*Until the discovery of fusion, this is what astronomers believed was the power source for the Sun:*

## Gravitational Energy : Dropping Mass

$$E \simeq \frac{G\,M^2}{R}$$

$E$ = energy released from dropping
$G$ = gravitational constant
$M$ = mass of spherical object
$R$ = radius of spherical object

$M_\odot = 2.0\times10^{30}$ kg
$R_\odot = 7.0\times10^{8}$ m
$G = 6.67\times10^{-11}$ m$^3$ kg$^{-1}$ s$^{-2}$

How much gravitational energy is released in assembling the Sun? What is the efficiency of this?

$$E \simeq \frac{G\,M^2}{R} = \frac{\left(6.67\times10^{-11}\ \frac{\mathrm{m}^3}{\mathrm{kg\ s}^2}\right)\left(2.0\times10^{30}\ \mathrm{kg}\right)^2}{7.0\times10^{8}\ \mathrm{m}}$$

$$= 4\times10^{41}\ \mathrm{J}$$

$$eff = \frac{3.8\times10^{41}\ \mathrm{J}}{(2.0\times10^{30}\ \mathrm{kg})\,(3.00\times10^{8}\ \mathrm{m/s})^2}$$

$$= 2\times10^{-6}$$

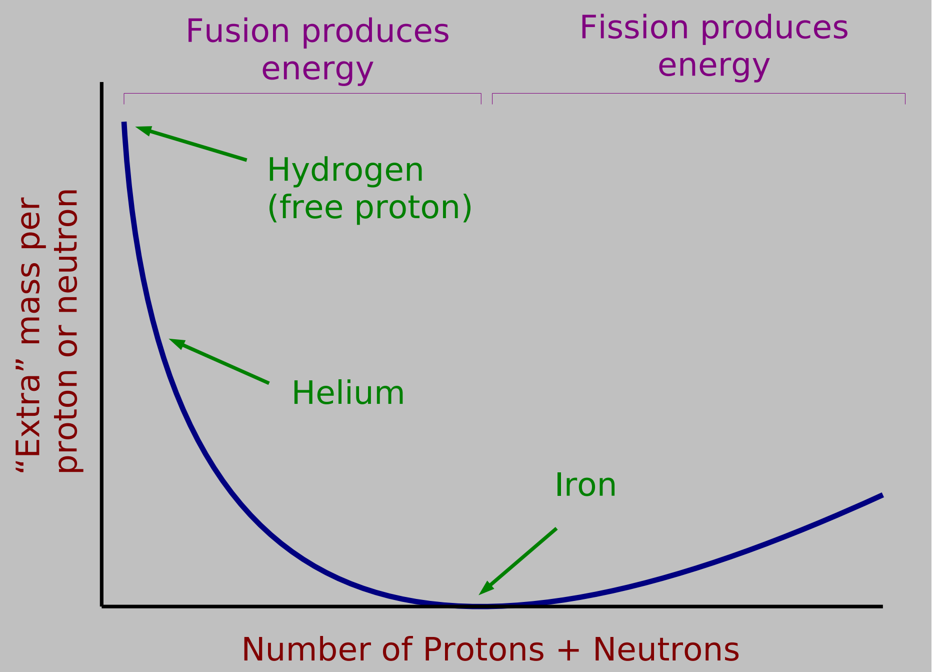
Still not good enough; we need at least 1000× more energ

To have been shining at its current luminosity for a few billion years, the sun needs an energy generation processes that has an efficiency of about $10^{-3}$ (or even a bit better).

Gravitational contraction of something the size and mass of the Sun has an efficiency of about $10^{-6}$.

If the Sun were generating its power through gravitational contraction, how old could it be?

