Phys 102 Astronomy

Name Solution

POWER FROM FUSION

THE ENERGY OF FUSION

The masses of subatomic particles are given in atomic mass units, amu's or u's where

$1\ u = 1.6605 \times 10^{-27}\ kg.$

Do the following subtraction to find how much mass is "lost" when 4 hydrogen atoms fuse to one helium:[2]

m_H	=	1.007825 u	x 4	:	4.031300 u
m_{He}	=	4.002603 u	x 1	:	− 4.002603 u

$(4.0313)(1.6605\times10^{-27}) = 6.69397\times10^{-27}$

mass "lost" in fusion = 0.028697 u

fraction of H mass "lost" in fusion $\left(\frac{m_{\text{Lost}}}{m_H}\right)$ = 0.007 ←

$\frac{0.028697}{4.031300} = 0.007$

"Bond. James Bond." Seems he knew something about fusion, eh?

Find the energy produced in each fusion reaction.

1.[2] **Convert** this "lost" mass **from u/fusion to kg/fusion** using $1\ u = 1.661 \times 10^{-27}\ kg$ (keep 5 sig figs)

Example:

$$\frac{0.028697\ u}{\text{fusion}}\left(\frac{1.6605\times10^{-27}\ kg}{1\ u}\right) = \frac{4.7653\times10^{-29}\ kg}{\text{fusion}}$$

$\frac{\text{kg of H}}{\text{fusion}}$

Use the conversion factor to multiply by one & get rid of unwanted units (u)!

2.[2] **Convert** from **mass/fusion** to **energy/fusion** (in Joules) using $E = mc^2$ and $c = 2.998 \times 10^8$ m/s (keep 4 sig figs)

Write your calculations, not just answers!

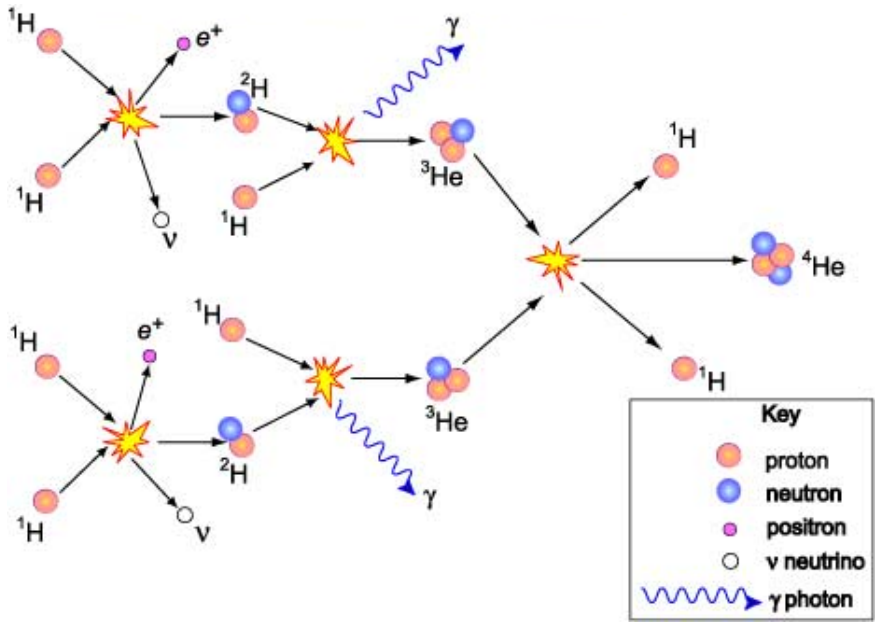
$$\frac{4.765\times10^{29}\ kg}{\text{fusion}}\left(2.998\times10^{8}\right)^2 = \frac{4.283\times10^{-12}\ J}{\text{fusion}}$$

$\frac{J}{\text{fusion}}$

3.[2] **Convert** the **energy/fusion** from **Joules** to **kilowatt-hour using** $1\ kWhr = 3.6 \times 10^6\ J$.

$$\frac{4.283 \times 10^{-12}\ J}{\text{fusion}}\left(\frac{1\ kWhr}{3.6 \times 10^{6}\ J}\right) = \frac{1.190 \times 10^{-18}\ kWhr}{\text{fusion}}$$

$\frac{\text{kWhr}}{\text{fusion}}$



The energy released by a single fusion reaction of 4 hydrogen atoms to one helium atom is:

$1.190 \times 10^{-18}\ \frac{\text{kWhr}}{\text{fusion}}$

How many pounds of H would we have to fuse to provide energy used in New York State?

