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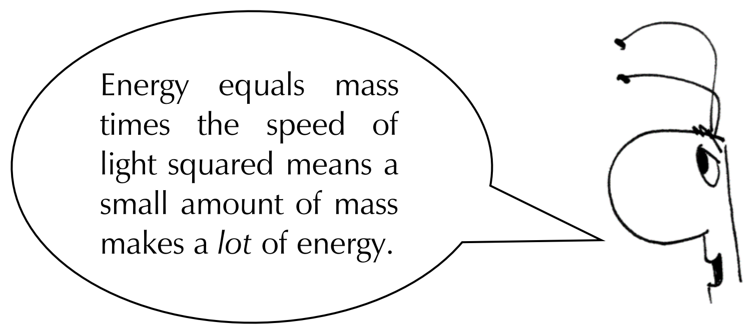
CA1 2.21: Age of the Sun Handout

Purpose: To use estimations and ratios to determine the age of the sun and how long it will last until it dies.

Background: The sun gets its energy from nuclear fusion. In a nuclear fusion reaction, four hydrogen atoms combine to form a helium atom. In the process some mass is lost, and this mass is converted to energy according to Einstein's equation $E = mc^2$. Using some basic facts about the sun, we can estimate the rate of burning and the available fuel to determine how long the sun will last.

The solar constant is the energy received by the earth, per square meter, from the sun. The total energy output is equal to the energy that hits a sphere the size of the earth's orbit. So, we take the solar constant times the surface area of a sphere with the radius of the earth's orbit.



Each step leads to the next answer. Be careful because one wrong answer will cascade throughout the worksheet to a final answer that is incorrect.

To help you keep track of the steps, each answer is referred to by line number in subsequent calculations. Certain answers are given partially as check points to help you avoid mistakes.

Constants

1370	Solar Constant (W/m^2)
1.5×10^{11}	radius of the earth's orbit (m)
1.99×10^{30}	mass of the sun (kg)
1.67325×10^{-27}	mass of one hydrogen atom (kg)
6.645×10^{-27}	mass of one helium atom (kg)
300,000,000	speed of light (m/s)

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Part One. Determine the energy output of the entire sun.	
1. Find the surface area of a sphere that has a radius equal to the radius of the earth's orbit by using the formula $A = 4\pi r^2$. Use the earth's orbital radius for *r* . (Find it on the previous page.)	
2. Multiply the answer to line 1 by the solar constant in Watts per square meter to find the total energy output of the sun. Note: a Watt is a Joule / sec, or energy per unit time.	
Part Two. Energy Output from Hydrogen Fusion. The sun is powered by hydrogen fusion. In hydrogen fusion, 4 hydrogen atoms combine to form one helium atom.	
3. Find the mass of four hydrogen atoms.	
4. Subtract the mass one helium atom.	
5. Find out how much energy this conversion generates by taking the difference (Answer to Line 4) and multiplying it by the speed of light squared. This is the application of $E = mc^2$. The answer comes out in Joules.	
Part Three. Find the rate at which conversions occur in the sun.	
6. Since the sun's total energy output is known (Line 2) for one second, we can compute the rate of conversions per second by dividing the energy output per second (line 2) by the energy for each conversion (Line 5). The answer is in "conversions per second." $\dfrac{\left(\dfrac{\text{Energy output of sun}}{\text{second}}\right)}{\left(\dfrac{\text{Energy provided by}}{\text{one conversion}}\right)} = \dfrac{\text{Line 2}}{\text{Line 5}} =$	
Part Four. Estimate the amount of fuel (Hydrogen) available in the sun for conversion.	
7. Hydrogen fusion can only occur in the central, hot core of the sun, which contains about 10% of the mass of the entire sun. Divide the mass of the sun by 10. Answer is in kilograms. (HINT: The answer is very nearly 2.0 x 10 to the something…)	
8. Assume that when the sun was formed, like most of the rest of the universe, it was made of about 90% hydrogen and 10% other. Multiply Line 7 by 0.90.	
9. Find out how many hydrogen atoms this represents by taking the available fuel mass (line 8) and dividing by the mass of one hydrogen atom.	

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10. Find out how many hydrogen-to-helium conversions this represents. Remember that one conversion takes four (4) hydrogen atoms. Divide line 9 by four (4). (HINT: This is not "divide line 9 by line 4,", it's) $\left(\frac{\text{The answer you got for line 9}}{\text{The number four (4.00)}}\right) =$	
Part Five. Compute the age of the sun and its expected lifetime.	
11. The sun has the number of conversions available during its lifetime as listed in line 10. Each second, it uses the number of conversions listed in line 6. To find out the number of seconds the sun can burn hydrogen over its entire life, take the value in line 10 divided by the value in line 6. This is the most important step and represents the fuel supply divided by the burn rate.	
12. Divide line 11 by 60 to find out the number of minutes the sun will exist. *(*HINT: Starts with 4.9…)	
13. Divide line 12 by 60 to find out the number of hours the sun will exist.	
14. Divide line 13 by 24 to find out the number of days the sun will exist.	
15. Divide line 14 by 365.25 to find out the number of years the sun will exist.	
16. The sun has existed for approximately 5 billion years. Subtract 5 billion from the answer in line 15 to determine how many more years we have until the sun runs out of fuel. (HINT: Answer comes out as a few *billion* years)	
Disclaimer: This rough estimate gives you an order of magnitude answer. Stellar models are very complex and give a somewhat different answer than the one provided here. There are other energy cycles besides the hydrogen to helium conversion in the sun. When the hydrogen runs out the sun will burn helium for a while. These factors are not considered in this calculation. By some estimations, the conversion of the sun into its red giant phase will occur within approximately 3 billion years. So your final answer should be at least that large or larger.	
17. For testing and assessment purposes: It is not that important to remember this entire 16-step process. What is most important is that your recall the age of the sun can be estimated by taking the amount of fuel available and dividing by the burn rate. Which of the sixteen steps above represents this most crucial step? https://openstax.org/details/books/astronomy	