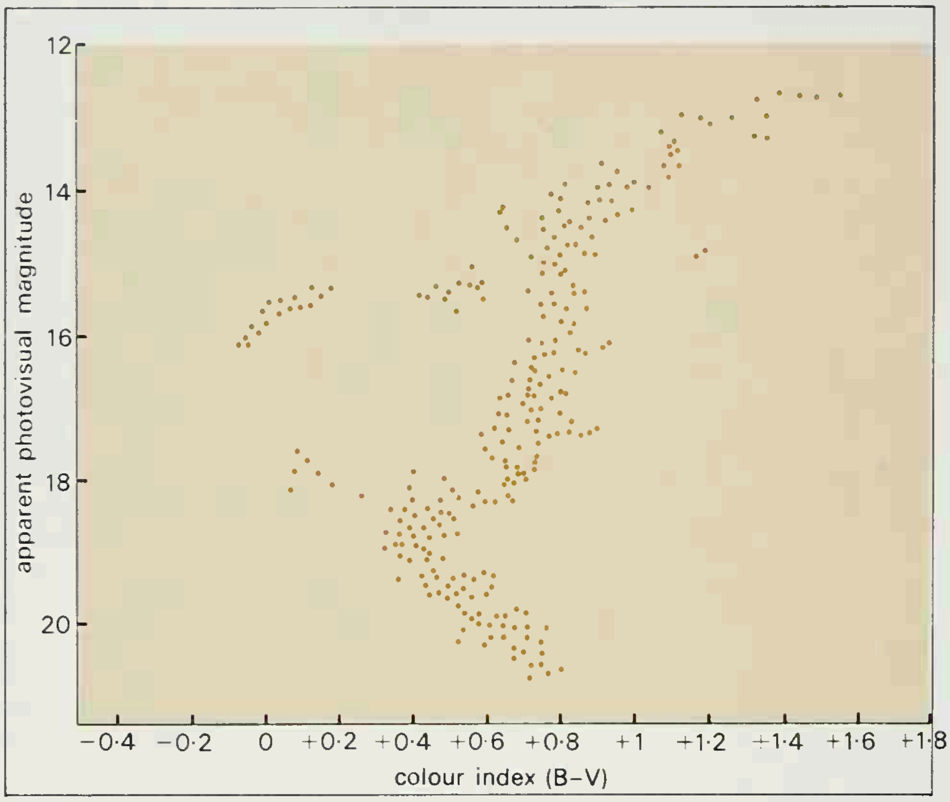

Fig. 3·11
H–R diagram for the globular cluster M3. This shows a protracted main sequence and well developed and heavily populated giant branch. Horizontal branch stars are found typically in globular clusters, but are absent from galactic (open) clusters. This is primarily because of the greater age of globular cluster stars.

formed at roughly the same time out of the same interstellar material. However, even a fleeting scrutiny of the two H–R diagrams exposes their conspicuous difference. Why is this? The predominant reason is the age of the clusters. Consider a very old cluster, approximately 10^{10} years old. Assuming a wide range of stellar masses were originally formed in the clusters, the more massive stars will have long ago converted all their hydrogen into helium. We would, therefore, not expect to see any highly luminous O, B or A stars. The main sequence would merely peter out as illustrated. On the other hand, in a young cluster, massive stars may not have had time to evolve from the main sequence. The cluster would have a long and unbroken main sequence. The length of the main sequence of a cluster of stars thus serves as a good indication of the age of the cluster. A schematic H–R diagram for several clusters is shown in Fig. 3·12 and from this we can say that all globular clusters are extremely old, while galactic clusters have varying ages but some are mere youngsters on an astronomical time scale; h and χ Persei may have an age of only 10^7 years.

The **thermal** (or Kelvin-Helmholtz) **time scale** is the time taken for energy to diffuse from the centre to the surface of a star. From our discussion of opacity and energy transport inside a star, we know that in the case of the Sun this time is about 10^7 years.

The **dynamical time scale** is much shorter, being the time required for the whole star to be aware of the absence of a pressure support. As an example, suppose the nuclear furnaces in the centre of the Sun were extinguished. With the sudden removal of the pressure support, the surface will be aware of this calamity in the time taken for a pressure wave to travel from the centre to the surface. For the Sun, this is about 30 minutes! Due to the great differences in these time scales, various processes playing alternate roles in the course of stellar evolution may be separated and studied in isolation.

