TABLE 12.1 Pre-main-sequence contraction times for the classical models presented in Fig. 12.11. (Data from Bernasconi and Maeder, *Astron. Astrophys.*, *307*, 829, 1996.)

Initial Mass ($M_\odot$)	Contraction Time (Myr)
60	0.0282
25	0.0708
15	0.117
9	0.288
5	1.15
3	7.24
2	23.4
1.5	35.4
1	38.9
0.8	68.4

reactions have little effect on the overall collapse; they simply slow the rate of collapse slightly.

As the central temperature continues to rise, increasing levels of ionization decrease the opacity in that region (see Fig. 9.10) and a radiative core develops, progressively encompassing more and more of the star's mass. At the point of minimum luminosity in the tracks following the descent along the Hayashi track, the existence of the radiative core allows energy to escape into the convective envelope more readily, causing the luminosity of the star to increase again. Also, as required by Eq. (3.17), the effective temperature continues to increase, since the star is still shrinking.

At about the time that the luminosity begins to increase again, the temperature near the center has become high enough for nuclear reactions to begin in earnest, although not yet at their equilibrium rates. Initially, the first two steps of the PP I chain [the conversion of ${}^{1}_{1}\mathrm{H}$ to ${}^{3}_{2}\mathrm{He}$; Eqs. (10.37) and (10.38)] and the CNO reactions that turn ${}^{12}_{6}\mathrm{C}$ into ${}^{14}_{7}\mathrm{N}$ [Eqs. (10.48–10.50)] dominate the nuclear energy production. With time, these reactions provide an increasingly larger fraction of the luminosity, while the energy production due to gravitational collapse makes less of a contribution to L.

Due to the onset of the highly temperature-dependent CNO reactions, a steep temperature gradient is established in the core, and some convection again develops in that region. At the local maximum in the luminosity on the H–R diagram near the short dashed line, the rate of nuclear energy production has become so great that the central core is forced to expand somewhat, causing the gravitational energy term in Eq. (10.36) to become negative [recall that $\epsilon = \epsilon_{\rm nuclear} + \epsilon_{\rm gravity}$; see Eq. (10.102)]. This effect is apparent at the surface as the total luminosity decreases toward its main-sequence value, accompanied by a decrease in the effective temperature.

When the ${}^{12}_{6}\mathrm{C}$ is finally exhausted, the core completes its readjustment to nuclear burning, reaching a sufficiently high temperature for the remainder of the PP I chain to become important. At the same time, with the establishment of a stable energy source, the gravitational energy term becomes insignificant and the star finally settles onto the main sequence. It is worth noting that the time required for a 1 $M_\odot$ star to reach the main sequence, according to the detailed numerical model just described, is not very different from the crude estimate of the Kelvin–Helmholtz timescale performed in Example 10.3.1.