Review Questions Ch. 16 RQ 1-19 (odd) and TorF 1-20 (all)

Chapter Review Answers

REVIEW AND DISCUSSION

1. Refer to Figure 16.2 for help in answering this question. The regions are:

(a) core—where energy is generated through fusion of hydrogen into helium
(b) interior—a layer of thick gasses that light from the core must travel through
(c) convective zone—where convection is the primary source of energy transfer
(d) photosphere—the "surface" of the Sun, where the gas is thin enough for light to escape
(e) chromosphere—a layer of low-density gas above the photosphere
(f) corona—the outermost atmosphere, which fades into the solar wind

The radius of the core is 200,000 km, the interior is 300,000 km thick, convective zone is 200,000 km thick, photosphere is 300 km thick, chromosphere is 3000 km thick, and the corona extends about a few million km above the chromosphere.

2. The Sun has 332,000 times the mass of the Earth.

3. The solar surface (the photosphere) is at a temperature of 5800 K and the interior is at a temperature of approximately 15 million K.

4. Luminosity is a measure of the true brightness or total energy output of an object. For the Sun, it can be measured by experimentally determining how much solar energy is received by 1 square meter at the distance of the Earth from the Sun. This is then multiplied by the surface area of a sphere whose radius is the semimajor axis of the Earth's orbit.

5. The Sun's energy output is fueled by nuclear fusion of hydrogen into helium. In this process that takes place in the core of the Sun, 4 hydrogen atoms (really just protons) come together and fuse to form a heavier element—helium. In this process, a small amount of mass is "lost." That missing mass has been converted to energy. According to Einstein's famous equation, $E = mc^2$, a small amount of mass can become a large amount of energy.

6. Six hydrogen atoms go into the proton-proton chain. What comes out is 1 helium nucleus, 2 neutrinos, 2 positrons (which are quickly annihilated by colliding with electrons), energy in the form of gamma rays, and 2 hydrogens. Thus, only 4 hydrogen atoms are consumed to make the helium.

7. The mass of helium produced by the nuclear fusion is 0.7% less than the mass of the 4 hydrogens that were fused to make it. This small amount of "lost" mass is converted into energy. The amount of energy is easily calculated from $E = mc^2$.

8. Knowing basic facts about the Sun, especially the fact that it is made primarily of light gasses, allows astronomers to predict the entire structure of the Sun. This is known as a model. The model is correct if it successfully predicts observed properties of the Sun, such as its luminosity, radius, and temperature. Some of the input information to the model is uncertain, but the results suggest how correct this input data is. By making slight adjustments in the input parameters, the model is adjusted until its predictions are in agreement with all the observed properties. Once the model "works," astronomers are then able to learn from the model about the properties in the interior of the Sun. Models are used as a test to see whether we fully understand the structure and processes of objects. They are also then used to predict properties that may not be directly observable. Models also make predictions of observables that help us further test the validity of the model.

9. Helioseismology is the study of waves that ripple across the surface of the Sun. Some of these waves travel from deep inside the Sun. Their appearance on the surface provides information about the interior of the Sun that cannot otherwise be observed, such as temperature, density, and rotation speed.

10. The oscillations observed on the solar surface are equivalent to seismic waves observed on Earth, although they are different in origin. The patterns of the waves are influenced by the internal structure of the Sun. Models of the solar interior predict how the waves should behave; observed waves suggest how the models need to be modified until there is agreement between observations and models.

11. The solar radiation is first produced in the core of the Sun, largely in the form of gamma rays. Because the gas in the core is totally ionized, it is transparent to radiation and so the radiation passes through it freely. However, as we get closer to the surface, the temperature drops, and more and more of the gas is not ionized, or only partially ionized. Such a gas is opaque to radiation. At the outer edge of the radiation zone, all the radiation has been absorbed by the gas. This heats the gas and it physically rises, while cooler gas from the surface falls. This is the region of convection. The energy is transported by convection to the photosphere. Here, the density of the gas is so low that radiation can freely escape into space, and travel in a straight line to Earth.