The birth of stars

Star formation is not well understood but the basic picture assumes that they are born in dense clouds of interstellar material. Such clouds collapse under their gravitational fields and condensations or **protostars** form. As these protostars continue slowly to contract to a star they use the gravitational potential energy liberated for internal heating and radiation. The protostar heats up and eventually resembles a star. It is very possible that T-Tauri type stars are in this pre-main-sequence phase of evolution; here the surface resembles an ordinary star, although the interior has not yet settled down to steady nuclear burning. Steady burning occurs only when the internal temperature eventually becomes sufficient for hydrogen fusion reactions to commence. The star then stops contracting: it has arrived on the main sequence (Fig. 3·13). The thermal contraction period before arriving on the main sequence is brief, perhaps lasting only 10 000 years for a 20 $M_\odot$ star. As a result we would not expect to find many stars in this phase on an H–R diagram, and we do not.

This demonstrates a crucial point in the use of an H–R diagram. If a region is well populated on the diagram, we can infer that stars spend a substantial fraction of their lives in these zones. Such regions are the main sequence and giant branches. If a region is sparsely populated or vacant, it may then be assumed either that conditions are not suitable for stars to exist there or that stars pass through such areas in a time which is short in an astronomical context, that is, less than a million years.

Fig. 3·12 below: *Composite H–R diagram for ten open clusters and one globular cluster, M3. As the main sequence is followed from top left to lower right, turn-off points for various clusters are observed. Because very hot, massive stars have short lifetimes on the main sequence, this progression of the turn-off from the main sequence identifies clusters of greater age. M67 is one of the oldest known open clusters with an age of about four thousand million years; this is to be constrasted with h and χ Persei of only ten million years. The globular cluster M3 is believed to have an age of twelve thousand million years. By studying such diagrams for many clusters, astronomers find clues to help them with the puzzle of stellar evolution.*

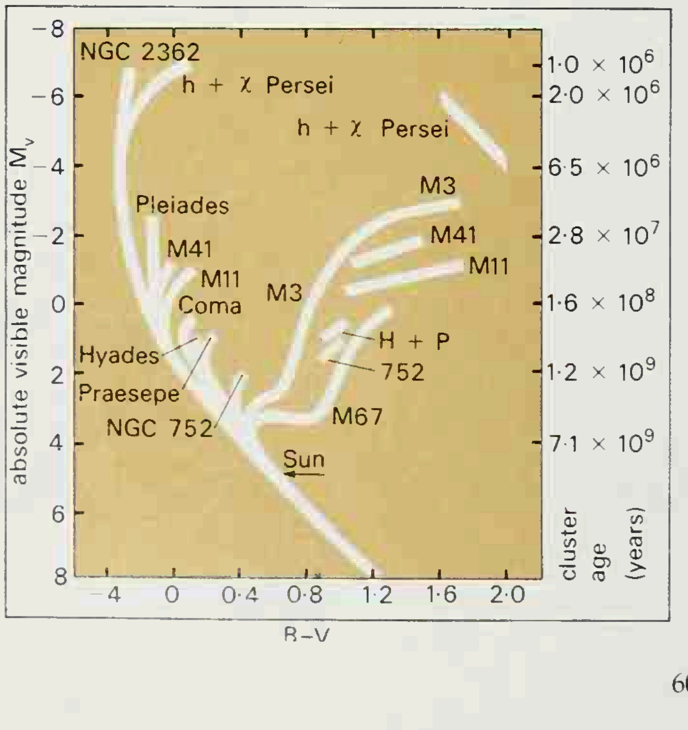

Fig. 3·14, opposite page, bottom left: *Schematic representation of the required time for stars of varying mass to contract on to the zero-age-main-sequence. Massive stars not only contract on a short time scale, they also consume their hydrogen extremely rapidly and therefore have relatively brief main sequence (nuclear) lifetimes. Hence old star clusters do not possess any giant O or B stars, and have protracted main sequences because the massive stars have long ago evolved to red giants and beyond.*