Phys 102 Astronomy   Name Key

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 = 1.6605402 x 10^{-27} kg.

The masses of the hydrogen nuclei that go into the reaction and the helium nuclei that result from it are:

4.031300 – 4.002603 = 0.028697

m_H = 1.007825 u x 4 = 4.031300 u

m_{He} = — 4.002603 u

mass converted in fusion = 0.028697 u

fraction of H mass converted in fusion $\left(\frac{m_{Lost}}{m_H}\right)$ = 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. **Convert** mass lost per fusion **from u/fusion to kg/fusion** using 1 u = 1.6605 x 10^{-27} kg (keep 5 sig figs)

$$\frac{0.028697\ \text{u}}{\text{fusion}}\left(\frac{1.6605\times10^{-27}\ \text{kg}}{1\ \text{u}}\right)=\frac{4.76514\times10^{-29}\ \text{kg}}{\text{fusion}}$$

$\frac{kg}{fusion}$ Converted to energy

2. **Convert** from **mass/fusion** to **energy/fusion** (in Joules) using **E = mc^2** and c = 2.998 x 10^8 m/s

$$\frac{4.76514\times10^{-29}\ \text{kg}}{\text{fusion}}\left(2.998\times10^{8}\right)^2=\frac{4.283\times10^{-12}\ \text{J}}{\text{fusion}}$$

$\frac{J}{fusion}$

Compare this to the energy used in US households.

1. **Convert** the energy from a single fusion **from Joules to kilowatt-hours**, 1 kWhr = 3.6 x 10^6 J.

$$\frac{4.283\times10^{-12}\ \text{J}}{\text{fusion}}\left(\frac{1\ \text{kWhr}}{3.6\times10^{6}\ \text{J}}\right)=\frac{1.190\times10^{-18}\ \text{kWhr}}{\text{fusion}}$$

$\frac{kWhr}{fusion}$

2. According to the Department of Energy, in 2005 (http://www.eia.doe.gov/) the average residential customer uses 11,040 kWhr. Calculate **how many fusion reactions** per customer it takes to produce this:

$$\frac{11040\ \text{kWhr}}{\text{Customer}}\left(\frac{\text{fusion}}{1.190\times10^{-18}\ \text{kWhr}}\right)=\frac{9.277\times10^{21}\ \text{fusions}}{\text{Customer}}$$

$\frac{fusions}{customer}$

It should seem like a HUGE number!! BUT … how much hydrogen is this? Fusion uses 4.0313 u/fusion or 6.694 x 10^{-27} kg/fusion … so **what mass of hydrogen does the average residential customer require**?

$$\frac{9.277\times10^{21}\ \text{fusions}}{\text{Customer}}\left(\frac{6.694\times10^{-27}\ \text{kg}}{\text{fusion}}\right)=\frac{6.210\times10^{-5}\ \text{kg}}{\text{Customer}}$$

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

For the 7 million NY households counted in the 2000 census, **how many kilograms of hydrogen** would need to undergo fusion to supply the annual residential power consumption?

$$\frac{6.210\times10^{-5}\ \text{kg}}{\text{Customer}}\left(\frac{7{,}000{,}000\ \text{Customers}}{\text{NY State}}\right)=\frac{434.7\ \text{kg}}{\text{NY State}}$$

$\frac{kg\text{ of H}}{\text{NY households}}$

What do you think of this number?

The Energy of Sol

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

$$L_{Sol} = 3.827\times10^{26}\ \frac{\text{Joules}}{\text{second}}$$

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

$$E_{fusion} = 4.283\times10^{-12}\ \frac{\text{Joules}}{\text{fusion}}$$

Calculate the number of hydrogen **fusions per second** that provide the luminosity of Sol (keep 4 sig figs).

$$\frac{3.827 \times 10^{26}\ \text{J}}{\text{second}}\left(\frac{1\ \text{fusion}}{4.283 \times 10^{-12}}\right) = \frac{8.935\ \text{fusions}}{\text{second}} \qquad \frac{\text{fusions}}{\text{second}}$$

The mass of H used to make He and energy each fusion is

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

what **mass** of hydrogen **must be converted** (in kg/sec) to He and energy by Sol each second?

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

A Nimitz Class aircraft carrier such as the USS Nimitz shown, weighs 98,556.67 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?)?

1. Find the mass of an aircraft carrier in kg (keep 4 significant figures)

$$1\ \text{ACC} = 98{,}556.67\ \text{tonnes} \times \frac{1{,}000\ \text{kg}}{\text{tonne}} = 9.856 \times 10^{7}\ \text{kg} \qquad \frac{\text{kg}}{\text{ACC}}$$

2. Convert the kg/second the sun fuses to aircraft carriers per second

$$\frac{5.981 \times 10^{11}\ \text{kg}}{\text{second}}\left(\frac{1\ \text{ACC}}{9.856 \times 10^{7}\ \text{kg}}\right) = \frac{6069\ \text{ACC}}{\text{second}} \qquad \frac{\text{ACC}}{\text{second}}$$

The sun fuses 6069 Aircraft Carrier masses of hydrogen to helium every second

… and fusing 435 kg would supply NY State for a year!!!

Some star, eh?