

POWER FROM FUSION

THE ENERGY OF FUSION

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

$$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg.}$$

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

$(4.03 \text{ u})(1.66 \times 10^{-27} \frac{\text{kg}}{\text{u}}) = 6.70 \times 10^{-27} \text{ kg of H}$	$m_{\text{H}} =$	1.007825 u	$\times 4$	$:$	4.031300 u
	$m_{\text{He}} =$	4.002603 u	$\times 1$	$:$	$- 4.002603 \text{ u}$
mass "lost" in fusion = $\underline{0.028697 \text{ u}}$					
$\frac{0.028697}{4.031300} = 0.007$	fraction of H mass "lost" in fusion $\left(\frac{m_{\text{Lost}}}{m_{\text{H}}}\right) = \underline{0.007}$ ←				

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

Find the energy (kWh) produced in each fusion reaction.

1)² Convert this "lost" mass from u/fusion to kg/fusion using $1 \text{ u} = 1.66 \times 10^{-27} \text{ kg}$ (keep 3 sig figs throught this lab)

Example: $\frac{0.0287 \text{ u}}{\text{fusion}} \left(\frac{1.66 \times 10^{-27} \text{ kg}}{1 \text{ u}} \right) = \frac{4.76 \times 10^{-29} \text{ kg}}{\text{fusion}}$ $\frac{\text{kg of H}}{\text{fusion}}$

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

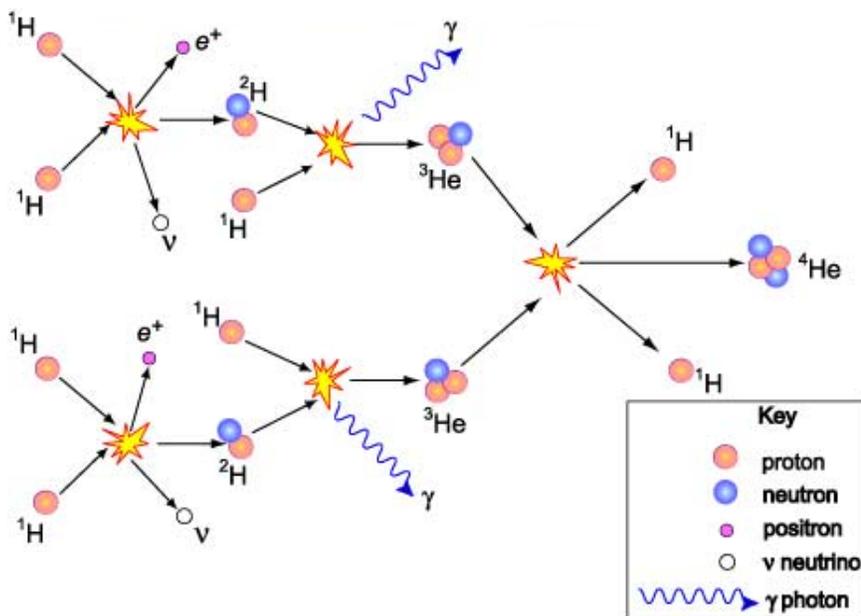
2)² Find the energy released by each fusion (in Joules) using $E = mc^2$ and $c = 3.00 \times 10^8 \text{ m/s}$

Write your calculations, not just answers!

$$\frac{4.76 \times 10^{-29} \text{ kg}}{\text{fusion}} (3.00 \times 10^8)^2 = \frac{4.29 \times 10^{-12} \text{ J}}{\text{fusion}}$$
 $\frac{\text{J}}{\text{fusion}}$

3)² Convert the energy/fusion from Joules to kilowatt-hour using $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$.

$$\frac{4.29 \times 10^{-12} \text{ J}}{\text{fusion}} \left(\frac{1 \text{ kWhr}}{3.6 \times 10^6 \text{ J}} \right) = \frac{1.19 \times 10^{-18} \text{ kWhr}}{\text{fusion}}$$
 $\frac{\text{kWh}}{\text{fusion}}$



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

$\underline{1.19 \times 10^{-18} \frac{\text{kWh}}{\text{fusion}}}$

FUSION NEEDED TO SUPPLY ENERGY TO RESIDENTS OF NY STATE (IN 2023)

Each resident of NY State used 14,565 kWh/NY resident in 2023¹. Each fusion reaction produces an energy of 1.19×10^{-18} kWh/fusion. How many fusion reactions will supply each NY resident with their annual energy?

$$\left(\frac{14565 \text{ kWhr}}{\text{NY resident}} \right) \left(\frac{\text{fusion}}{1.19 \times 10^{-18} \text{ kWhr}} \right) = \frac{1.22 \times 10^{22} \text{ fusions}}{\text{NY Resident}}$$

Write the annual energy use as a fraction Flip this factor for kWhr to cancel & leave

This is a **HUGE** number!! BUT ... how many kilograms of hydrogen is this?

