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Solutions to Assignment 8

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1 Ch. 20 #1

The horizontal branch is like a second main sequence but instead of core Hydrogen fusion a star on the horizontal branch is undergoing core Helium fusion. The horizontal branch is located above the main sequence and to the left of the red giant branch on the H-R diagram. This means that horizontal branch stars are hotter but less luminous than red giant branch stars.

Ch. 20 #3

The asymptotic giant branch (AGB) is the last leg of a massive stars life when it is burning different elements in different shells around the core, the heavier elements closer to the core where it is hotter and denser. It is a bit like a second red giant phase but instead of just Hydrogen shell fusion, there is in addition to Hydrogen fusion in the outer-most fusing shell, Helium fusion as well as fusion of heavier elements in deeper layers. These stars have an onion like structure to them. The AGB is located above the red giant branch. This means that AGB stars are about the same temperature but more luminous than red giant stars, so they are bigger.

Ch. 20 #11

A white dwarf is the remnant of a medium sized star. After core Helium fusion the core is composed of Carbon and Oxygen. When this core begins to collapse it an electron degeneracy pressure builds, and if the core is less than 1.4 solar masses (the Chandrasekhar limit) this pressure will be enough to hold that core up. This means that the core will not contract any more and therefore will not get hot or dense enough for Carbon fusion of occur. A white dwarf produces light because it is a black body, just like the Sun, but since there is no energy source inside this star it will slowly fade away.

Ch. 20 #12

White dwarfs with more mass have smaller radii than less massive white dwarfs. See p.532. For other stars, the relationship is reversed; more massive stars have the larger radii. Roughly speaking this is because the higher pressures and temperatures inside of more massive stars accelerate the fusion process so they tend to puff out more.

2 Ch. 20 #13

The Chandrasekhar limit is the maximum mass that a white dwarf can have. Any higher and the electron degeneracy pressure will be insufficient to hold the star up. If a Carbon Oxygen core is inside of a massive star, degeneracy pressure is never enough to hold it up and Carbon fusion proceeds with no problem. But if the carbon oxygen core is the left over remnant of a medium sized star, it can sit out in space forever without fusing carbon. Now if we find that white dwarf in a binary system with another star (a less massive one) that is on the red giant branch and puffing matter out into space, some of the matter will collect onto the white dwarf. The white dwarf will gain mass and shrink until it reaches 1.4 solar masses. At that point degeneracy pressure gives out and the core collapses, spontaneously fusing all of the carbon in the naked core. This dramatic event is known as a Type 1a supernova. Type 1a supernovas are very important in astronomy because they help us measure large distances in space. They are very luminous so we can see them in other galaxies, but more importantly they are all exactly the same (Carbon cores of 1.4 solar masses) so they're luminosities can be inferred, so we can tell their distances to us from their brightness here on Earth.

3 Ch. 20 #15

Again, white dwarfs are held up by electron degeneracy pressure, not thermal pressure like other stars. This pressure is independent of temperature and therefore does not need the heat from thermonuclear reactions. A white dwarf can therefore radiate away all of its heat into space and still not collapse.

Ch. 20 #22

An aging massive star will have many layers or shells where fusion of different elements is taking place.

Ch. 20 #25

During a core collapse the protons in the Iron nuclei combine with electrons to form Neutrons. This process releases neutrinos. We can detect neutrinos, even though they rarely interact with matter, by watching a very large quantity of water with very sensitive light detectors. If a neutrino does interact with a water molecule the process produces light that we can measure. Neutrinos from supernovas are much more energetic that those produced in the Sun and we can tell the difference in the light that they produce in water.

4

If the products of a fusion reaction have less mass per nuclear particle than the atoms going into the reaction, the reaction will produce energy (from the extra mass). If the product has more mass per nuclear particle than the reactants the reaction will require (absorb) energy.

5

Ch. 20 #14

See the Cosmic Connections H-R Diagram on p. 534. The Sun will have about half its mass as a white dwarf. The rest of the mass will be ejected in the form of a “planetary nebula”.

Ch. 20 #16

A white dwarf is the relic that remains at the very end of the evolution of a star between about 0.4 and 4 solar masses. Thermonuclear reactions are no longer taking place in its interior, but it maintains such high temperatures with such a small radius because the burnt-out core is so dense that most of the electrons in the core are degenerate. The pressures in the white dwarf do not depend on temperature so even as it cools it remains nearly the same size. A red dwarf is a cool main-sequence star with a mass between about 0.08 and 0.4 solar masses. The energy emitted by a red dwarf in the form of light comes from its core, where fusion reactions convert hydrogen into helium. A brown dwarf has internal pressures and temperatures too low to sustain nuclear reactions. A brown dwarf releases energy because it is slowly contracting, a process that releases energy.

Ch. 20 #17

Most of the white dwarfs astronomers have detected are relatively close to the sun because they are very faint objects. Try calculating the luminosity of a white dwarf based on its radius and surface temperature.

Ch. 20 #19

Temperature can be thought of in terms of the motions of particles in a gas. The higher the temperature, the faster the atoms in a gas are moving about. In order for thermonuclear reactions to take place, the temperature must be high enough so that gas atoms (of Hydrogen, for instance), will have enough speed to fuse together when they collide.

Ch. 19 #31

Our sun is not likely to become a supernova because it lacks the mass. Only stars with initial masses of 8 times that of the sun will undergo a violent explosion at their final stages of stellar evolution.

6

a) Stars don't burn forever. If they are heavy enough to achieve internal pressures and temperatures high enough, two Silicon atoms (atomic weight 28.0855, 2X28.0855 = 56.171) fuse to produce one Iron atom (atomic weight 55.845, which is less than 56.171). The mass of two Silicon atoms is more than the mass of one Iron atom, and the extra mass goes into energy production ($E=mc^2$). If a star were to then fuse two iron atoms (2X55.845 = 111.69) to produce Cadmium (atomic weight 112.411) it would need to add (112.411-111.69 =) 0.721 atomic mass units. This extra mass would have to come from energy ($m=E/ c^2$) provided by the star. If the product of a fusion reaction is any element greater than Iron the reaction would require energy rather than produce it and that reaction could not sustain a star.

b) The rare elements are those that require energy to produce (anything above Iron in the table of elements). These are not produced in significant quantities in stellar thermo-nuclear fusion.

7

a) High mass stars achieve high internal pressures and temperatures, enough to produce energy by fusing elements up to Iron. They are heavy enough to overwhelm the electron degeneracy pressure that hold up Carbon Oxygen cores (called White Dwarfs when they're by themselves) and eventually wind up with an iron core that will not produce energy from fusion no matter how hot it gets.

b) When the core of a massive star has turned completely to Iron it will not produce any more energy from fusion reactions to provide the temperatures and pressure necessary to hold the star up. A core collapse supernova ensues. When the Iron atoms are compressed enough the electrons combine with the protons to form neutrons. This reaction releases neutrinos.