Physics 13-04 Nuclear Fusion Name: _______________

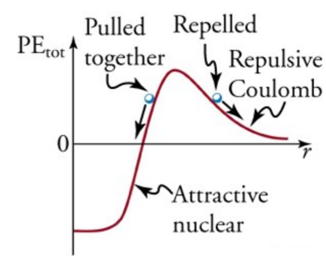
Fusion

- 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



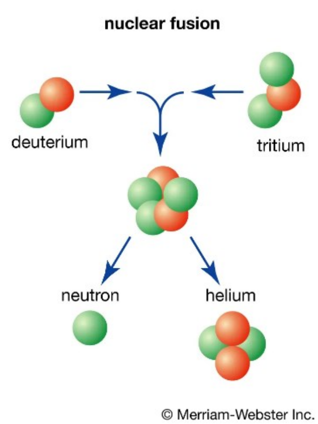
- The parent products must have enough ____________energy to overcome the ____________force forcing the positive protons apart
    - Use high ____________to make the KE
- Once the parent elements are close enough the ____________nuclear force does work pulling the pieces together into one nucleus releasing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

Process to combine H to make He

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

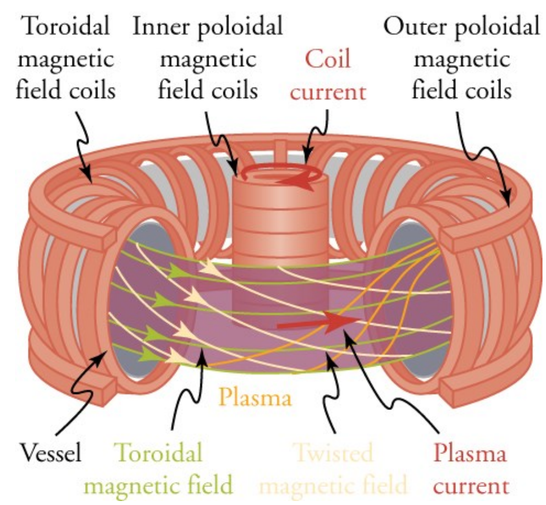
Overall cycle

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



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. ($m({}^{1}H) = 1.007825\ u, m({}^{2}H) = 2.014102\ u, m({}^{3}He) = 3.016030\ u, m({}^{4}He) = 4.002602\ u, m(e^{+}) = 0.00054858\ u, m(\nu_e) \approx 0$) (OpenStax 32.27) $\mathbf{0.420\ MeV, 5.49\ MeV, 12.86\ MeV}$
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) $\mathbf{3.11 \times 10^{5}\ kg}$
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? ($m(n) = 1.008664\ u, m({}^{2}H) = 2.014102\ u, m({}^{3}He) = 3.016030\ u$) (OpenStax 32.31) $\mathbf{6.27\ MeV}$
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) $\mathbf{20.58\ MeV, 2.22\ MeV; {}^{4}He}$
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) $\mathbf{3 \times 10^{38}\ protons}$