CHAPTER 32

Solar Physics

INTRODUCTION 32.1

As you awake one morning, a cheery radio weather presenter announces:

> The weather forecast this morning is for moderate to high temperatures, sunlight early yielding 620 watts per square metre rising to 980 watts per square metre on the coast and 1100 watts per square metre inland. Those in southern regions will require battery reserves.

In the future, this scenario could prove true for communities that have their electrical power generation supplemented by solar energy. The Earth's star is a self-sustaining nuclear fusion reactor whose output is an incredible 4×10^{26} W, of which central Australia receives only about 1.0×10^{3} W m^{-2} on the ground. If the nuclear reactions in the Sun's core were to be switched off now, it would be 10 million years before the outer solar surface started to cool and before the Earth would feel the effects. Such is the power of the Sun!

Even animals are affected by solar processes. On 7 July 1988, 3000 homing pigeons were released from cages in northern France for their annual race back home towards southern England. Two days before, unusual solar flare activity had sent vast clouds of charged protons and subatomic particles into space, some of which disrupted the Earth's magnetic field patterns. In poor weather the pigeons used internal magnetic compasses to guide them. Misled by the solar disturbances caused to the Earth's magnetism, the pigeons flew way off course. Most of the 3000 never returned!

Solar physics is the study of the Sun's energy processes and the ways in which modern technology can use both its heat and its light. One of the best examples of solar technology assisting engineering was the feat of American aeronautical engineer Paul MacCready, who designed the famous *Solar challenger* human-powered aircraft. In July 1981, Steve Ptacek pedalled this aircraft, whose wings were covered with solar cells on their upper surfaces, over 262 km from Cormeilles en Vexin near Paris, across the English Channel to Manson in Kent.

In this chapter we will look at the Sun itself, the major methods of obtaining energy from the Sun, both passively and actively, as well as one of the main dangers to the health of all Australians, namely, ultraviolet radiation.

SOLAR RADIATION 32.2

The Sun as a star

Our Sun, called *Sol*, dominates the planetary system that includes the Earth. The Sun provides the input energy for most of the food webs that make up our natural environment. The Sun radiates energy at the tremendous rate of 4.0×10^{26} W, of which the Earth receives approximately 1.8×10^{17} W at its outer atmosphere. About half of this actually reaches the ground and provides the driving energy for our climate and weather systems as well as the photosynthetic requirements of plants as the food chain producers.

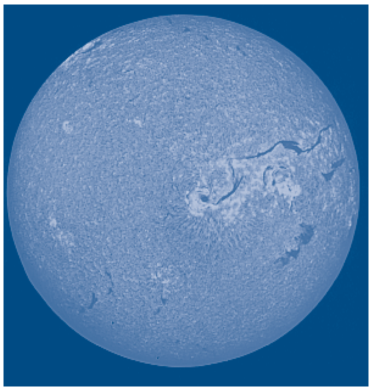
The Sun has been studied scientifically since the time of Galileo (1611), who used the first telescopes to discover sunspots on its surface. Table 32.1 lists the physical data of the Sun. It is a very average star by comparison with those in the rest of the universe and is about half-way through its lifespan — middle-aged you might say, with only about 4.5 billion years left to keep radiating its energy. Our next nearest stellar neighbour is the bright star in the Centaurus (pointers) constellation called Alpha Centauri, at 4.3 light-years distance.

Table 32.1 SOLAR DATA

Diameter	1.39×10^9 m	Spectral type	G
Mass	1.99×10^{30} kg	Mean distance	149 597 000 km (8.3 light-minutes)
Specific gravity	1.409	Rotation period (equatorial)	25.38 days
Axial inclination	7° 15′	Absolute magnitude	+4.71
Effective temperature (black body)	5800 K	Escape velocity	617.5 km s^{-1}

In 1814 the German physicist Joseph von Fraunhofer used a spectroscope to break the Sun's light radiation up into its component wavelengths and examined it carefully. Recall that Isaac Newton had also performed spectral dispersion with a prism as early as 1666. Fraunhofer's spectral analysis enabled an explanation of the solar atmosphere. He found that the continuous emission spectrum of the Sun was crossed by a complex set of dark lines. It was Gustav Kirchhoff in 1859 who showed that these dark **Fraunhofer lines** were actually absorption lines caused by atoms present in the low pressure solar atmosphere lying between the Sun's source of light, called the **photosphere**, and the experimental observer. By comparing these lines with the emission spectra of known elements on Earth, it was shown that the Sun itself contains most of the known elements. The inert gas helium was named because of this. In 1889 the American astronomer George E. Hale invented the spectroheliograph (Greek *helios* = 'Sun'), which enabled the Sun to be studied in the light emitted by one element alone, such as the light of hydrogen or calcium. Today, spectral filters can do much the same job.

Photo 32.1
Sun's surface features.



