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Constants and conversions: 1MeV=1.600E-13J
m_p=938.27MeV/c^2=1.6726E-27Kg
m_n=939.57MeV/c^2=1.6749E-27Kg
m_e=0.511MeV/c^2=9.1E-31kg
Atomic mass unit: 1u=1.6605E-27kg = 931.5MeV/c^2

Chapter 7 and 8:

1) Consider a projectile traveling horizontally and slowing down under the influence of air resistance. The mass of this projectile is 45.36 kg, and the speed as a function of time is $v=655.9 - 61.14t+3.26t^2$ where speed is measured in m/s and time in seconds.

a) What is the instantaneous power removed from the projectile by air resistance? P=Fv=m·dv/dt ·v

b) What is the kinetic energy at time t=0.00s and at time t=3.00 s? 9.76 10^6J, 5.71·10^6J

c) ΔK/Δt What is the average power for the time interval from 0 to 3 seconds? ΔK/Δt 1.35 10^6J/s

2) A 20 kiloton nuclear bomb has an explosive energy of 20,000 tons of TNT, or 8.4·10^{13} Joules. How many kilograms of rest mass must be converted in this explosion?

Answer: 9.3E-4kg or about 1g.

3) How much energy will be released by the annihilation of one electron and one anti-electron (both initially at rest)? Express your answer in MeV.

answer: 1MeV

4) In a high speed collision between an electron and a positron, the two particles can annihilate each other and create a proton and a anti-proton. The reaction: $e+e^{+}=p+\overline{p}$ converts the rest mass energy and kinetic energy of the electron and positron into the rest mass energy of the proton and antiproton. Assume that the electron and the positron collide head on with opposite velocities of equal magnitudes and that the proton and antiproton are at rest immediately after the collision. Calculate the kinetic energy (in MeV) and speed of the electron required for this reaction. 940MeV;

$$\gamma m_0^e c^2 = m_0^p c^2;\ \gamma = \frac{m_0^p c^2}{m_0^e c^2} = 1843$$

$$\frac{\mathrm{v}}{\mathrm{c}} = 0.999\,999\,85$$

5) The sun emits energy in the form of radiant heat and light at the rate of 4·10^{26} Watts. At what rate does this carry away mass from the sun? How many years does it take for the sun to burn up 1% of its mass? The mass of the sun is 2·10^{30} kg.

dm/dt =4.4E9 kg/s; 4.5E18s = 142 billion years = 10 times the life of the universe.

6) The yearly energy expenditure of the United States is about 1·10^{20} Joules. The energy of sunlight arriving at the surface of the earth amounts to about 1kW per square meter of surface, facing the sun. If the entire energy incident could be converted into useful energy, how many square meters of collector area would we need to satisfy the energy needs of the US?

Power = energy/year = 3.17E9 kW
3.16E3 km^2 = 1,116 sqmi (The total area of the US is about 6 million square miles or 10 million square kilometers. The surface of the earth is about 2E8 sqmi)

California uses power at a rate of about 30 GW.

7) The reaction that supplies the sun with energy is H+H+H+H = He + energy
(The reaction involves several intermediary steps, which are not of relevance here.) The mass of one hydrogen atom is 1.00813 u and that of the Helium atom is 4.00388 u. The difference between the rest-mass energy of four separate hydrogen atoms and one Helium atom is the binding energy of the Helium nucleus. This energy is liberated when a Helium nucleus is created in the fusion of 4 Hydrogen atoms.
$1u=1.6605E-27kg = 931.5MeV/c^2$

a) How much energy is released in the conversion of 4H into He? $\Delta m \cdot c^2 = 26.75$ MeV

b) How much energy is released in the conversion of 1kg of hydrogen?

250 moles contain 250 N atoms = 1.5E26 atoms which will create 4.026E27 MeV energy.

c) The sun releases energy at the rate of $3.9 \cdot 10^{26}$ W. At what rate in kg/s does the sun consume hydrogen?

The consumption of hydrogen corresponds roughly to the total radiation of the sun: divide the number above by c^2 to get 4.3E9 kg/s

d) The sun contains about $1.5 \cdot 10^{30}$ kg of hydrogen. If it continues to consume hydrogen at the rate of c), how long will it take to use 10% of the total hydrogen? (in years)

3.46E19 s =1.09 trillion years.

8) 1hp =746 Watts; 1eV=1.6E-19 J; 1MeV= 1.6E-13 J; 1cal=4.186 J.

Any object of temperature T emits energy in the form of electromagnetic radiation (light, photons)

$$\frac{dE}{dt} = P = eA\sigma T^4$$

e is called emissivity, which is a characteristic number <1. A is the surface area ($4\pi r^2$ for a spherical surface. σ is Stefan's constant $=5.67 \cdot 10^{-8}$, T is the absolute temperature in Kelvin)

Calculate the energy output of the sun with a surface temperature of 5800 K.

Answer: P=3.9E26Watts or 4.3 billion tons of matter per second.

This energy is spread spherically into the universe. At the distance of the earth the power is spread over and area of $4\pi R^2$, where R is the distance from the sun to the earth, corresponding to about 1390 Watts/m^2, which is the intensity of the sun at the outer surface of the atmosphere. Intensity is defined as power divided by the area to which the radiation power is incident perpendicularly.

The temperature in a room is a result of the average kinetic energy of the air molecules.

$\frac{1}{2}m\overline{v^2} = \frac{3}{2}kT;$ m is the mass of the molecule, k is Boltzmann's constant=1.38E-23.

Multiplying both sides by Avogadro's number N=6.02E23 gives the same formula for a mole of a gas with R=Nk=8.314.

We get the "average" speed of an oxygen molecule at room temperature (293K) to be about 478 m/s. The path of any molecule is quickly interrupted because of collisions. Note that the average above is the average of the squared velocity, not the square of the average velocity. This is why the average square is referred to as the "root mean square" or rms value.