Answers to Chapter Questions

Chapter 1

1. (a). It is estimated that there are 10^{11} stars in our galaxy. This can be estimated by assuming that the solar system is in a circular orbit around the center of the galaxy. Using R = 30,000 light-years and T = 200,000,000 years, Newton's Law of Gravitation can be applied ($G = 6.67259 \times 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$):

$$\frac{GM_{galaxy}M_{ss}}{R^2} = \frac{4\pi^2 M_{ss}R}{T^2} \rightarrow M_{galaxy} = \frac{4\pi^2 R^3}{GT^2}$$

This gives, for M_{galaxy} is 3.4×10^{41} kg, and using 10^{30} as a typical star mass gives 3.4×10^{11} as the number of stars in the galaxy.

(b). From the estimated size of the Universe (radius of 15 billion light-years) and distribution of galaxies, it is estimated that there are about 10^{11} galaxies in the Universe.

(c). $10^{11} s \times \dfrac{1y}{365.24d} \times \dfrac{1d}{86400s}\ s \cong 3169\ years\ \ or\ \ about\ \ 3,000\ years$

(d). $10^{11}\ stars/galaxy \times 10^{11}\ galaxies/universe \approx 10^{22}\ stars/universe$

(e). $10^{22}\ stars/universe \times 10^{30}\ kg/star \approx 10^{52}\ kg/universe$
This is the mass of the visible stars. It is now believed that there must be a large amount of mass we can't see in the form of "dark matter."

2. Just as an "Earth-year" is the time for Earth to travel around the Sun (the period of revolution of the Earth), a Sun-year is the time for the Sun to travel once around the center of the galaxy. This time is estimated to be 200,000,000 years.
(a). This occurs when the Sun is about 10 billion years old.

$$10\ billion\ yrs \times \frac{1\ Sun\text{-}year}{.2\ billion\ yrs} = 50\ Sun\text{-}years\ old$$

(b). About the same age. It remains a red giant for about 250 million years or 1.25 Sun-years.

(c). $15\ billion\ yrs \times \dfrac{1\ Sun\text{-}year}{.2\ billion\ yrs} = 75\ Sun\text{-}years\ old$

3. Time could be added as another axis, in the third dimension (out of this page), like a z-axis.

4. Conservation of Angular Momentum: Iw = I'w'

$$since\ I = \frac{2}{5}MR^2\ \ (for\ a\ sphere)$$

$$\text{and } w = \frac{2\pi}{T} \quad : \left(\frac{2}{5}MR^2\right)\left(\frac{2\pi}{T}\right) = \left(\frac{2}{5}MR'^2\right)\left(\frac{2\pi}{T'}\right)$$

$$\frac{R^2}{T} = \frac{R'^2}{T'} \rightarrow T' = \left(\frac{R'}{R}\right)^2 T$$

$$using\ R' = \frac{6.95 \times 10^{8}\ m}{1.49 \times 10^{11}\ m/AU} = 4.66 \times 10^{-3}\ AU$$

$$T' = \left(\frac{4.66 \times 10^{-3}\ AU}{5\ AU}\right)^{2}(12\ y) \quad = 1.04 \times 10^{-5}\ y \times 365\ d/y = 3.80 \times 10^{-3}\ days$$

$$= 5.5\ minutes$$

5. (a). The Sun contains all of the first 92 elements, but by far the most abundant are Hydrogen (92%) and Helium (7.8%).

   (b). Helium and carbon can be produced by fusion inside a star the size of the Sun.

   (c). For larger stars, elements in the periodic table up to Iron (#26) can be produced.

   (d). Elements 27 to 92 are formed in the Super Nova process.

6. Ideas, models, and calculations of how a star ends its life are still evolving, and so some of the specifics may undergo change in the future. Generally, if a star has about the mass of the sun, it goes through a red giant stage and then eventually becomes a white dwarf. A white dwarf has a mass about the Sun's mass or greater, but a size only as big as Earth, and eventually cools down to become a cold, black dwarf.

   More massive stars may lose some of their mass during their lifetime. Their final mass determines what becomes of the stars. Mass losses during the life of a star are poorly known, but it is now thought that stars with initial masses up to 6 or 8 solar masses can end up as white dwarfs. Stars whose final mass is greater than 1.4 solar masses (the Chandrasekhr limit) cannot end up as white dwarfs. Stars that initially have between 8 and 20 solar masses end up as neutron stats, many of them shedding mass by becoming supernovas. Stars with initial masses more than 20 solar masses are also thought to form neutron stars in an intermediate stage, but if the neutron star mass is greater than some limit (not known exactly, but probably between 1.6 and 2.4 solar masses), a new stellar collapse occurs and nothing can stop it—there is no form of pressure that can counteract gravity and an unlimited collapse continues. The core becomes a black hole in less than one thousandth of a second.

