

POWER FROM FUSION

THE ENERGY OF FUSION

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

$$1 \text{ u} = 1.6605402 \times 10^{-27} \text{ kg.}$$

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		
mass "lost" in fusion =						<u>0.028697 u</u>	
fraction of H mass "lost" in fusion $\left(\frac{m_{\text{Lost}}}{m_H}\right)$ =						<u>0.007</u>	←

"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 $1 \text{ u} = 1.6605 \times 10^{-27} \text{ kg}$ (keep 5 sig figs)

Example:
$$\frac{0.028697 \text{ u}}{\text{fusion}} \left(\frac{1.6605 \times 10^{-27} \text{ kg}}{1 \text{ u}} \right) = \frac{4.7653 \times 10^{-29} \text{ kg}}{\text{fusion}} \quad \frac{\text{kg of H}}{\text{fusion}}$$

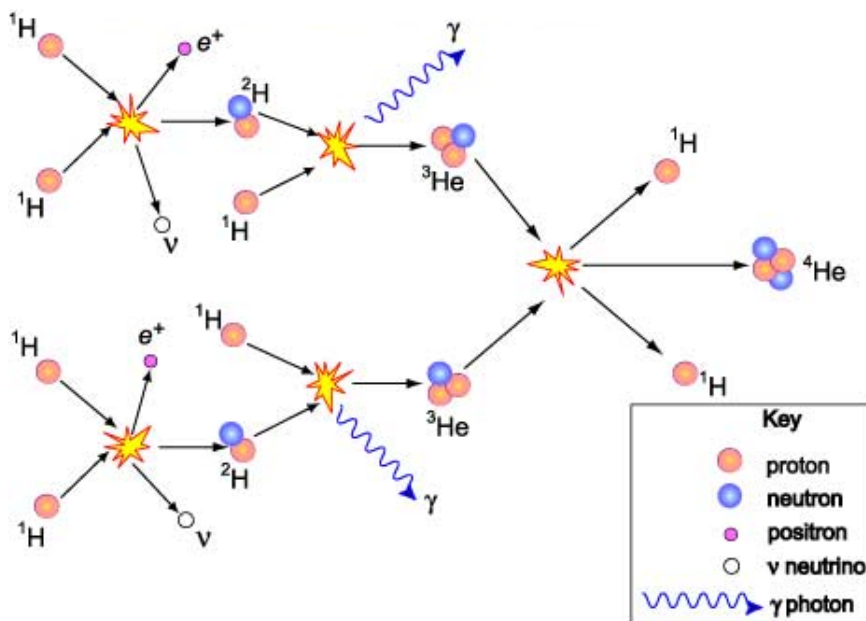
Use the conversion factor to multiply by one & get rid of unwanted units (u)!

2.² Convert from mass/fusion to energy/fusion (in Joules) using $E = mc^2$ and $c = 2.998 \times 10^8 \text{ m/s}$

$$\frac{4.7653 \times 10^{-29} \text{ kg}}{\text{fusion}} (2.998 \times 10^8)^2 = \frac{4.2830 \times 10^{-12} \text{ J}}{\text{fusion}} \quad \frac{\text{J}}{\text{fusion}}$$

3.² Convert the energy/fusion from Joules to kilowatt-hour using $1 \text{ kWhr} = 3.6 \times 10^6 \text{ J}$.

$$\frac{4.2830 \times 10^{-12} \text{ J}}{\text{fusion}} \left(\frac{1 \text{ kWhr}}{3.6 \times 10^6 \text{ J}} \right) = \frac{1.1897 \times 10^{-18} \text{ kWhr}}{\text{fusion}} \quad \frac{\text{kWhr}}{\text{fusion}}$$



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

1.1897×10^{-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 (1.190×10^{-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 State Usage. (keep 4 sig figs)

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

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 6.694×10^{-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

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

6.² To supply 19,840,000 NY residents, how many kg of hydrogen would need to undergo fusion ?

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

7.² How many pounds of hydrogen is this if 1 kg = 2.2 lb? What do you think of this number?

