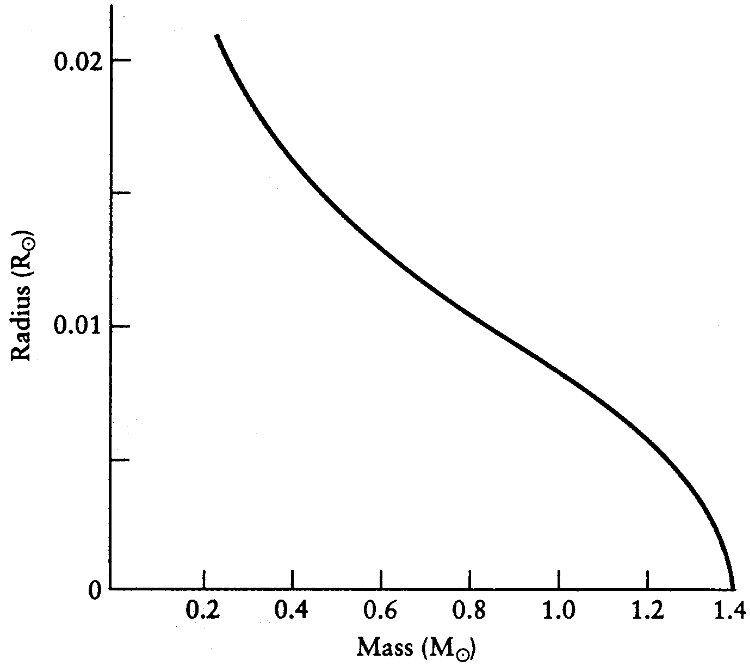
What Happens to Matter at the Centers of Stars and Why is there a Limit to the Masses of Stellar Cores?

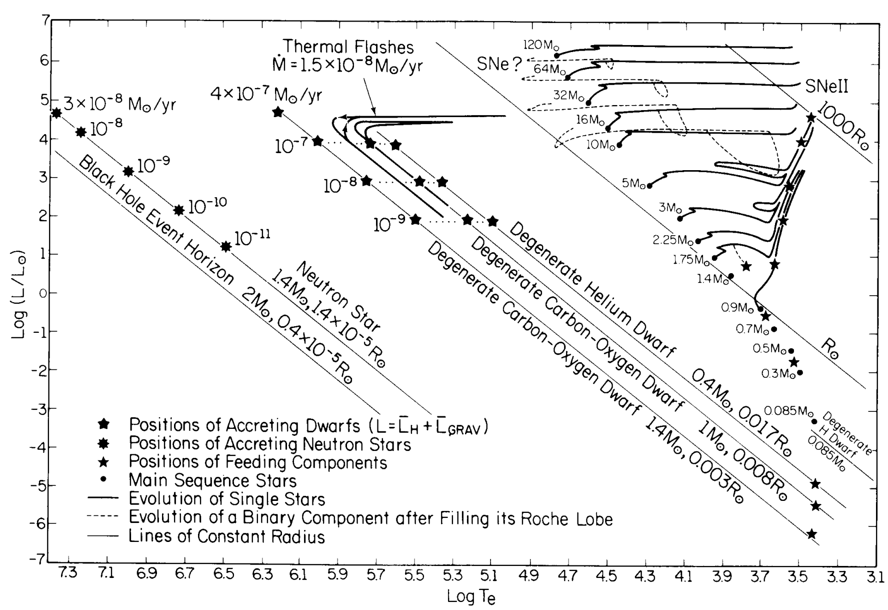
- Red Giant stars have a composite structure with:
  - A core supported by quantum pressure consisting of Helium or Carbon/Oxygen/Neon and lacking any nuclear energy source.
  - A shell source which provides the stellar luminosity in a transition layer with little mass and which is supported by high temperature pressure. This layer is where Hydrogen is converted to Helium and possibly includes a conversion of the Helium to a mixture of Carbon, Oxygen and Neon.
  - An outer envelope which has convection currents mixing matter and carrying energy throughout most of its volume. This part of the star must have a high abundance of Hydrogen.
- The core grows continuously due to the conversion of Hydrogen into Helium and/or Carbon/Oxygen/Neon in the shell source.
- The increased mass in the core must be supported by quantum pressure so we need to know what happens to the density as the pressure increases.