Chapter 2

1. Sun-Earth distance $= 1.5 \times 10^{8}\ km \quad = 1.5 \times 10^{11}\ m$

$$use\ v = \frac{\Delta x}{\Delta t} \rightarrow t = \frac{x}{v}$$

   (a). $t = \frac{1.5 \times 10^{11}\ m}{3.0 \times 10^{8}\ m/s} = 500\ s = 8\,\text{min}\,20\ s$

   (b). Same as (a) since $V_{x\text{-rays}} = 3.0 \times 10^{8}\ m/s$

   (c). 400 *km/s* = $4 \times 10^{5}\ m/s \rightarrow t = \frac{x}{v} = \frac{1.5 \times 10^{11}}{4.0 \times 10^{5}} = 3.75 \times 10^{5}\ s \approx 4.34\ days$

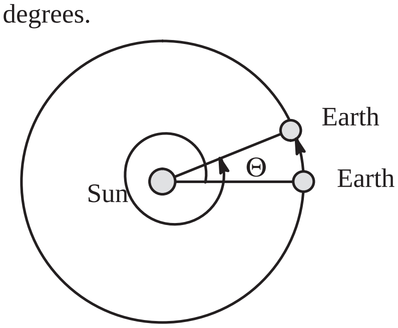
   (d). 500 *mi/hr* = 223 *m/s* $\rightarrow t = \frac{1.5 \times 10^{11}}{2.23 \times 10^{2}} = 6.71 \times 10^{8}\ s \approx 21.3\ y$

2. $v = \frac{2\pi R}{T}$ from circular motion

R = $6.95 \times 10^{8}\ m$, T = 26.8 days = $2.32 \times 10^{6}\ s$

$$v = \frac{(6.28)(6.95 \times 10^{8}\ m)}{(2.32 \times 10^{6}\ s)} = 1.88 \times 10^{3}\ m/s$$

3. (a). 8000 K (b). 4300 to 50,000 K (c). about 10^{6} K
4. (a). About 10^{-6} kg/m^3 (b) $\sim 10^{-4}$ kg/m^3 (c). 10^{-17} kg/m^3
5. .7% of total mass disappears, or 0.007 $\times$ mass of He^4.
   He^4 has mass of 4 atomic units or $4 \times m_p = 4 \times 1.67 \times 10^{-27}$ *kg per atom*
   Mass that disappears = $(0.007)(6.68 \times 10^{-27}) = 4.68 \times 10^{-25}$ *kg*
   Energy that appears = E=mc^2 = $(4.68 \times 10^{-25})(3.0 \times 10^{8})^2 = 4.20 \times 10^{-8}$ *joules per reaction*
   $$\frac{10^{26}\ J/s}{4.21 \times 10^{-8}\ J/reaction} = 2.38 \times 10^{33}\ reactions/s$$
6. 5×10^{6} *tons/s* $\times$ 907 *kg/ton* = 4.536×10^{9} *kg/s*
   $$\frac{1.99 \times 10^{30}\ kg}{4.55 \times 10^{9}\ kg/s} = 4.39 \times 10^{20}\ s = 1.39 \times 10^{13}\ yrs$$
   About 10,000 times longer than the age of the Earth!
7. $$E_k = \frac{3}{2}k_B T = \frac{1}{2}mv^2$$
   $$v = \sqrt{\frac{3k_B T}{m}} = \sqrt{\frac{3\ (1.38 \times 10^{-23})(1.5 \times 10^{7})}{1.67 \times 10^{-27}}} = 6.1 \times 10^{5}\ m/s$$
8. $$P = K_B T\left(\frac{N}{v}\right) \to \left(\frac{N}{v}\right) = \frac{P}{K_B T} = \frac{1.01 \times 10^{5}\,\frac{N}{m^2}}{(1.38 \times 10^{-23})(293)} \qquad \frac{(1\ atmosphere,\ sea\ level)}{(room\ temperature)}$$
   NOTE: for Boulder, CO, use 0.83 instead of 1.01 in the above equation.
   (a) $\left(\frac{N}{v}\right) = 2.5 \times 10^{15}\ \frac{particles}{m^3}$
   (b) Assuming that the particles are protons with *m* = 1.67×10^{-27} *kg*:
   $$10^{-6}\frac{kg}{m^3} \times \frac{1\ particle}{1.67 \times 10^{-27}\ kg} = 5.99 \times 10^{23}\ \frac{particles}{m^3}$$
   (c) Assuming a density of $2 \times 10^{9}\frac{kg}{m^3} \times \frac{1\ particle}{1.67 \times 10^{-27}\ kg}$
   $$= 1.2 \times 10^{27}\ \frac{particles}{m^3}$$
9. Synodic rotation period is seen from Earth. Relative to the stars, the Sun had actually "over-rotated" by Θ degrees.



