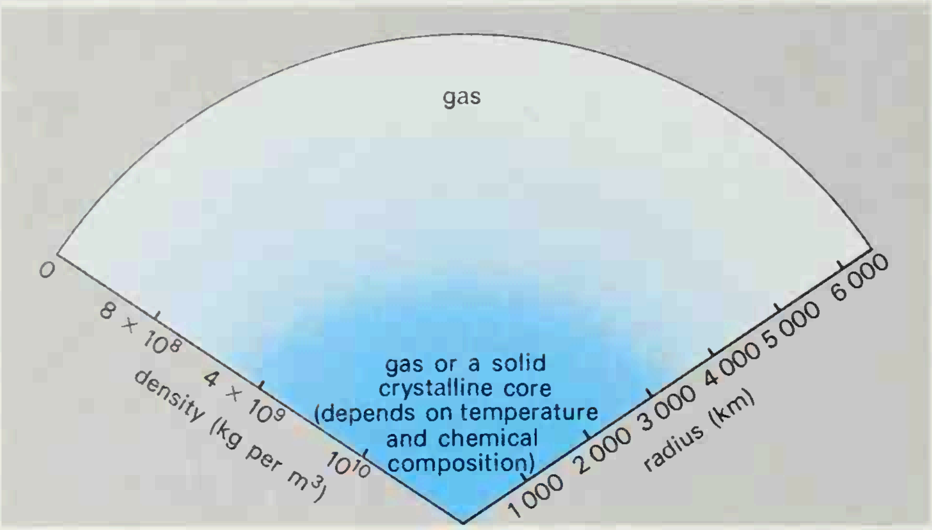


Fig. 3·23 Sector diagram of a white dwarf illustrating how the interior density varies with distance from centre. The model is for a 0·9 solar mass star and the radius is virtually the same as for the Earth. The central temperature is 10^6 K and the core is liquid if composed of carbon, but becomes solid for all heavier elements. A white dwarf composed mainly of iron would be virtually totally solid.

White dwarfs

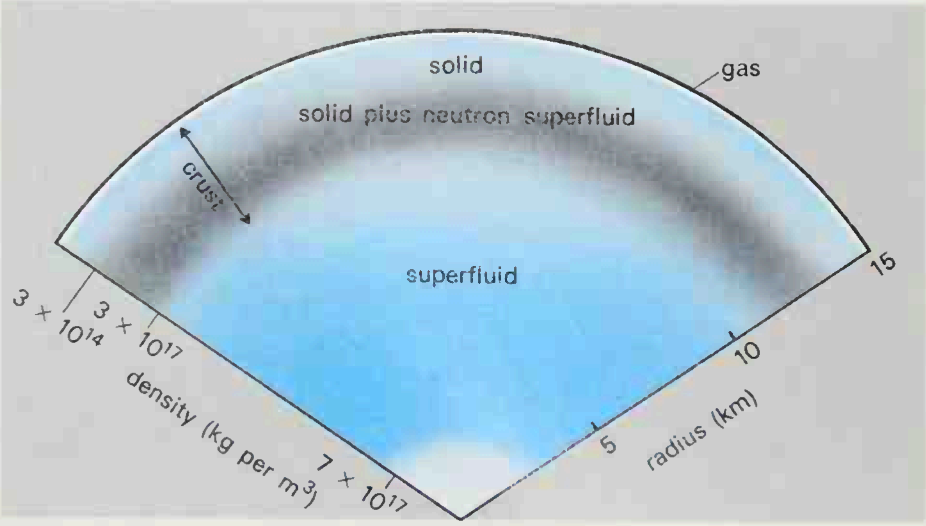
White dwarfs are stable because their gravitational pressure is balanced by their electrons resisting being squeezed. Indeed, the behaviour of degenerate materials like this depends only on its density, and the mass of the degenerate particle (in this case the electron). Unlike normal matter, it is not dependent on temperature, with the dramatic consequences of burning we have seen for the helium flash. Another consequence is that as the mass of a degenerate body increases the radius shrinks, so the most massive white dwarfs are the smallest! However, there is a maximum mass that a white dwarf may attain – the Chandrasekhar mass limit of 1·4 $M_\odot$. Beyond this the velocities of the electrons become **relativistic** (that is, they approach the velocity of light), the degenerate material becomes unstable and a rapid collapse begins until, perhaps, the neutron star state is reached. The internal structure of a white dwarf is shown in Fig. 3·23.

The observational evidence for white dwarfs is strong. It began in 1862 with the observation of a dim companion star to Sirius, a companion whose presence had been predicted nearly 20 years earlier by Friedrich Bessel to explain a wobble in Sirius' motion. In the early 1900s, spectroscopic measurements showed that this companion had the same surface temperature as Sirius, although it was ten magnitudes fainter! This then made it a very strange object occupying a deserted region of the H–R diagram.

Now because the luminosity of the binary companion, Sirius B, was 10 000 times less than Sirius although their surface temperatures were the same, the temperature-luminosity relationship (page 45) showed that Sirius B must be 100 times smaller (that is, $R \sim R_\odot/50$). But study of the orbital motion of the pair showed that it had a mass about equal to the Sun ($M_\odot$). Therefore, with a density of nearly 10^5 times that of the Sun, Sirius B had to be a white dwarf.

Many other similar stars have now been found in the Galaxy and many more are probably present though unseen because, as they grow older, they cool until they become too faint to observe.

Fig. 3·24 Cross section of the interior of a neutron star. The core composition is unknown but will probably be a mix of exotic elementary particles. The rigid crust is a good electrical conductor and pins the enormously strong magnetic field to the surface, making it sweep out a region of space as the neutron star rotates. The mechanism for pulsar emission is believed to originate somehow with this rotating magnetic field plasma.



Neutron stars

Neutron stars are, by any stretch of the imagination, exotic. Like white dwarfs their internal stability comes from their atomic particles resisting squeezing, although neutrons not electrons are doing this. The high number of neutrons have mostly been formed by electrons reaching relativistic velocities and interacting with protons to produce neutrons. The entire structure of a neutron star is really bizarre; it has a mass of about one solar mass but a radius of only 10 km!

In some ways it looks more planetary than stellar, although further comparison quickly vanishes. The crust is extremely rigid, 10^{18} times more so than steel, and, because of the tremendous gravitational force, surface features are minor. The highest mountain would be measured in millimetres and climbing it would require the same energy as carrying 10^7 kg to the summit of Everest! The internal structure is shown in Fig. 3·24.

It is now thought that the exotic objects which give rise to the **X-ray bursters**, where pulses of energy lasting only 3 to 100 seconds are observed, include a neutron star as one component of a binary system. In a similar manner to the nova mechanism (page 65) these produce the X-ray pulses by accretion of material on to the neutron star. The gravitational fields around neutron stars are so strong that relativistic effects have to be taken into account, and it would seem that these X-ray bursters can only be properly explained if a modified theory of gravity proposed by J. W. Moffat, and for which there is other evidence, is accepted.