FYI A Cosmic Balancing Act

Toward the end of stars' lives, their cores come under increasing gravitational force due to their decreasing size. The gravitational force becomes so strong that the structure of the matter at the atomic scale may be changed. Clouds of loosely bound electrons that surround the nucleus of every atom push against each other and act as the glue that holds ordinary matter together. Under Earthbound conditions, forces are never great enough to compress the electron clouds and move them closer together. Only under extreme conditions in a laboratory, or in the very dense core of a star, can matter be squeezed enough to increase its density beyond its normal value. Gold has a density of 19.3 g/cm^3, about 19 times denser than water. Using ordinary force, you will find that no matter how hard you pound on a roll of gold foil, no matter what size your sledgehammer, you will never exert enough force to overcome the electron-cloud force and increase the density of the gold beyond 19.3 g/cm^3.

Density of Ordinary Earth Materials

Material	Density (g/cm^3)
Planet Earth	5.5
Granite	2.7
Iron	7.9
Water	1.0
Air	0.001225
Oil	0.8
Aluminum	2.7
Platinum	21.4

In the later stages of life for low-mass stars, however, gravitational forces compress the core of the star, and the core decreases in volume. Atoms form a super-hot plasma—a state of matter that exists only at temperatures of millions of degrees. In a white dwarf star, nuclear fusion no longer generates thermal pressure to support the star against gravitational collapse. White dwarf stars' surface temperatures reach 50,000 degrees K, but they are compressed to the size of Earth, about 15,000 km in diameter. These stars are so dense that a tablespoon of star matter would weigh ten tons. At this tremendous density and temperature, unusual things occur.

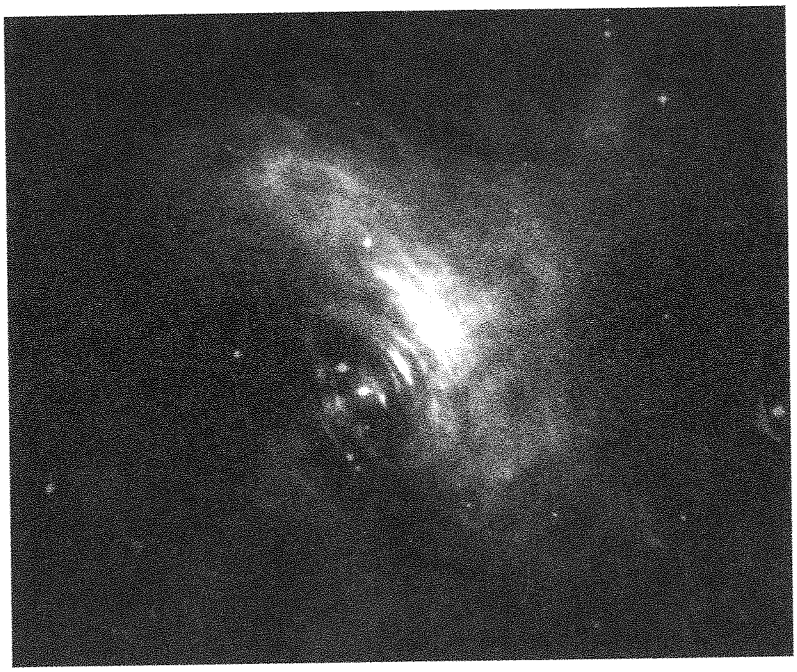
At this great temperature and density, all the possible energy states for electrons around an atom are filled, and the star is said to be in the state of **electron degeneracy**. Electrons around an atom must occupy specific energy states, and there cannot be any two atoms in the exact same state. Therefore, in a very hot and dense gas, the extra electrons build up an outward-pushing pressure called *electron degeneracy pressure*. But the electron degeneracy that supports the white dwarf star can only hold up so much mass. If the mass of the star exceeds 1.4 solar masses, the star will collapse under its own gravitational force—even electron degeneracy pressure is not great enough to support it—and the stellar core will become even more dense. The maximum mass that a white dwarf can have is called the **Chandrasekhar limit**. As white dwarfs increase in mass, their volume decreases, leading to higher pressures exerted on the core of the star. Most white dwarfs are small, averaging 0.6 solar mass.

Inside a more massive star, the layers of the star implode upon the core, and several solar masses are compressed beyond the ability of electron degeneracy to hold up the material in the star. Electrons are pressed so close to protons that they combine to produce neutrons. The core becomes a ball of neutrons, essentially a large nucleus about 20 km in diameter, the size of a city on Earth. The star is said to be in a state of **neutron degeneracy**, and the nuclear forces hold up the star. Since normal atoms are mostly empty space, a ball of neutrons has an incredibly high density—a tablespoon of neutron star would weigh 250,000 tons. The maximum mass that can be in a neutron star is thought to be about 2.5 solar masses.

Although there are limits to the amount of force that can be exerted by degenerate states of matter in white dwarf and neutron stars, there are NO limits that govern the mass of the star and the resulting force of gravity exerted on the core.

Checking In

1. What characteristic determines whether a white dwarf, neutron star, or black hole forms at the end of a star's life?
2. Explain electron degeneracy pressure in your own words.



An x-ray image of the center of the Crab nebula