Like all stars, the Sun is composed mostly of hydrogen, together with helium (27%) and other heavy elements (2%). At the core of the Sun, the temperature is 16 000 000 K and has a density about 150 times that of water. In these conditions hydrogen nuclei fuse to produce helium via reactions called **nuclear fusion**. The solar nuclear fusion process is actually a series of three collisions between atomic particles called the 'proton–proton cycle'. The three collision processes are not of equal probability but end up fusing four hydrogen nuclei (protons) into one helium nucleus. As the final helium nucleus is only 99.3% as massive as the original four protons the missing energy appears as gamma rays and a neutrino according to Einstein's $E = mc^2$ formula. The neutrino is totally unreactive and escapes the Sun very quickly, while the gamma rays may bounce around internally for millions of years. Even though the timescale for the proton–proton cycle is large, the staggering number of particles in the Sun means a massive amount of total energy is continuously released via gamma rays that radiate outward toward the convection layers of the Sun. It is in this outer one-third of the Sun's volume that large-scale convective turbulence not only reduces the temperature but produces most of the Sun's radiation energy. The photosphere is the top surface of these convection cells, which give it a mottled appearance called **solar granulation**. The granulated cells on the photosphere last typically for 5–15 minutes and are about 2000 km in diameter. The temperature of the photosphere is about 6000°C. The German-born American physicist Hans Bethe was awarded the 1967 Nobel prize for physics for his work on the fusion cycle reactions that are the source of the Sun's tremendous energy production.

Sunspots

Sunspots are smaller regions of the photosphere that are, on average, 2000°C cooler than their surroundings and depressed into the surface slightly. They tend to occur in pairs. In 1908 George E. Hale discovered that they contain very strong magnetic fields, with each pair containing magnetic flux that points in opposite directions, either into or out of the Sun's interior. A sunspot cycle occurs, in which the number of sunspots varies from a maximum to a minimum over an 11-year cycle. As a new 11-year cycle begins, the magnetic polarity of the leading sunspot of each pair in each hemisphere of the Sun's surface reverses. This represents a full solar cycle of 22 years. Sunspots forming early in the cycle in each hemisphere tend to start at higher latitudes (45°) than sunspots later in the cycle (10°). These cyclic changes seem to indicate a definite connection between the Sun's magnetic field, the convection zone in the Sun's outer layers, and the Sun's rotation period itself, which is faster at its equator than at its poles.

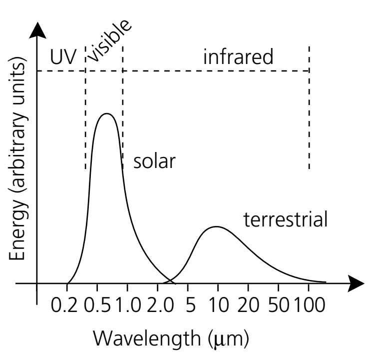
Solar flares and prominences

The Sun's **chromosphere** (Greek *chroma* = 'colour') rises to about 9600 km above the photosphere, with an average density about one thousand times less than the photosphere and a temperature of about 30 000 K. Elements in the chromosphere absorb light and produce the Fraunhofer lines in the Sun's emission spectrum. The upper layer is not uniform but produces **spicules** or high temperature gas plasma eruptions that are continuously penetrating the outer layer or **corona** (Greek *corona* = 'crown'). Because of the continuous agitation, plasma particles are being thrown off into space, causing the **solar wind**, which eventually reaches the Earth. Near sunspots the chromosphere radiation is more active, producing very rapid releases of magnetic energy and plasma particles called **solar flares**. Among the phenomena that accompany solar flares are intense X-rays, radio waves and other energetic particles that may also eventually reach the Earth to cause auroral displays and disrupt radio and telecommunications services.

The corona extends for several solar radii from the disc of the Sun itself. All the structural detail within the corona is due to the solar magnetic field. The corona is at a very high temperature of about 1 000 000°C indicating very high particle velocities. Occasionally, the corona traps low temperature plasma emissions on a large scale from the chromosphere. These produce **prominences**, which may extend out from the Sun's surface for hundreds of thousands of kilometres and are best seen during periods of solar eclipses at the edge of the Sun's disc. These prominences can also release tremendous numbers of particles into the solar wind. The largest recorded could have swallowed the Earth many times over.

Solar radiation at the Earth

Figure 32.1
Solar and terrestrial energy emissions.



The Earth receives a constant energy flow from the Sun of about 1.23×10^{17} W (122 500 TW). As the Earth gains thermal energy its temperature will rise but, like any hot body, its rate of energy emission also increases with temperature. If the received and emitted thermal energies were equal in wavelength this would lead to an average equilibrium temperature of about −17°C for the Earth. Fortunately, the Earth reradiates its thermal energy at much longer wavelengths, as shown in Figure 32.1. These longer wavelengths are absorbed by the atmospheric water vapour and carbon dioxide. This absorbed energy is reradiated with about 85% of it returning to further heat the Earth to an average global value of 15°C (288 K). This effect is called the **greenhouse effect** and without it most life forms on Earth would die. The commonly held view that the greenhouse effect is bad stems from a misunderstanding of the basic effect. Modern technology needs to be applied to reduce the emissions of greenhouse gases into the atmosphere. This will prevent an increase in the natural greenhouse effect, which would lead to a rise in average temperatures or **global warming**. The planet Venus has an atmosphere of dense carbon dioxide, which produces a surface temperature of 470°C through its natural greenhouse effect. Let us hope the Earth never gets to this point.