

37. (a) Let M be the mass of the Sun at time t and E be the energy radiated to that time. Then, the power output is

$$P = dE/dt = (dM/dt)c^2,$$

where $E = Mc^2$ is used. At the present time,

$$\frac{dM}{dt} = \frac{P}{c^2} = \frac{3.9 \times 10^{26} \text{ W}}{(2.998 \times 10^8 \text{ m/s})^2} = 4.3 \times 10^9 \text{ kg/s}.$$

(b) We assume the rate of mass loss remained constant. Then, the total mass loss is

$$\begin{aligned} \Delta M &= (dM/dt) \Delta t = (4.33 \times 10^9 \text{ kg/s}) (4.5 \times 10^9 \text{ y}) (3.156 \times 10^7 \text{ s/y}) \\ &= 6.15 \times 10^{26} \text{ kg}. \end{aligned}$$

The fraction lost is

$$\frac{\Delta M}{M + \Delta M} = \frac{6.15 \times 10^{26} \text{ kg}}{2.0 \times 10^{30} \text{ kg} + 6.15 \times 10^{26} \text{ kg}} = 3.1 \times 10^{-4}.$$

45. (a) Since two neutrinos are produced per proton-proton cycle (see Eq. 43-10 or Fig. 43-10), the rate of neutrino production R_ν satisfies

$$R_\nu = \frac{2P}{Q} = \frac{2(3.9 \times 10^{26} \text{ W})}{(26.7 \text{ MeV})(1.6 \times 10^{-13} \text{ J/MeV})} = 1.8 \times 10^{38} \text{ s}^{-1}.$$

(b) Let d_{es} be the Earth to Sun distance, and R be the radius of Earth (see Appendix C). Earth represents a small cross section in the “sky” as viewed by a fictitious observer on the Sun. The rate of neutrinos intercepted by that area (very small, relative to the area of the full “sky”) is

$$R_{\nu, \text{Earth}} = R_\nu \left(\frac{\pi R_e^2}{4\pi d_{es}^2} \right) = \frac{(1.8 \times 10^{38} \text{ s}^{-1})}{4} \left(\frac{6.4 \times 10^6 \text{ m}}{1.5 \times 10^{11} \text{ m}} \right)^2 = 8.2 \times 10^{28} \text{ s}^{-1}.$$

49. Since 1.00 L of water has a mass of 1.00 kg, the mass of the heavy water in 1.00 L is $0.0150 \times 10^{-2} \text{ kg} = 1.50 \times 10^{-4} \text{ kg}$. Since a heavy water molecule contains one oxygen atom, one hydrogen atom and one deuterium atom, its mass is

$$\begin{aligned} (16.0 \text{ u} + 1.00 \text{ u} + 2.00 \text{ u}) &= 19.0 \text{ u} = (19.0 \text{ u})(1.661 \times 10^{-27} \text{ kg/u}) \\ &= 3.16 \times 10^{-26} \text{ kg}. \end{aligned}$$

The number of heavy water molecules in a liter of water is

$$(1.50 \times 10^{-4} \text{ kg}) / (3.16 \times 10^{-26} \text{ kg}) = 4.75 \times 10^{21}.$$

Since each fusion event requires two deuterium nuclei, the number of fusion events that can occur is $N = 4.75 \times 10^{21} / 2 = 2.38 \times 10^{21}$. Each event releases energy

$$Q = (3.27 \times 10^6 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV}) = 5.23 \times 10^{-13} \text{ J}.$$

Since all events take place in a day, which is $8.64 \times 10^4 \text{ s}$, the power output is

$$P = \frac{NQ}{t} = \frac{(2.38 \times 10^{21})(5.23 \times 10^{-13} \text{ J})}{8.64 \times 10^4 \text{ s}} = 1.44 \times 10^4 \text{ W} = 14.4 \text{ kW}.$$