- A Billions ($10^9$) of years
- B Millions ($10^6$) of years
- C Thousands ($10^3$) of years
- D Just a few years old
- E It would burn out in a few days



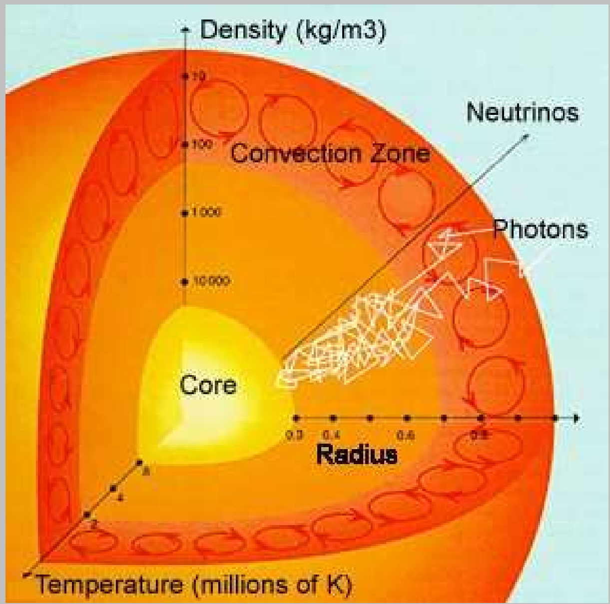



*Image: CSE, SSL, UCB*

## How do we know that the Sun is powered via fusion?

- Fusion is the only plausible energy generation mechanism that can keep the Sun around for the 4.6 billion years we know it has been here.
- Detailed models of fusion and the interior structure of the Sun can explain the temperature and luminosity of the Sun as we observe it.

$$4p \rightarrow \alpha + 2e^{+} + 2\nu + \text{energy}$$

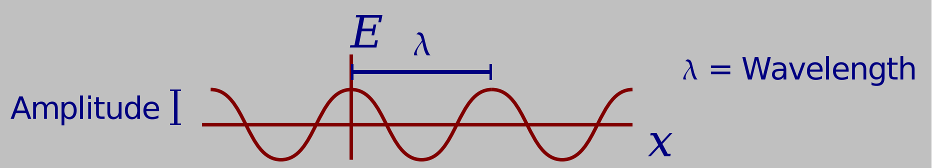
- We have directly observed the neutrinos from the Sun, and they match what is predicted!

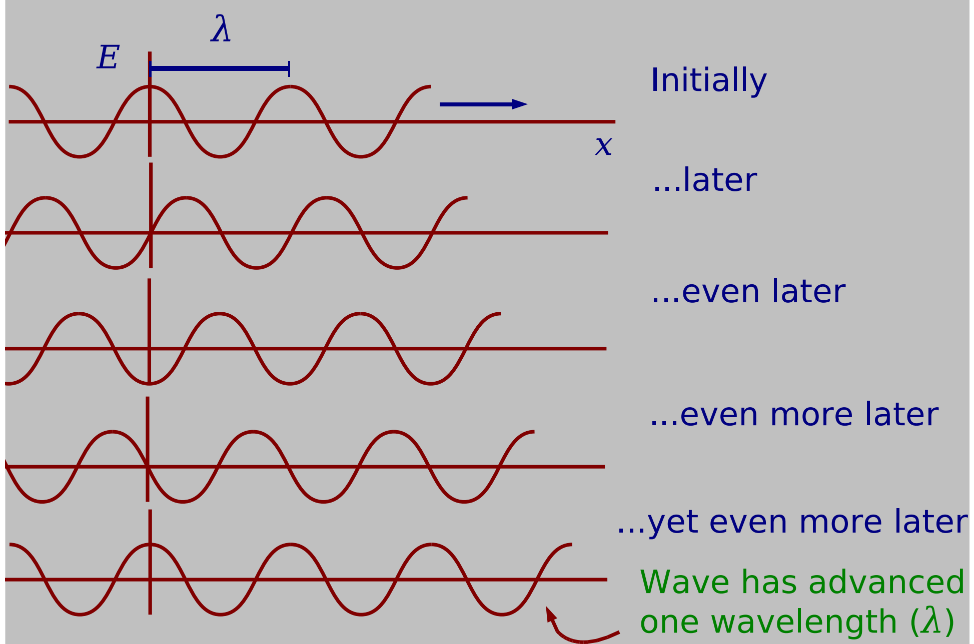
(Note : "Solar Neutrino Problem" is solved)

