CHAPTER FOUR

The Sun

Although the Sun is a typical star it requires special comment for a number of reasons. It is unique to us among the stars because it provides the light and heat necessary to sustain life on Earth. For the astronomer it is the only star whose surface can be observed in detail, and it acts as a giant nearby astrophysical laboratory. Scientific studies of specific conditions found in the Sun and its atmosphere, but not on the Earth, have led to advances in the fields of plasma, nuclear and atomic physics. Moreover, by studying the Sun astronomers can investigate physical conditions typical of most stars. Biologists, climatologists and meteorologists are also interested in it because its radiant energy has significant repercussions for life on the Earth. Table 4·1 (page 91) lists the overall properties of the Sun.

The visible disc

We know that the Sun is an incandescent sphere of gas, yet when we view the **photosphere**, the highly luminous surface, its edge or limb appears sharp, as if it were a solid body. It does not gradually merge into the blackness of space as we would expect. The interpretation of this basic observation is that the region from which most of the visible radiation is coming must be thin compared with the radius of the Sun, and is only a few hundred kilometres deep. In this zone, the gas becomes more opaque with depth, with completely opaque gas below it and a transparent solar atmosphere above. Photographs of the Sun reveal that the disc is perceptibly fainter at its rim than the centre, a phenomenon known as **limb-darkening**. The explanation for this is very simple. A line of sight to the disc centre penetrates to a greater vertical depth before reaching an opaque layer. We therefore see slightly deeper into the Sun where the regions are hotter and in consequence more luminous. A line of sight to the limb on the other hand passes obliquely into the solar atmosphere and becomes opaque at a slightly higher and cooler level. The way this effect depends on magnitude and wavelength is very important in assisting astronomers to define the structure of the solar atmosphere.

The black body temperature of the Sun is obtained by comparing the continuous spectrum with that for black bodies and turns out to be 6 000 K. The effective temperature derived from the luminosity of the photosphere (using the relation ($L \propto R^2T^4_{eff}$)) is 5 800 K, although limb-darkening means that the centre and limb temperature will straddle this average value. The solar surface also reveals fine structure brightness variations, referred to as granulation, the granules being bright patches with a dark border about 1 000 km in size. This irregular mosaic is continually changing on a time scale of minutes; high speed photography shows that the solar surface resembles a pan of simmering soup. By observing the Doppler shifts from these granules we know that their hot centres are rising whilst the cooler, darker boundaries are sinking.

This is evidence of convective motion taking place just below the visible surface and is believed to happen because hydrogen is undergoing a change from being completely ionized in the deep interior to neutral at the surface. In this intermediate zone, radiation flowing out from the core meets a sudden increase in opacity; energy is then transported to the surface not by radiation but primarily by turbulent convective currents of heated gas. The transition region begins at about 0·85 of the distance from the centre to the surface. In the lower convective zone three main layers are thought to exist, the deepest forming giant cells, with supergranular cells next and finally granular cells above, the tops of these forming the Sun's visible surface.

Chromosphere and corona

Above the photosphere the atmosphere of the Sun rapidly thins and the temperature drops to 4 000 K in a 500-km-thick layer. This thinner, cooler gas is transparent to most wavelengths of the continuous photospheric spectrum but it asborbs radiation at wavelengths characteristic of the atoms in this layer. This is the zone which produces the solar spectrum absorption lines first studied by Fraunhofer. By analysing this incredibly complex spectrum, solar astrophysicists have been able to deduce the abundances of chemical elements and also their relative states of ionization. This cooler zone, occasionally referred to as the **reversing layer**, is the lower portion of a much larger zone extending a few thousand kilometres from the surface and called the chromosphere. These outer zones have no sharp boundaries and gradually merge into one another; indeed, the outermost region, the corona, extends for many solar diameters before it merges into the general interplanetary medium and solar wind.

The chromosphere is only optically visible for a few seconds before and after a total eclipse of the