Part VIII
Compact Objects

Stellar evolution can lead to somewhat extreme final stages. We have seen in Chaps. 33 and 35 that the evolution tends to produce central regions of very high density. On the other hand it is known that stellar matter can be ejected (see Chap. 34). The mechanisms are only partly (if at all) understood, but they do exist according to observations (normal mass loss, planetary nebulae, explosions). It may be that in certain cases the whole star explodes without any remnant left (see Chap. 36). Often enough, however, only the widely expanded envelope is removed, leaving the condensed core as a *compact object*. Relative to "normal stars" these objects are characterized by small radii, high densities, and strong surface gravity.

There are three types of compact objects, distinguished by the "degree of compactness": white dwarfs (WD), neutron stars (NS), and black holes (BH). Typical values for WD are $R \approx 10^{-2} R_{\odot}, \varrho \approx 10^6\,\mathrm{g\,cm^{-3}}$, escape velocity $v_{\mathrm{E}} \approx 0.02c$; their configuration is supported against the large gravity by the pressure of highly degenerate electrons (instead of the "thermal pressure", which dominates in the case of normal stars). For NS one has typically $R \approx 10\,\mathrm{km}, \varrho \approx 10^{14}\,\mathrm{g\,cm^{-3}}$, $v_{\mathrm{E}} \approx c/3$; their pressure support is provided by densely packed, partially degenerate neutrons. This is the dominant species of particles since normal nuclei do not exist above a certain density. Indeed a NS represents very roughly a huge "nucleus" of 10^{57} baryons.

As a simple illustration, suppose that in both cases (WD and NS) ideal, non-relativistic degenerate fermions (of mass m_{e} or m_{n}) provide the pressure balancing the gravity. The stars then are polytropes of index $n = 3/2$. With a mass-radius relation (19.28), where the constant of proportionality can be seen to be $\sim K \sim 1/m_{\mathrm{fermion}}$, we have $R \sim 1/m_{\mathrm{fermion}}$. The ratio of m_{n} to m_{e} then provides the ratio of typical radii for WD and NS of the same mass. The pressure–gravity balance by degenerate neutrons can only be maintained up to limiting masses corresponding to about 2×10^{57} fermions.

Clearly for objects with gravity fields like those in NS general relativity becomes important. It will be the dominant feature for the last group of compact objects, namely BH with $R \approx 1\,\mathrm{km}$ and $v_{\mathrm{E}} = c$.

The first WD was detected long before theoreticians were able to explain it, whereas NS were predicted theoretically before they were, accidentally, discovered in the sky. Today, also the existence of BH is proven beyond doubt.

The physics of compact objects is interesting and complex enough to fill special textbooks (e.g., Shapiro and Teukolsky 1983). We refer to these for details and limit ourselves to indicating a few main characteristics.