HW5 Solutions

1

The minimum energy needed for photons to produce electrons comes from the pair production of a positron and electron.

$$E_{min} = m_{e^-}c^2 + m_{e^+}c^2$$

$$E_{min} = 2m_{e^-}c^2 = 2 * 0.511\ MeV = 1.022\ MeV$$

2

In the lab frame both protons will have a speed:

From Momentum conservation:

$$\vec{p}_{before} = \vec{p}_{after}$$

To produce a Higgs particle at rest $\vec{p}_{after} = 0$:

$$\vec{p}_{proton,1} + \vec{p}_{proton,2} = 0$$

$$\vec{p}_{proton,1} = -\vec{p}_{proton,2}$$

This means the protons are travelling at the same speed in opposite directions.

From Energy conservation:

$$E_{before} = E_{after}$$

$$\gamma(m_pc^2 + m_pc^2) = m_{higgs}c^2$$

$$(100m_p)c^2 = 2\gamma m_pc^2$$

$$\gamma = 50$$

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = 50$$

$$\frac{v}{c} = 0.9998$$

3

In the early universe:

$$p \approx m_p c$$

Then:

$$\Delta p = 2m_p c$$

$$T \propto a^{-1} \propto x^{-1}$$
$$x = x_{now}\frac{T_{now}}{T}$$

$$\Delta x \Delta p = \hbar$$
$$x_{now}\frac{T_{now}}{T}2m_p c = \hbar$$
$$T = 2\frac{m_p c}{\hbar}x_{now}T_{now}$$

$x_{now} = 10^{10}\ Mpc$ and $T_{now} = 3K$. This means at :

$$T \geq 8 \times 10^{48} K$$

We don't know how many protons there are due to the momentum uncertainty.

4

The proton is made of bound quarks, the mass of the proton is the binding energy of the quarks making the proton. If the proton were given energy equal to it's binding energy the quarks would become unbound. Going back in time there is a temperature this would happen at, approximately:

$$k_b T = E = m_p c^2 = 938.27 MeV$$

$$T = 1.089 \times 10^{13} K$$

5

$$F_{grav} = \frac{Gm_e^2}{d^2}$$

$$F_{EM} = \frac{kq_e^2}{d^2}$$

$$\frac{F_{grav}}{F_{EM}} = \frac{Gm_e^2}{d^2}\frac{d^2}{kq_e^2} = \frac{Gm_e^2}{kq_e^2} = 2.4 \times 10^{-43}$$

This is independent of distance.

6

Just taking the ratio of the new gravitational force to the one before (old here refering to question 5) we have:

$$\frac{F_{grav,new}}{F_{grav,old}} = \frac{M_{sun}M_{Earth}}{m_e^2} = 1.4 \times 10^{115}$$

$$\frac{F_{grav,new}}{F_{EM,new}} = \frac{F_{grav,new}F_{grav,old}}{F_{grav,old}F_{EM,new}}$$

As the $F_{EM,new} = F_{EM,old}$:

$$\frac{F_{grav,new}}{F_{EM,new}} = \frac{F_{grav,new}}{F_{grav,old}}\frac{F_{grav,old}}{F_{EM,old}}$$

$$\frac{F_{grav,new}}{F_{EM,new}} = \frac{M_{sun}M_{Earth}}{m_e^2} * \frac{Gm_e^2}{kq_e^2} = 1.4 \times 10^{115} * 2.4 \times 10^{-43}$$

$$\frac{F_{grav,new}}{F_{EM,new}} = 3.4 \times 10^{72}$$

This means gravity dominates at large scales because at large scales, objects are much more massive than they are charged.

7

$$\lambda_{max} T = 0.002898\ m\ K$$

For the sun's average T:

$$\lambda_{max} = \frac{0.002898\ m\ K}{5800\ K} = 499.6\ nm$$

This is green light.

For the sunspot's T:

$$\lambda_{max} = \frac{0.002898\ m\ K}{4000\ K} = 724.4\ nm$$

This is Red/near-Infrared light.

8

With a given mass M in kg:

$$100\ W = \frac{\Delta M}{\Delta t} c^2 = \frac{0.7M}{\Delta t} c^2$$

$$\Delta t = \frac{0.7Mc^2}{100\ W}$$

$$\Delta t = 6.291 \times 10^{14} s \left(\frac{M}{kg} \right)$$

This equation says for example a $70kg$ person takes $\Delta t = 4.404 \times 10^{16} s$

9

The interior is determined from:
-Mathematical models using the laws of physics which should predict what is seen on the surface of the sun
-Solar vibrations which can be observed by looking for Doppler shifts and gives an insight on the core similar to seismology on Earth
-Solar neutrinos, a product of fusion which can be observed from Earth.

10

If the strong interaction is ten times as strong and the weak interaction remains the same, the minimum separation distance needed for two nuclei to fuse also increases. This means fusion gets easier and so the interior temperature increases.