12. Virtually all the visible radiation we receive from the Sun comes from a thin layer called the photosphere. It is only 500 km thick—a small fraction of the Sun's radius. The gas below the photosphere is too thick for light to escape, and the gas above is too thin to absorb and emit significant quantities of light. Light can only escape from this narrow region, so the Sun has a very well-defined edge.

13. "Coronium" was first discovered in the 1920s when spectra of the Sun's corona, visible during a solar eclipse, showed emission lines never before seen. These mysterious lines were at first thought to indicate the presence of a new element, "coronium." Further investigation showed that these lines were actually due to known elements, but in unfamiliar, highly ionized states. The extreme ionization is due to the corona's very high temperature, about 1 million K.

14. Because the corona of the Sun is hot, some of the gas particles are traveling fast enough to escape the gravity of the Sun. The gas is mostly composed of the separated components of ionized hydrogen, protons, and electrons. This flow of high-speed particles away from the Sun is known as the solar wind.

15. Activity in the Sun's magnetic field creates the cycle of sunspots seen on the Sun. The solar magnetic field reverses itself every 11 years, so it takes 22 years to go through an entire cycle of magnetic reversals.

Ch. 16 Homework (cont.)

16. All of these phenomena are caused by activity in the magnetic field of the Sun. Sunspots are caused by kinks or loops of magnetic field extending through the lower atmosphere. These areas of concentrated magnetic field repel hot material trying to rise up from the Sun's interior, so the section of the Sun underneath the knot cools off and darkens. Flares by contrast are areas where large amounts of energy are released in a short period. Their origin is mysterious, but they are somehow connected to instabilities in the magnetic field. Prominences are caused by material ejected from the Sun's surface that follows along huge loops of magnetic field that carry the luminous gas far above the solar surface.

17. A coronal mass ejection is a cloud of ionized gas that travels quickly from the surface of the Sun to Earth, where it will mostly be captured by the Earth's magnetic field. Some of it can get through, however, and ionize the upper atmosphere. This can affect radio communication. The particles are swept along by the magnetic field and can induce large currents in electrical power grids, knocking them out. Earth satellites are particularly vulnerable to these electrical and magnetic storms because of their delicate electronics and exposed position above the atmosphere.

18. Neutrinos are produced in the proton-proton chain, which occurs in the core of the Sun. The neutrinos pass unimpeded through the Sun at nearly the speed of light. Therefore, neutrinos, in a sense, allow astronomers to observe directly the core of the Sun and the processes that occur there, almost as they happen. For a long time, astronomers were puzzled because the Sun did not seem to be producing as many neutrinos as predicted. A combination of more sophisticated measurement techniques and a better understanding of neutrino behavior has solved this problem, however, and predictions are more in line with observations.

19. There were two possible explanations for the low number of solar neutrinos received on Earth: either the Sun was under-producing neutrinos, or something was happening to the neutrinos as they traveled to Earth. The first possibility was disturbing, as it would likely require the Sun's core to be cooling by 10%. But what could alter a neutrino across the void of space? Recently, we have discovered that there are different kinds of neutrinos, and that they can transform into each other during the trip to Earth through "oscillations." By creating neutrino detectors that can detect different neutrinos, we have confirmed that the Sun is producing all the neutrinos we expect it to.

20. Light waves can take millions of years to fight their way out of the thick gasses in the Sun's interior, while neutrinos fly out in a straight line at almost the speed of light. Therefore, if we have a means of detecting neutrinos, we would know within minutes if nuclear fusion in the Sun were to shut down. If we only relied on visible light, however, it could take millions of years before the Sun would start to dim.

CONCEPTUAL SELF-TEST

1. T
2. T
3. F; Mass is "lost" as it is transformed into energy.
4. T
5. F; Hot gas rises and cool gas sinks.
6. F; Elements produce multiple absorption lines.
7. F; The density is much lower.
8. F; Sunspots are cooler than their surroundings.
9. T
10. F; We have finally been able to detect all the different kinds of neutrinos.
11. C
12. B
13. C
14. A

15. A
16. B
17. B
18. C
19. C
20. B