Table 1 The 8 stages in the life of the sun. The size is relative to its size at present. Abbreviations: M for million (10^6) and B for billion (10^9).

		Lifetime	Temperature		Radius
			Center	Surface	
1	Interstellar Cloud	0.1Myr	10K	10K	10^8
2	Protostar	10Myr	1MK	4000K	6
3	Main-sequence Star	10Byr	15MK	5600K	1
4	Red Giant	1.3Byr	50MK	3000–5000K	3–100
5	Helium Burning Star	100Myr	200MK	5000K	10
6	Double Shell-burning Red Giant	20Myr	250MK	3000–5000K	3–500
7	Planetary Nebula	0.1Myr		3000K	1000
	Star in center		300MK	100,000K	0.01
8	White Dwarf (newly formed)		200MK	50,000K	0.01

1. The solar system including the sun is 4.6 billion year old. Consider a carbon nucleus that eventually became part of my hand. That nucleus existed before the sun formed.

   a. (3 pts.) Describe a possible environment of that carbon nucleus 1 billion years ago.

   One billion years ago, the earth was no longer young. Possible environments: (1) In a rock. Many types of rocks have carbon. (2) In the air. Air has carbon dioxide. (3) In the ocean. Carbon dioxide is dissolved in oceans.

   b. (3 pts.) Describe a possible environment of that carbon nucleus 5 billion years ago.

   At this time the sun (and earth) had not formed. Possible environments: (1) In the space between stars. Later the material would have to be pulled together by gravity and form part of earth. (2) In a star. The star would have to explode or shed its outer layers to get the carbon nucleus out into space. Then the same scenario must occur as in (1).

   c. (3 pts.) Describe a possible environment of that carbon nucleus 8 billion years from now when the sun is dead.

   Possible environments: (1) in interstellar space. In stage 4 or 6, the carbon nucleus is stripped off of earth by the huge sun. When the sun sheds its outer parts, either in stages 4 or 6, the carbon nucleus is thrown into interstellar space. (2) On earth. The carbon nucleus would have to be buried in rock to prevent what happens in possible environment #1.

2. The Life of the Sun.

   a. (2 pts.) Why is no lifetime given for the white dwarf stage?

   A white dwarf does not change into anything else.

   b. (2 pts.) Why is the central temperature of stages 4, 5, and 6 hotter than that of the present sun?

In stage 4, the sun had to shrink because it ran out of fuel in the core. By shrinking, the temperature increased enough to burn hydrogen in a shell. In stages 5 & 6, helium is fusing to form carbon. Since helium has twice the charge of hydrogen, the electric repulsion is 4 times as strong. Therefore it takes a greater speed (and a higher temperature) to overcome the repulsion.

c. (2 pts.) For which of stages 3-7 will the earth be inside the sun? (The earth is 100 solar radii from the sun.) The answer changes over the course of some stages.

In the red giant and double shell burning red giant stages, the outer part of the sun is large enough to engulf earth.

d. (3 pts.) Scale the lifetimes of Stages 1-7 by a factor of 10^{-10}. For example, the lifetime as a main-sequence star is $10\text{Byr} \times 10^{-10} = 1\text{yr}$. Express your answers in terms of years, months, days, hours, minutes, seconds, whichever yields a small integer. (1 month=0.03yr. 1day=0.0003yr. 1hr=0.0001yr. 1min=2e-6yr. 1s=3e-8yr) Use a scale where 10 Byr is 1 year. (1 pt.) In the scaled time, how old is the sun? (1 pt.) In terms of the scaled time, how long does the shortest stage(s) last?

Stage	Calculation	Answer
1 Interstellar cloud	0.1Myr 1e-10=0.1 1e-10=1e-5yr min/(2e-6yr)	5min
2 Protostar	(500min) 100 times longer	10hr
3 Main sequence star	10Byr 1e-10	1yr
4 Red giant	0.13 as long	2mo
5 Helium Burning Star	10times as long as #2	4days
6 Double Shell-burning Red Giant	Twice as long as #2	10min
7 Planetary Nebula	Same as #1	5min

e. (6 pts.) For stages 2-7, how is the sun producing energy?

In the proto-star stage, the sun is shrinking. Gravitational energy is changing into kinetic energy. In stage 3, hydrogen is fusing to produce helium. In stage 4, hydrogen is fusing in a shell. In stage 5, helium is fusing to produce carbon. In stage 6, hydrogen and helium are fusing in two shells. In stage 7, the energy source is complicated, even on Wikipedia. (Not graded.)

f. (4 pts.) Simplicio reasons, "For stage 8, the sun has run out of fuel to burn. Therefore it will not produce any light." Correct Simplicio's misconception, and explain to him why he is wrong.

In stage 8, the sun *has* run out of fuel, and it is not producing any energy. However, it has stored up energy that is released as light.

g. (2 pts.) Why is the sun in stage 8 so much smaller than it is now?

The physics of pressure is different in a white dwarf. In a white dwarf, the quantum mechanical motion causes pressure. In other stages, motion of hot gas causes pressure.-