With the depletion of hydrogen in the core, the generation of energy via the pp chain must stop. However, by now the core temperature has increased to the point that nuclear fusion continues to generate energy in a thick hydrogen-burning shell around a small, predominantly helium core. This effect can be seen in the luminosity curve in Fig. 13.3. Note that the luminosity remains close to zero throughout the inner 3% of the star's mass. At the same time, the temperature is nearly constant over the same region. That the helium core must be isothermal when the luminosity gradient is zero can be seen from the radiative temperature gradient, given by Eq. (10.68). Since $L_r \simeq 0$ over a finite region, $dT/dr \simeq 0$

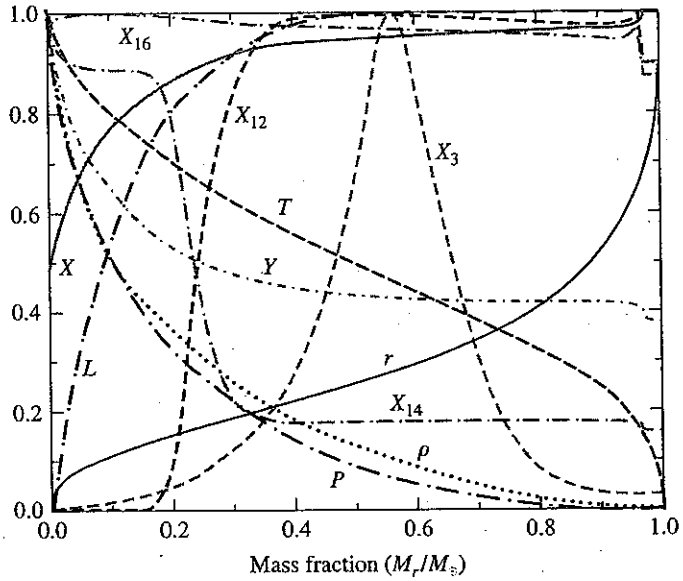

FIGURE 13.2 The interior structure of the present-day Sun (a 1 $M_\odot$ star), 4.57 Gyr after reaching the ZAMS. The model is located between points 1 and 2 in Fig. 13.1. The maximum ordinate values of the parameters are $r = 1.0\ R_\odot$, $L = 1.0\ L_\odot$, $T = 15.69 \times 10^6$ K, $\rho = 1.527 \times 10^5$ kg m^{-3}, $P = 2.342 \times 10^{16}$ N m^{-2}, $X = 0.73925$, $Y = 0.64046$, $X_3 = 3.19 \times 10^{-3}$, $X_{12} = 3.21 \times 10^{-3}$, $X_{14} = 5.45 \times 10^{-3}$, and $X_{16} = 9.08 \times 10^{-3}$. (Data from Bahcall, Pinsonneault, and Basu, *Ap. J.*, *555*, 990, 2001.)

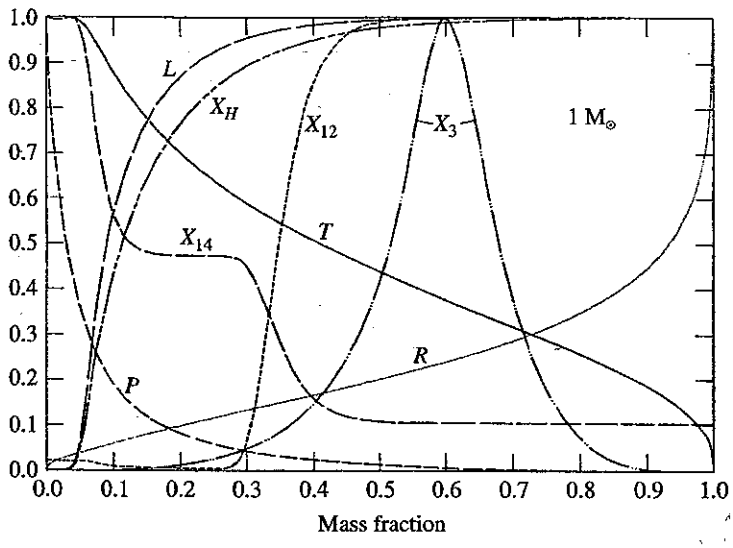

FIGURE 13.3 The interior structure of a 1 $M_\odot$ star near point 3 in Fig. 13.1, as described by the pioneering calculations of Icko Iben. Although specific values of quantities in modern models differ somewhat from those given here, state-of-the-art models do not significantly differ qualitatively from these calculations. The maximum ordinate values of the parameters for the Iben model are $R = 1.2681\ R_\odot$, $P = 1.3146 \times 10^{17}$ N m^{-2}, $T = 19.097 \times 10^6$ K, $L = 2.1283\ L_\odot$, $X_H = 0.708$, $X_3 = 5.15 \times 10^{-3}$, $X_{12} = 3.61 \times 10^{-3}$, and $X_{14} = 1.15 \times 10^{-2}$. The radius of the star is $1.3526\ R_\odot$. (Figure adapted from Iben, *Ap. J.*, *47*, 624, 1967.)

and T is nearly constant. For an isothermal core to support the material above it in hydrostatic