Look up the half-life of the final nucleus to see if it lives long enough to be a useful fuel. (OpenStax 23.48) ***Z* = 90, *N* = 142; Thorium; Daughters are ^{233}Pa and ^{233}U; 141 neutrons; 160000 yrs**
7. The electrical power output of a large nuclear reactor facility is 900 MW. It has a 35.0% efficiency in converting nuclear power to electrical. (a) What is the thermal nuclear power output in megawatts? (b) How many ${}^{235}U$ nuclei fission each second, assuming the average fission produces 200 MeV? (c) What mass of ${}^{235}U$ is fissioned in one year of full-power operation? (OpenStax 32.49) **2570 MW; $\mathbf{8.04 \times 10^{19}}$ fissions/s; 990 kg**

Physics 13-04 Nuclear Fusion *Name: ______________*

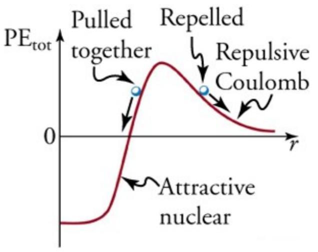
Fusion

- Combining ____________nuclei into one
- Releases a lot of ____________
- Fission ____________apart large nucleus
- Fusion ____________small nuclei

For nuclei less than iron,

- Nuclear forces holding the nucleus ____________are stronger than the electrical force pushing it ____________
- Strong nuclear force does ____________when adding more nucleons to small nuclei releasing energy
- For elements higher than iron, energy must be ____________for fusion
  - Stars can only create elements up to ____________
  - There is debate amongst atheists about where heavier elements come from

Why fusion is difficult



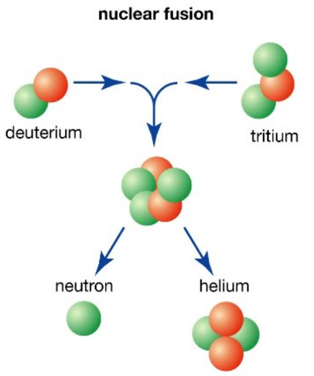
- The parent products must have enough ____________energy to overcome the ____________force forcing the positive protons apart
  - Use high ____________to make the KE
- Once the parent elements are close enough the ____________nuclear force does work pulling the pieces together into one nucleus releasing ____________

Process to combine H to make He

- $^1H + {^1H} \rightarrow {^2H} + e^+ + \nu_e + 0.42$ MeV (×2)
- $^1H + {^2H} \rightarrow {^3He} + \gamma + 5.49$ MeV (×2)
- $^3He + {^3He} \rightarrow {^4He} + {^1H} + {^1H} + 12.86$ MeV

Overall cycle

- $2e^- + 4\,{^1H} \rightarrow 4\,{^4He} + 2\nu_e + 6\gamma + 26.7$ MeV



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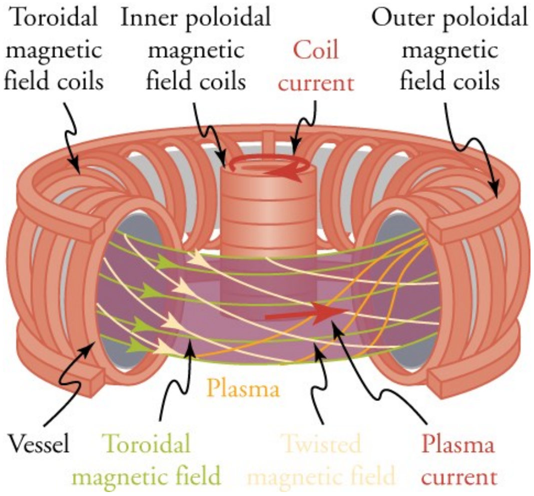
Fusion Reactor

- Better than ____________
  - Plentiful ____________
  - Products are ____________
  - More energy ____________
- Deuterium and tritium injected into vessel with high ____________and ____________
- EM field turn the hydrogen into ____________
- H fuses into He
- High-velocity neutrons released are ________________by EM field
- Neutrons strike sides of vessel creating heat, makes _________, turns turbine



How much energy is released from the fusion of 1.00 kg of hydrogen?