The structure of the core is largely independent of the presence of the outer envelope and shell source. It can be approximated as being just a White Dwarf embedded inside some large structure. Therefore, a way to understand what happens to the core is to discuss the simpler case of the structure of a White Dwarf.

White Dwarf Structure



This figure shows that the radius of a white dwarf decreases as the mass increases. At a critical mass, the radius becomes zero which means that the solution is no longer valid. For a larger mass in the core, something else must happen such as a collapse to a neutron star or a stellar explosion.

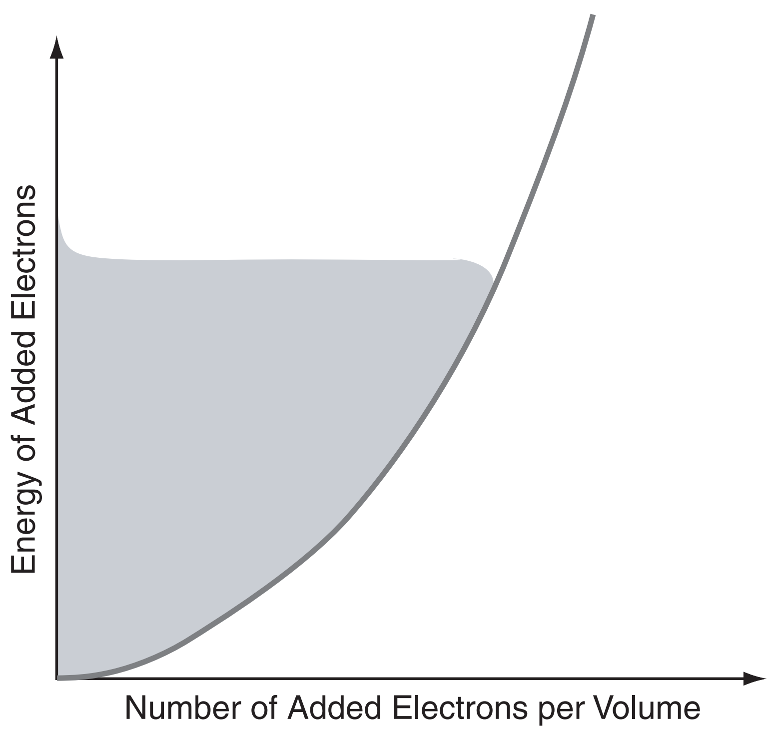


This figure shows the evolutionary positions of the White Dwarfs and Neutron Stars with relationship to the rest of the Hertzsprung-Russell diagram evolution of Red Giants.

What happens to the Electrons and the Pressure they Exert?

We have to start by understanding what makes up pressure. The gases in the Earth's atmosphere push on our skin or on airplane wings because the molecules constituting the gas are in motion and bump into surfaces. Whenever a molecule bumps into a surface, its direction is changed. Just as you must push on an opposing linebacker to reverse his direction and keep him from reaching your quarterback, the airplane wing must push on the molecule to reverse its direction. If the linebacker is running quickly toward your fullback, you will have to exert a larger force to reverse his direction; if he is heavier you will also have to push harder to stop him. The pressure is the sum of all these collisions and could be measured in terms of the product of the number of linebacker per second crossing the line of scrimmage per second times their average velocity times their mass.

For the case of the red giant core, we have to ask how does the energy and velocity of the electrons increase as we add more mass to a fixed volume. This is governed by the laws of quantum mechanics and has the form below:



How does the situation change at very high densities?

The continual increase in required pressure brought about by the growing red giant core eventually causes the energy of the last electrons added to reach a level where it is comparable to the rest mass of the electron. At this point the laws of special relativity must be introduced. The results we will need as applied to the red giant core are:

- No particle can move faster than the speed of light.
- When the energy of motion for a particle is less than its rest mass energy $E = m_{\text{rest}}c^2$, added energy goes into increasing velocity.
- When the energy of motion for the particle is larger than its rest mass energy, added energy goes into the mass leaving the velocity near the speed of light.

These rules show that the rest mass energy of the electron provides a critical transition. When the top energy of the electrons in the volume is greater than this value, added energy increases the push required to reverse the electron direction but it does not increase the rate at which the electrons cross the line of scrimmage. For densities below this critical level, increasing the energy of the electron increases both the push required for the reversal of direction and the rate of line of scrimmage crossing.

> For the highest densities, the matter is less able to resist further compression than is true of the lower densities. If a white dwarf is composed entirely of regions where all the electrons have energies higher than their rest energies, the only solution is for a zero radius.