## Light = Electromagnetic Wave

Oscillations of the Electromagnetic (E-M) Field

At one moment in time, the electric field *E* varies with position:



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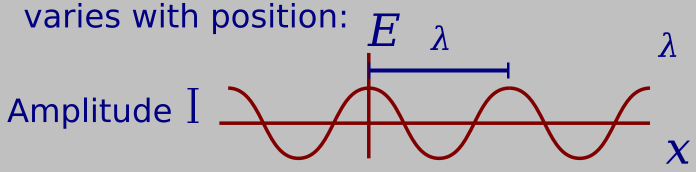
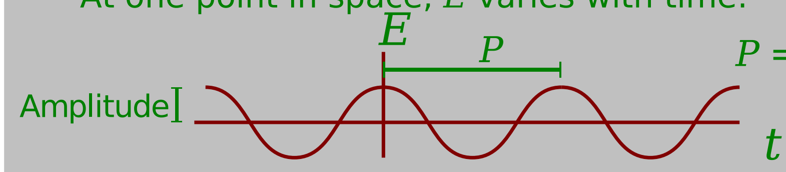



$\lambda$ = Wavelength

At one point in space, $E$ varies with time:




$P$ = Period

$f = \frac{1}{P}$ = *Frequency*

How long does it take a light wave to move the distance of one wavelength?

amount = rate × time

$$\lambda = c\,t$$

$$t = \frac{\lambda}{c}$$

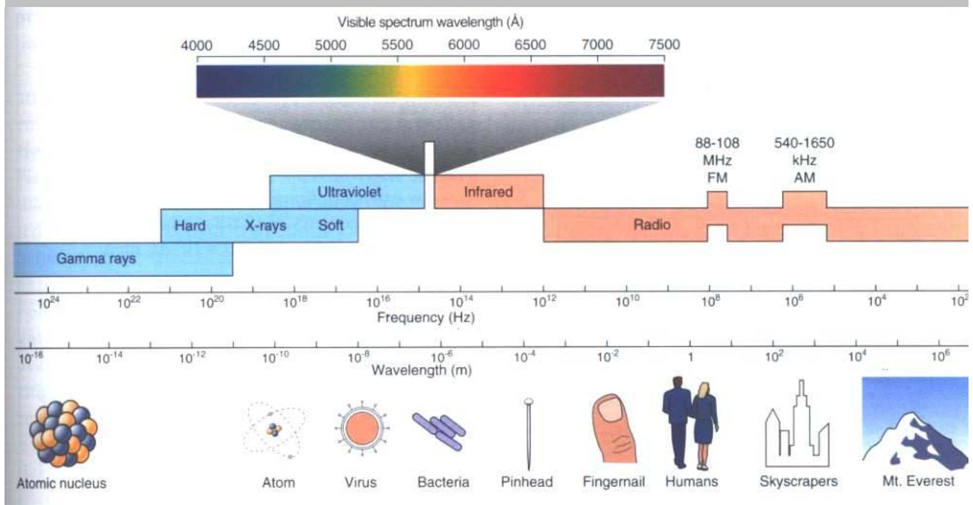
c = speed of light = $3.00\times10^{8}$ m/s

This time is also the *Period P*

$$f = \frac{1}{P}$$

$$\frac{1}{f} = \frac{\lambda}{c}$$

$$\lambda f = c \qquad f = \frac{c}{\lambda} \qquad \lambda = \frac{c}{f}$$




Red light has wavelength $\lambda$ = 6700 Å. What is the frequency of red light?
(1 Å = $10^{-10}$ m.)

A $1.5\times10^{-4}$ Hz

B $4.5\times10^{4}$ Hz

C $4.5\times10^{14}$ Hz

D It is impossible to say from the information provided.