Principles of Stellar Structure

VOLUME *2*. APPLICATIONS TO STARS

Introduction to Part II

We shall here be concerned for the most part (except in Chaps. 25 and 27 and in parts of Chap. 26) with stars which are in both *hydrostatic* and *thermal* equilibrium. As we have seen, stars in *hydrostatic* equilibrium are in *pressure* balance against gravity, *i.e.*, the pressure at each point in the star is just great enough to support the weight of the overlying layers. Such stars can change their physical properties significantly only in times long compared to $t_{\rm ff}$, the "free-fall" time (*cf.* Chaps. 0, 1, and 27):

$$t_{\rm ff} \sim 3 \times 10^3 (\bar{\rho})^{-1/2} \text{ sec},$$

where $\bar{\rho}$ is the mean density of the star in gm/cm^3. This time $t_{\rm ff}$ is the characteristic time required for significant changes in the state of a star which is *not* in hydrostatic equilibrium. Stars which are also in *thermal* equilibrium are in *energy* balance, *i.e.*, the loss of energy by radiation from the photosphere (or by neutrino emission if this is an important energy-loss mechanism) is balanced by nuclear energy generation in the interior. The characteristic time for significant changes in the condition of such a star is $t_{\rm nuc}$, the "nuclear" time scale; for a hydrogen-burning star we have (*cf.* Sect. 17.7)

$$t_{\rm nuc} \sim 10^{10} M/L \text{ years},$$

where M and L are mass and total luminosity (photonic plus neutrinic) in solar units. Stars which are in *hydrostatic* but not *thermal* equilibrium may be expected to change their physical properties appreciably in times of the order of $t_{\rm K}$, the "Kelvin" time (*cf.* Sect. 17.4):

$$t_{\rm K} \sim 2 \times 10^7 \frac{M^2}{RL} \text{ years},$$

where the radius R is also in solar units. A good example of this kind of star is a gravitationally contracting star; such a star is sometimes said to be in "quasi-hydrostatic" equilibrium.

Henceforth we shall frequently use the terms "complete equilibrium" or simply "equilibrium" to mean both hydrostatic and thermal equilibrium. We shall also generally neglect any neutrino energy losses unless we state

explicitly otherwise, so that L shall always mean the *non-neutrinic* (usually the *photonic*) luminosity. Some effects of neutrino losses will be discussed in Sects. 25.5, 25.6, and 26.5. We shall also neglect forces (such as magnetic stresses) other than those arising from gravity and pressure gradients, unless we explicitly state otherwise.

In Chaps. 18–25 we shall discuss general principles of stellar structure and properties of certain special kinds of stars in equilibrium. A review of stellar evolution is presented in Chap. 26, and in Chap. 27 a survey of the subject of variable (pulsating) stars is presented.

Other general works and discussions in the general fields of stellar structure and evolution are Eddington [Ed26]; Jeans [Je28]; Chandrasekhar [Ch39,51]; Aller [Al54]; Schwarzschild [Sc58b]; Vol. 51 (1958) of *Handbuch der Physik* (ed. S. Flügge); Menzel, Bhatnagar, and Sen [Me63]; Frank-Kamenetskii [Fr62]; Hayashi, Hōshi, and Sugimoto [Ha62a]; Gratton [Gr63]; Aller and McLaughlin [Al65]; Cameron [Ca65]; and Stein and Cameron [St66a]. A recent bibliography of references on stellar interiors from 1958 to mid-1966, including an extensive table of stellar models, has been compiled by Langer, Herz, and Cox [La66].