Physics 13-04 Nuclear Fusion **Name: ______________**

Practice Work

1. Why does the fusion of light nuclei into heavier nuclei release energy? (OpenStax C32.14)
2. Aside from energy yield, why are nuclear fusion reactors more desirable than nuclear fission reactors? (HSP 22.3)
   a. Nuclear fusion reactors have a low installation cost.
   b. Radioactive waste is greater for a fusion reactor.
   c. Nuclear fusion reactors are easy to design and build.
   d. A fusion reactor produces less radioactive waste.
3. Why are large electromagnets necessary in nuclear fusion reactors? (HSP 22.14)
   a. Electromagnets are used to slow down the movement of charge hydrogen plasma.
   b. Electromagnets are used to decrease the temperature of hydrogen plasma.
   c. Electromagnets are used to confine the hydrogen plasma.
   d. Electromagnets are used to stabilize the temperature of the hydrogen plasma.
4. Describe the potential energy of two nuclei as they approach each other. (HSP 22.29)
   a. The potential energy will decrease as the nuclei are brought together and then rapidly increase once a minimum is reached.
   b. The potential energy will decrease as the nuclei are brought together.
   c. The potential energy will increase as the nuclei are brought together.
   d. The potential energy will increase as the nuclei are brought together and then rapidly decrease once a maximum is reached.
5. Verify that the total number of nucleons, and total charge are conserved for each of the fusion reactions in the proton-proton cycle in ${}^{1}_{}H + {}^{1}_{}H \rightarrow {}^{2}_{}H + e^{+} + \nu_e$, ${}^{1}_{}H + {}^{2}_{}H \rightarrow {}^{3}_{}He + \gamma$, and ${}^{3}_{}He + {}^{3}_{}He \rightarrow {}^{4}_{}He + {}^{1}_{}H + {}^{1}_{}H$. (List the value of each of the conserved quantities before and after each of the reactions.) (OpenStax 32.26)
6. Calculate the energy output in each of the fusion reactions in the proton-proton cycle, and verify the values given in the above summary. ($m\left({}^{1}_{}H\right) = 1.007825\ u, m\left({}^{2}_{}H\right) = 2.014102\ u, m\left({}^{3}_{}He\right) = 3.016030\ u, m\left({}^{4}_{}He\right) = 4.002602\ u, m(e^{+}) = 0.00054858\ u, m(\nu_e) \approx 0$) (OpenStax 32.27) $\boldsymbol{0.420\ MeV, 5.49\ MeV, 12.86\ MeV}$
7. The energy produced by the fusion of a 1.00-kg mixture of deuterium and tritium was found to be $3.37 \times 10^{14}\ J$ in the Example Calculating Energy and Power from Fusion. Approximately how many kilograms would be required to supply the annual energy use in the United States of $1.05 \times 10^{20}\ J$? (OpenStax 32.30) $\boldsymbol{3.11 \times 10^{5}\ kg}$
8. Tritium is naturally rare, but can be produced by the reaction $n + {}^{2}_{}H \rightarrow {}^{3}_{}H + \gamma$. How much energy in MeV is released in this neutron capture? ($m(n) = 1.008664\ u, m\left({}^{2}_{}H\right) = 2.014102\ u, m\left({}^{3}_{}He\right) = 3.016030\ u$) (OpenStax 32.31) $\boldsymbol{6.27\ MeV}$
9. Two fusion reactions mentioned in the text are $n + {}^{3}_{}He \rightarrow {}^{4}_{}He + \gamma$ and $n + {}^{1}_{}H \rightarrow {}^{2}_{}H + \gamma$. Both reactions release energy, but the second also creates more fuel. Confirm that the energies produced in the reactions are 20.58 and 2.22 MeV, respectively. Comment on which product nuclide is most tightly bound, ${}^{4}_{}He$ or ${}^{2}_{}H$. (OpenStax 32.32) $\boldsymbol{20.58\ MeV, 2.22\ MeV; {}^{4}_{}He}$
10. The power output of the Sun is $4 \times 10^{26}\ W$. (a) If 90% of this is supplied by the proton-proton cycle, how many protons are consumed per second? (OpenStax 23.35) $\boldsymbol{3 \times 10^{38}\ protons}$

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, $\nu = 0$ 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.

Physics Unit 13: Fission, Fusion, and Radioactivity Review

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

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

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

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

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.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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