Boston Area QuarkNet

2022 Summer Workshop: Fusion

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**UNITS REVIEW** \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 Name

 1 therm = 105 BTU = 2.52 x 107 calorie = 1.055 x 108 J = 29.3 kWh

 1 Da = 1 u = 1.66 x 10-27 kg = 0.9315 GeV/*c*2

**Energy Sources and the Sun**

1. **Chemical Energy – Heat of Combustion**

Burning hydrogen gas in oxygen produces 286 kJ/mol H2 or 142 MJ/kg H atoms

1. Calculate the energy released per H atom (in eV/H atom) for burning in oxygen.
2. If the Sun (*m*S = 2 x 1030 kg) were made of 2 x 1029 kg of H2 and 16 x 1029 kg of O2 and
2 x 1029 kg of inert materials, calculate the energy that could be produced by the reaction H2 + (1/2) O2 → H2O .
3. The Sun’s luminosity is *L*S = 3.85 x 1026 J/s . If the luminosity were produced by
H2 + (1/2) O2 → H2O at a constant rate of burning, how many years would the energy calculated in (b) last?

2. **Nuclear Energy – Radioactive Decay**

Most of the uranium on Earth (99.3%) is U-238, which decays via a-emission in the process

 $\rightarrow $ .

The relative nuclear masses (no electrons) for He adapted from the National Institute of Standards and Technology website, <http://www.physics.nist.gov> , and for heavier isotopes adapted from Lawrence Berkeley Laboratory website, <http://t2.lanl.gov/data/map.html> , are

*m*U238 = 238.001451 u , *m*Th234 = 233.995366 u , *m*α = *m*He4 = 4.001506 u ,

1. Calculate the energy released in the decay of one U-238 atom in MeV units.
2. If the Sun (*m*S = 2 x 1030 kg) were made of U-238, how many uranium atoms would it contain?
3. Recall that for radioactive decay the number (*N*) of atoms remaining at a later time (*t*) after *t* = 0 is given by $N=N\_{0}e^{-t/τ}$ , where *N*0 is the number of atoms at *t* = 0 and *t* is the mean lifetime of the radioactive atoms. U-238 has a half-life of *t*1/2 = 1.41 x 1017 s
(4.5 x 109 years). Show that *t* = 2.03 x 1017 s.
4. Calculate the rate of energy production if the Sun were made of U-238 and compare that with the Sun’s measured luminosity, *L*S = 3.85 x 1026 J/s.

3. **Nuclear Energy – Fission**

 A typical fission reaction is $++2$
 D*E* = 184.3 MeV/U-235 nucleus.

1. If the Sun (*m*S = 2 x 1030 kg) were made of U-235, how many atoms would it contain?
2. If the Sun’s luminosity were due to a controlled fission of U-235, how long would it shine at its present luminosity, *L*S = 3.85 x 1026 J/s, (in seconds and years)?
3. Apparently, the Sun’s luminosity and lifetime can be accounted for by U-235 fission. What arguments and evidence indicate that U-235 fission is not the mechanism that powers the Sun?

4. **Nuclear Energy – Fusion**

Arthur Eddington in “The Internal Constitution of the Stars” (1920) was the first to speculate that stars, including the Sun, were powered by hydrogen fusing to helium. In 1938 Hans Bethe provided a workable series of nuclear reactions (pp cycle) that could produce the Sun’s luminosity from hydrogen fusion to helium and another series of reactions (CNO cycle) that could produce the luminosity of stars with larger mass that the Sun. A simplified version of the pp cycle follows.

$2(+)\rightarrow 2(+e^{+}+ν\_{e})$ D = deuterium (1)

$2(+)\rightarrow 2(+γ$) T = tritium (2)

$+\rightarrow ++$ (3)

The electron neutrino (ne) in equation (1) escapes. The positron (e+) in equation (1) annihilates with an electron to produce gamma ray photons (g). The net result of the reactions is to produce a helium nucleus (a particle) from four protons with the liberation of energy.

1. The proton mass is *m*p = 1.007276 u. The mass of an a particle is *m*a = 4.001506 u.
Calculate the energy (MeV) produced in the formation of one a particle in the above reactions.
2. The Sun’s mass (*m*S = 2 x 1030 kg) consists of about 73% H, 25% He, and 2 % heavier elements by mass. Calculate the number of H nuclei in the Sun.
3. If hydrogen fusion in the Sun’s core (central 10% of Sun’s mass) produces the Sun’s energy, how much longer (seconds and years) could the Sun shine at its current luminosity, *L*S = 3.85 x 1026 J/s?