4. **Convert this** (1.190 x 10^{-18} kWhr/fusion) to **fusions/NY resident** using 15,651 kWhr per capita which the US Energy Information Administration gives as the 2021 New York Sate Usage. (keep 4 sig figs)

$$\frac{15651\ \text{kWhr}}{\text{NY resident}}\left(\frac{\text{fusion}}{1.190 \times 10^{-18}\ \text{kWhr}}\right) = \frac{1.315 \times 10^{22}\ \text{fusions}}{\text{NY Resident}} \qquad \frac{\text{fusions}}{\text{NY resident}}$$

Use the conversion factor to multiply by one & get rid of unwanted units (kWhr)!

Flip this factor to get fusions on top, then get rid of kWhr with the conversion factor

It should seem like a HUGE number!! BUT … how much hydrogen is this?

5.[2] Each fusion reaction uses 6.694 x 10^{-27} kg of H (that becomes He and energy). Find the total H that would have to be fused to supply an average households energy using your result in #4

$$\frac{1.315 \times 10^{22}\ \text{fusions}}{\text{NY resident}}\left(\frac{6.694 \times 10^{-27}\ \text{kg}}{\text{fusion}}\right) = \frac{8.804 \times 10^{-5}\ \text{kg}}{\text{NY resident}} \qquad \frac{\text{kg of H}}{\text{NY resident}}$$

6.[2] **To supply 19,840,000 NY residents**, how many **kg of hydrogen** would need to undergo fusion ?

$$\frac{8.804 \times 10^{-5}\ \text{kg}}{\text{person}}\left(\frac{19{,}840{,}000\ \text{persons}}{\text{NY State 2021}}\right) = \frac{1{,}747\ \text{kg H}}{\text{NY State}} \qquad \frac{\text{kg of H}}{\text{NY State}}$$

7.[2] How many **pounds of hydrogen** is this if 1 kg = 2.2 lb? What do you think of this number?

$$\frac{1{,}747\ \text{kg H}}{\text{NY State residents}}\left(\frac{2.2\ \text{lb}}{\text{kg}}\right) = \frac{3843\ \text{lb}}{\text{NY State}} \sim \text{about 2 tons!} \qquad \frac{\text{lb of H}}{\text{NY State}}$$

What do you think of this number?[2] Pretty small for the entire state!!

The Energy of Sol … How much H does Sol fuse each second?

Sol's luminosity is 3.827×10^{26} Watts or

$$L_{Sol} = 3.827 \times 10^{26} \ \frac{\text{Joules}}{\text{second}}$$

provided by the fusion of hydrogen into helium. On p. 1 (#2), you calculated that **Each fusion yields** an energy of

$$E_{fusion} = 4.283 \times 10^{-12} \ \frac{\text{Joules}}{\text{fusion}}$$

1.[2] Use these to find the number of hydrogen **fusions per second** that provide Sol's **3.827×10^{26} J/sec** (keep 4 sig figs).

$$\frac{3.827 \times 10^{26} \text{ J}}{\text{second}} \left(\underbrace{\frac{1 \text{ fusion}}{4.283 \times 10^{-12} \text{ J}}}_{\text{Flip this factor to get fusions on top, then get rid of J with Sol's Luminosity}} \right) = \frac{8.935 \times 10^{37} \text{ fusions}}{\text{second}} \qquad \frac{\text{fusions}}{\text{second}}$$