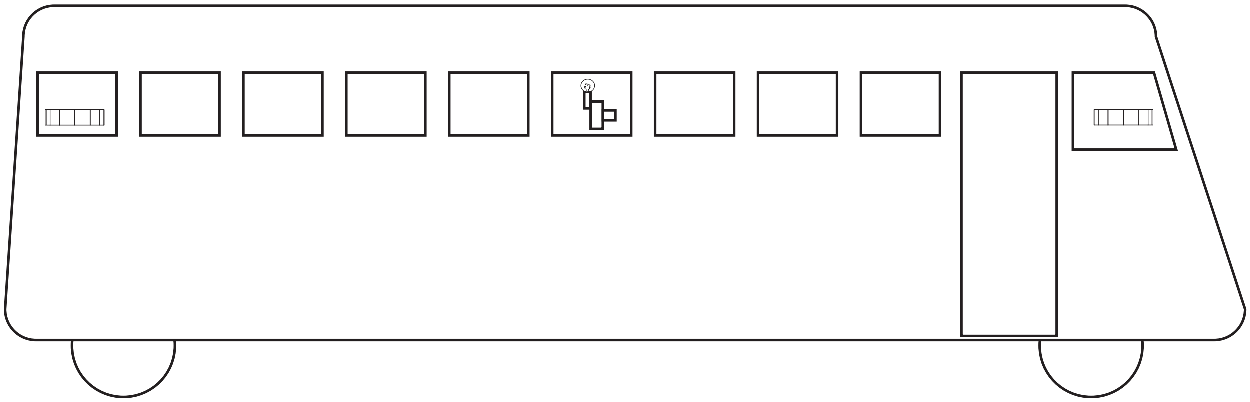
Introduction to Special Relativity

The essential points about special relativity revolve around the nature of observations and the fact that no observer has a preferred state. All observers must measure the speed of light to be the same. This requirement leads to the results that:

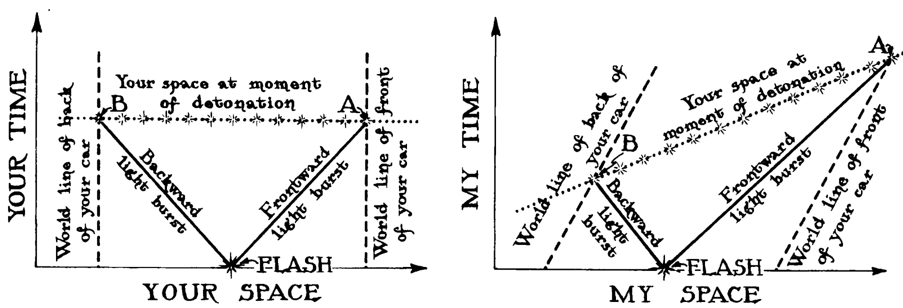
- Clocks run more slowly when they are in motion.
- Distances in the direction of motion are shorter than they are when the objects are at rest.
- Both above statements are made by one observer referring to objects in motion relative to him. An observer on the moving object would make the same statements about the outside observer who becomes in motion relative to the inside observer.
- Observers disagree about the simultaneity of events.

To describe the problem consider a Resurrection Tour by the Rolling Stones put on by means of cloned DNA in the year 2065. The Resurrected Rolling Stones are travelling in a large and very fast tour bus. They have decorative mirrors hung at the front an back of the bus and are shooting off flash bulbs to entertain the crowd. As the bus speeds by the roadside is lined with fans all taking digital movies of the passing bus and their cameras all include a little time stamp which is accurate to the nearest nanosecond (a billionth of a second). The question is: When do the flashes from the central bulb reach the front and back of the bus and get recorded by the fans.

Diagram of the Rolling Stones Resurrection Tour 2065



The nature of the measurement is described by the following diagram:



The tour group on the bus near the front and back record the same time of arrival of the flash since the flash bulb is in the middle of the bus and the distance to each of their digital recorders is the same. For the fans outside the bus, the situation is different. After the flash goes off, the light photons going toward the front must catch up with the moving bus so they have to travel further. The photons traveling to the rear find that the bus is catching up to them so they hit the mirror earlier. Therefore the fans outside comparing their images afterward find that the photons did not hit the mirrors simultaneously whereas the tour group on the bus concludes that they did.