4)² The mass going into each fusion is 6.69×10^{-27} kg of H/fusion. Use the number of fusions per NY resident to determine the mass of H fused for each resident.

$$\frac{1.22 \times 10^{22} \text{ fusions}}{\text{NY resident}} \left(\frac{6.69 \times 10^{-27} \text{ kg}}{\text{fusion}} \right) = \frac{8.18 \times 10^{-5} \text{ kg}}{\text{NY resident}} \quad \frac{\text{kg of H}}{\text{NY resident}}$$

5)² How much H must be fused to supply all 19,571,000 NY residents of NY State?²

$$\frac{8.18 \times 10^{-5} \text{ kg}}{\text{person}} \left(\frac{19,571,000 \text{ persons}}{\text{NY State 2023}} \right) = \frac{1,602 \text{ kg H}}{\text{NY State}} \quad \frac{\text{kg of H}}{\text{NY State}}$$

6)² What do you think of this number (one kilogram = 2.2 pounds)?

Pretty small for the entire state!!



¹ [US Energy Information Administration](#)
² [Empire Center for Public Policy](#)

HYDROGEN FUSED BY SOL EVERY SECOND

Sol's luminosity, 3.83×10^{26} Joules/second is provided by the fusion of hydrogen into helium. On p. 1 (#2), you calculated that fusion yields 4.29×10^{-12} Joules/fusion. Write these as fractions:

$$L_{\text{Sol}} = \frac{3.83 \times 10^{26} \text{ Joules}}{\text{second}} \qquad E_{\text{fusion}} = \frac{4.29 \times 10^{-12} \text{ Joules}}{\text{fusion}}$$

These gave the number of hydrogen fusions per second needed to provide Sol's 3.83×10^{26} J/sec:

$$\left(\frac{3.83 \times 10^{26} \text{ J}}{\text{second}} \right) \left(\frac{1 \text{ fusion}}{4.29 \times 10^{-12} \text{ J}} \right) = \frac{8.93 \times 10^{37} \text{ fusions}}{\text{second}} \qquad \frac{\text{fusions}}{\text{second}}$$

Sol's luminosity as a fraction
Flip this for Joules to cancel and leave fusions/second

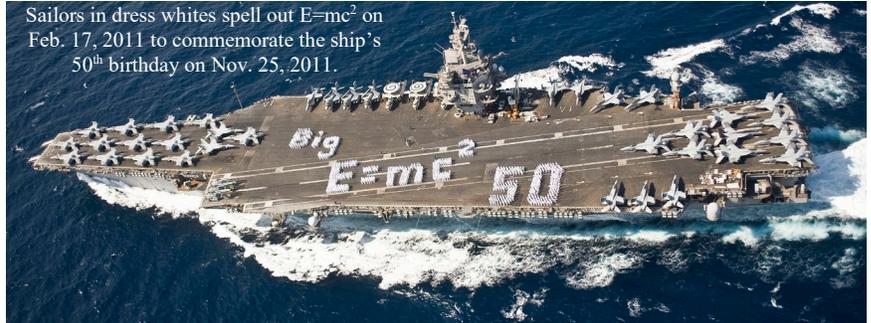
The mass of H used in each fusion (to become He and energy) is

$$m_{\text{fusion}} = \frac{6.69 \times 10^{-27} \text{ kg of H}}{\text{fusion}}$$

7)² Use this to change Sol's number of fusions 8.935×10^{37} fusions/sec to mass of H fused in kg/sec .

$$\frac{8.93 \times 10^{37} \text{ fusions}}{\text{second}} \left(\frac{6.69 \times 10^{-27} \text{ kg}}{1 \text{ fusion}} \right) = \frac{5.98 \times 10^{11} \text{ kg}}{\text{second}} \qquad \frac{\text{kg of H fused}}{\text{second}}$$

An aircraft carrier such as the USS Enterprise (CVN-65) shown, has a mass of 9.48×10^7 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??)



8)² Write the mass of the USS Enterprise as a fraction equal to one:

$$\frac{9.478 \times 10^7 \text{ kg}}{\text{USS Enterprise}} = 1$$

9)² Convert the amount the Sun fuses from kg/sec to USS Enterprises Fused/second.

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

10)² Compare this to the amount needed to supply New York State residents in 2023

The Sun fuses 6310 USS Enterprise masses of hydrogen to helium every second ... and fusing 3842 lb would supply NY State for a year!!!

MATTER TURNED TO ENERGY BY SOL EVERY SECOND

Sol's luminosity, 3.83×10^{26} Joules/second is provided by the fusion of hydrogen into helium. On p. 1 (#2), you calculated that fusion yields 4.29×10^{-12} Joules/fusion. Writing these as conversion factors:

$$L_{\text{Sol}} = \frac{3.83 \times 10^{26} \text{ Joules}}{\text{second}} \quad E_{\text{fusion}} = \frac{4.29 \times 10^{-12} \text{ Joules}}{\text{fusion}}$$

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

$$N_{\text{fusions}} = \frac{8.94 \times 10^{37} \text{ fusions}}{\text{second}}$$

The mass of H used by the Sun per second is

$$m_{\text{H fused}} = \frac{6310 \text{ USS Enterprises}}{\text{second}}$$

11)² On p. 1, you found that 0.007 times the mass of the hydrogen ... matter ... used is converted to pure energy. Use this to find how many of the 6310 Enterprises of hydrogen the Sun fuses each second turn to pure energy EVERY SECOND.

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

12)² What do you think of this much matter being converted entirely to energy EVERY SECOND??

It blows my mind!!