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

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

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

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

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

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).

$$\frac{3.827 \times 10^{26} \text{ J}}{\text{second}} \left(\frac{1 \text{ fusion}}{4.283 \times 10^{-12} \text{ J}} \right) = \frac{8.935 \times 10^{37} \text{ fusions}}{\text{second}} \quad \frac{\text{fusions}}{\text{second}}$$

Flip this factor to get fusions on top, then get rid of J with Sol's Luminosity

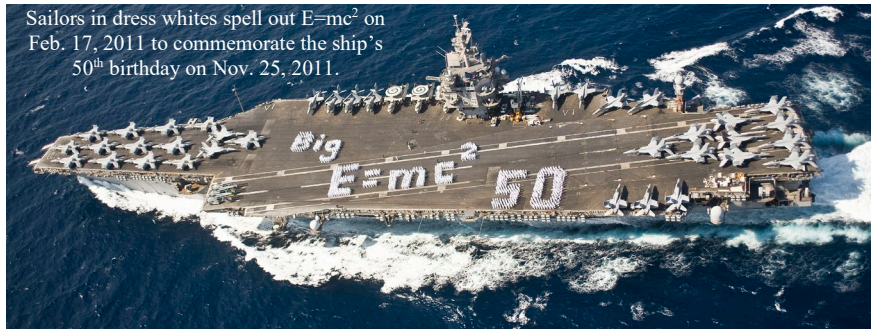
The total mass of H used in each fusion (to become He and energy) is

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

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

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

An aircraft carrier such as the USS Enterprise (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=mc² 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)

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

2.² **Convert** the amount the sun fuses from **kg/sec** to **aircraft carriers/second** (USS Enterprise/sec)

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

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!!!

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

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

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

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

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

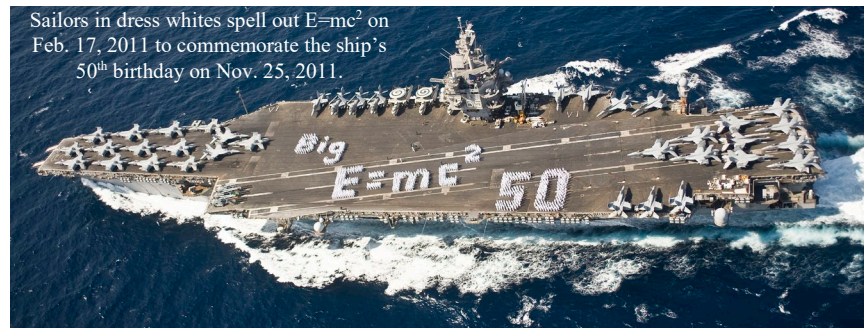
$$N_{\text{fusions}} = 8.935 \times 10^{37} \frac{\text{fusions}}{\text{second}}$$

The **mass of H transformed to energy in each fusion** is

$$m_{\text{lost in fusion}} = 4.7653 \times 10^{-29} \frac{\text{kg of H}}{\text{fusion}}$$

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

$$\frac{8.935 \times 10^{37} \text{ fusions}}{\text{second}} \left(\frac{4.765 \times 10^{-29} \text{ kg}}{1 \text{ fusion}} \right) = \frac{4.258 \times 10^9 \text{ kg}}{\text{second}} \quad \frac{\text{kg of H}}{\text{second}}$$



The mass of the USS Enterprise in kg

$$m_{\text{USS Enterprise}} = 9.478 \times 10^7 \frac{\text{kg}}{\text{USS Enterprise}}$$

5.² **Convert** the amount the sun converts to energy from **kg/sec** to **aircraft carriers/second**

$$\frac{4.258 \times 10^9 \text{ kg}}{\text{second}} \times \left(\frac{1 \text{ USS Enterprise}}{9.4781 \times 10^7 \text{ kg}} \right) = \frac{45 \text{ USS Enterprises}}{\text{second}} \quad \frac{\text{USS Enterprises}}{\text{second}}$$

6.² What do you think of this much **matter being converted entirely to energy EVERY SECOND??**

It blows my mind!!