You are made from stardust

Mr Cotton

(who contains a lot more star dust than you!)
Let's use hydrogen to release some chemical energy.
What is "burning"?

Burning is the conversion of molecular binding energy into E-M radiation
The Question: How long would the Sun shine for the case of coal power?

63000 years
How long would the Sun last at its current luminosity if it was GPE powered?
(Note that it would contract at about 40m per year)

Lots of GPE

Less GPE
This converts to 16 million years

This is still too short!
Curiously, although Brown flatly declared that astronomy could contribute nothing to the question of the earth’s age, he made no mention of one particularly important problem about which new information was rapidly becoming available, the energy of the sun. During the years immediately preceding the report, A.S. Eddington and James Jeans had begun to apply Einstein’s principle of mass-energy conversion to the problem of solar heat, and had found that it could account for a virtually limitless store of energy — at least of the order of $10^{12}$ years. And in addition, Jeans had shown that the Laplacian nebular hypothesis could not account for the formation of the solar system without violating the conservation of momentum.\textsuperscript{126}

Thus, in a single sweep they had produced still another possible alter-
Proton  Neutron
<table>
<thead>
<tr>
<th>Interaction</th>
<th>Current theory</th>
<th>Mediators</th>
<th>Relative strength[^1]</th>
<th>Long-distance behavior</th>
<th>Range (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong</td>
<td>Quantum chromodynamics (QCD)</td>
<td>gluons</td>
<td>$10^{38}$</td>
<td>$\frac{1}{r^2}$</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>Electromagnetic</td>
<td>Quantum electrodynamics (QED)</td>
<td>photons</td>
<td>$10^{36}$</td>
<td>$\frac{1}{r^2}$</td>
<td>$\infty$</td>
</tr>
<tr>
<td>Weak</td>
<td>Electroweak Theory</td>
<td>W and Z bosons</td>
<td>$10^{25}$</td>
<td>$\frac{1}{r}$ $e^{-m_{W,Z} r}$</td>
<td>$10^{-18}$</td>
</tr>
<tr>
<td>Gravitation</td>
<td>General Relativity (GR)</td>
<td>gravitons (hypothetical)</td>
<td>1</td>
<td>$\frac{1}{r^2}$</td>
<td>$\infty$</td>
</tr>
</tbody>
</table>
Beta\(^+\) decay: \[ p \rightarrow n + \beta^+ + \nu \]

Proton \hspace{5cm} Neutron
Nuclear Fusion
The proton-proton chain

Helium

proton
neutron

gamma ray
neutrino
positron
The force responsible for holding all nucleons together is the strong nuclear force. The graph below shows the strong nuclear force between nucleons as a function of the separation of the nucleons.
A2 FORMULAE

MOMENTUM

force
\[ F = \frac{\Delta (mv)}{\Delta t} \]

impulse
\[ F \Delta t = \Delta (mv) \]

CIRCULAR MOTION

angular velocity
\[ \omega = \frac{v}{r} \]
\[ \omega = 2\pi f \]

centripetal acceleration
\[ a = \frac{v^2}{r} = \omega^2 r \]

GASES AND THERMAL PHYSICS

gas law
\[ pV = nRT \]

\[ pV = NkT \]

kinetic theory model
\[ pV = \frac{1}{3} Nm (c_{rms})^2 \]

kinetic energy of gas molecule
\[ \frac{1}{2} m (c_{rms})^2 = \frac{3}{2} kT = \frac{3RT}{2N_A} \]
# Fundamental Constants and Values

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>speed of light in vacuo</td>
<td>$c$</td>
<td>$3.00 \times 10^8$</td>
<td>m s$^{-1}$</td>
</tr>
<tr>
<td>permeability of free space</td>
<td>$\mu_0$</td>
<td>$4\pi \times 10^{-7}$</td>
<td>H m$^{-1}$</td>
</tr>
<tr>
<td>permittivity of free space</td>
<td>$\varepsilon_0$</td>
<td>$8.85 \times 10^{-12}$</td>
<td>F m$^{-1}$</td>
</tr>
<tr>
<td>magnitude of the charge of electron</td>
<td>$e$</td>
<td>$1.60 \times 10^{-19}$</td>
<td>C</td>
</tr>
<tr>
<td>the Planck constant</td>
<td>$h$</td>
<td>$6.63 \times 10^{-34}$</td>
<td>J s</td>
</tr>
<tr>
<td>gravitational constant</td>
<td>$G$</td>
<td>$6.67 \times 10^{-11}$</td>
<td>N m$^2$ kg$^{-2}$</td>
</tr>
<tr>
<td>the Avogadro constant</td>
<td>$N_A$</td>
<td>$6.02 \times 10^{23}$</td>
<td>mol$^{-1}$</td>
</tr>
<tr>
<td>molar gas constant</td>
<td>$R$</td>
<td>$8.31$</td>
<td>J K$^{-1}$ mol$^{-1}$</td>
</tr>
<tr>
<td>the Boltzmann constant</td>
<td>$k$</td>
<td>$1.38 \times 10^{-23}$</td>
<td>J K$^{-1}$</td>
</tr>
</tbody>
</table>
\[ V = \frac{1}{4\pi \varepsilon_0} \frac{Q}{r} \]

\[ \Delta W = Q \Delta V \]

\[ \frac{1}{2} \ m \ (c_{\text{rms}})^2 = \frac{3}{2} \ kT \]
force between two point charges

\[ F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1 Q_2}{r^2} \]

Work done = force \times \text{Distance moved} (in the direction of the applied force).
\[= kq_1 q_2 \int_{-\infty}^{r_0} \frac{1}{r^2} \, dr\]

\[= kq_1 q_2 \left[ \frac{-1}{r} \right]_{-\infty}^{r_0}\]

\[= kq_1 q_2 \left[ -\frac{1}{r_0} - \left(-\frac{1}{\infty}\right) \right] = 0\]
\[ q, q_2 \begin{bmatrix} \frac{1}{r} \end{bmatrix} - \begin{bmatrix} \infty \end{bmatrix} + \begin{bmatrix} \end{bmatrix} \]

\[ k_1 q_2 \begin{bmatrix} \frac{1}{r_0} \end{bmatrix} \]
\[
\Delta W = Q \Delta V
\]

\[
qV = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r} q
\]
\[ V = \frac{1}{4\pi \epsilon_0} \frac{Q}{r} \]

\[ QV = \frac{1}{4\pi \epsilon_0} \frac{Q^2}{r} \]

Energy \((QV)\) = \[
\frac{1}{4 \times 3.14 \times 8.85 \times 10^{-12}} \times \frac{(1.60 \times 10^{-19})^2}{1 \times 10^{-15}}
\]

\[ \text{Energy} = 2.3 \times 10^{-13} \text{J} \]
\[ \frac{1}{2} m (c_{\text{rms}})^2 = \frac{3}{2} kT \]

*Average kinetic energy* = \( \frac{3}{2} KT \)

\[ 2.3 \times 10^{-13} = \frac{3}{2} \times 1.38 \times 10^{-23} \times T \]

\[ T = 1.1 \times 10^{10} \, K \]
Temperature needed for fusion

$1.1 \times 10^{10} \, K$

Actual temperature of the core

$1.5 \times 10^{7} \, K$
The energy equivalent of the mass-defect is called the binding-energy of the nucleus.
Physics is the map not the terrain!
Physics is the map not the terrain!
Not only is the universe stranger than we think, it is stranger than we can think.

(Werner Karl Heisenberg)