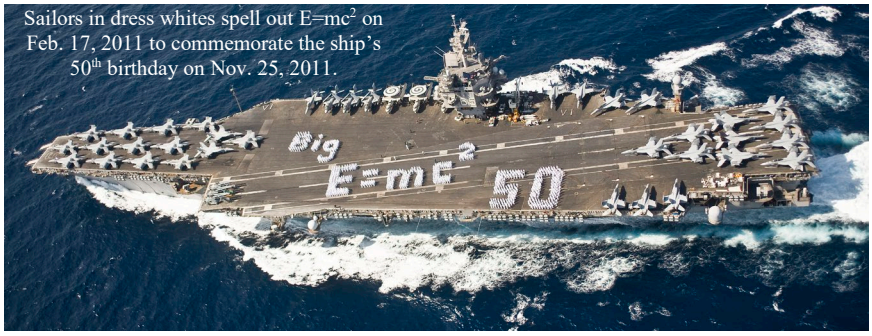
The total mass of H used in each fusion (to become He and energy) is

$$m_{fusion} = 6.694 \times 10^{-27} \ \frac{\text{kg of H}}{\text{fusion}}$$

2.[2] **Convert** your result from #1 (8.935×10^{37} fusions/sec) from **fusions/sec** to **kg/sec** using this.

$$\frac{8.935 \times 10^{37} \text{ fusions}}{\text{second}} \left(\frac{6.694 \times 10^{-27} \text{ kg}}{1 \text{ fusion}} \right) = \frac{5.981 \times 10^{11} \text{ kg}}{\text{second}} \qquad \frac{\text{kg of H}}{\text{second}}$$

An aircraft carrier such as the USS Eneterprise (CVN-65) shown, weighs 94,781 metric tons (1 metric ton = 1 tonne = 1000 kg). How many of these ships would have to be fused each second to supply Sol's energy (IF they were pure hydrogen … not a great shipbuilding material, but hey, this is the ivory tower, eh?)?



Sailors in dress whites spell out $E=mc^2$ on Feb. 17, 2011 to commemorate the ship's 50th birthday on Nov. 25, 2011.

1.[2] Find the mass of the USS Enterprise in kg (keep 4 sig figs)

$$\frac{94781 \text{ tonnes}}{1 \text{ USS Enterprise}} \times \left(\frac{1000 \text{ kg}}{\text{tonne}} \right) = \frac{9.478 \times 10^{7} \text{ kg}}{\text{USS Enterprise}} \qquad \frac{\text{kg}}{\text{USS Enterprise}}$$

2.[2] **Convert** the amount the sun fuses **from kg/sec** to **aircraft carriers/second** (USS Enterprise/sec)

$$\frac{5.981 \times 10^{11} \text{ kg}}{\text{second}} \times \left(\frac{1 \text{ USS Enterprise}}{9.4781 \times 10^{7} \text{ kg}} \right) = \frac{6310 \text{ ACC}}{\text{second}} \qquad \frac{\text{USS Enterprises}}{\text{second}}$$

3.[2] Compare this to the amount needed to supply New York State

The sun fuses **6310 USS Enterprise masses of hydrogen** to helium every second

… and fusing **3842 lb would supply NY State** for a year!!!

Some star, eh?

The Energy of Sol … How much H does Sol turn from matter to energy each second?

Sol's luminosity is 3.827×10^{26} Watts or

$$L_{Sol} = 3.827 \times 10^{26} \frac{\text{Joules}}{\text{second}}$$

provided by the fusion of hydrogen into helium. On p. 1 (#2), you calculated that **Each fusion yields** an energy of

$$E_{fusion} = 4.283 \times 10^{-12} \frac{\text{Joules}}{\text{fusion}}$$

The number of hydrogen **fusions per second** that provide Sol's **3.827×10^{26} J/sec** is

$$N_{fusions} = 8.935 \times 10^{37} \frac{\text{fusions}}{\text{second}}$$

The mass of H used by the Sun per second is

$$m_{H\ fused} = 6310 \frac{\text{ACC Fused}}{\text{Second}}$$

4.[2] On p. 1, you found that 0.007 times the mass of the hydrogen … matter … used is converted to pure energy. Calculate the mass of hydrogen turned completely into energy by the Sun each second

$$\frac{6310\ \text{ACC Fused}}{\text{second}} \times (0.007) = \frac{45\ \text{ACC to Energy}}{\text{second}}$$

$\frac{\text{ACC to Energy}}{\text{second}}$

5.[2] What do you think of this much matter being converted entirely to energy EVERY SECOND??

It blows my mind!!