$$\Theta = \frac{28\ days}{365\ days} \times 360^{o} = 27.6^{o}$$

or Sun has actually rotated

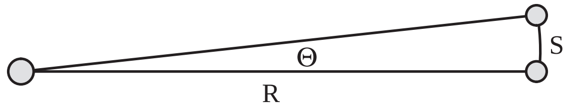
$$360^{o} + 27.6^{o} = 387.6^{o}$$

Sidereal Period will be

$$\frac{360^{o}}{387.6^{o}} \times 28\ days\ = (93\%) \times 28\ days = 26\ days$$

Chapter 3

1. Angular size = $\Theta = \frac{S}{R}$



$$\Theta_{Moon} = \frac{Diameter}{Earth\text{-}Moon\ distance} = \frac{3.48 \times 10^6\ m}{3.8 \times 10^8\ m} = 9.16 \times 10^{-3}\ rad \times \frac{360^o}{2\pi\ rad} = 0.525^o$$

$$\Theta_{Sun} = \frac{Diameter}{Earth\text{-}Sundistance} = \frac{1.39 \times 10^9\ m}{1.5 \times 10^{11}\ m} = 9.27 \times 10^{-3}\ rad = 0.531^o$$

The angular sizes are nearly identical so the Moon almost exactly covers the disk of the Sun during a total eclipse. This reveals the reddish chromosphere which lies just outside the bright disk of the photosphere.

2. (a). White light is a mixture of nearly all the visible wavelengths. The visible wavelengths arise from energy level transitions in atoms at temperatures of about 6000 K, which is typical of the photosphere and low chromosphere.

   (b). The Hα wavelength of 656 nm results when Hydrogen atoms make the transition from the 2nd excited state to the first excited state, emitting a 1.9 *eV* photon. This occurs at temperatures of about 4000 K found in the low chromosphere.

   (c). Ultraviolet light (UV) originates in the high chromosphere at temperatures of about 70,000 K. This UV results from transition in atoms.

   (d). X-rays are largely the result of plasma rapidly decelerating as it slams into denser material. This occurs when plasma from flares returns and collides with the denser chromosphere. These are known as Bremsstrahlurg x-rays.

   (d) and (e). Radio and microwaves (really the same) are generated when charges are driven into circular motion as they wrap around magnetic field lines. This happens during flares. Radiation from charges in circular motion is known as synchrotron radiation.

3. The Zeemann effect is the splitting of emission lines which occurs when the emitting atom is in a magnetic field. By studying the Zeemann effect on light from the Sun, we can estimate the strength of the field at the place on the Sun where the light originates. Magnetograms (or magnetic maps) are constructed in this way.

4. In white light the sunspots appear clearly but no other features are apparent. In Hα many other features appear. The most important of these are filaments. In the x-rays, coronal holes and other evidence of coronal activity can be seen.

5. The energy levels in eV of hydrogen can be found from $E_n = 13.6 - \frac{13.6}{n^2} = 13.6\left(1 - \frac{1}{n^2}\right)$

   n = 1 gives 0 (the ground state); n = 2 gives 10.20 *eV* and n=3 gives 12.09 *eV*. The transition from the n = 3 to the n = 2 energy level produces a photon of energy 12.09 – 10.20 = 1.89 *eV*. The wavelength of this photon is given by $\lambda = \frac{hc}{E}$.

   A convenient form of this is $\lambda = \frac{1240\ eV \cdot nm}{E} = \frac{1240\ eV \cdot nm}{1.89\ eV} = 656\ nm$

6. See section 3.2

7. See section 3.2 and Figure 3–4.

8. See section 3.3 and Figure 3–5.

9. See section 3.3

10. See section 3.4

11. See section 3.5

12. Similar to problem 1 (a), Chapter 1
Using the Law of Gravitation and the centripetal force equation:

$$F = \frac{GM_{earth}m_{satellite}}{R^2} = \frac{4\pi^2 m_{satellite}R}{T^2}$$

solving for R (orbit size): $$R = \left[\frac{GM_{earth}T^2}{4\pi^2}\right]^{1/3}$$

$$= \left[\frac{(6.67 \times 10^{-11}\ m^3kg^{-1}s^{-2})(5.98 \times 10^{24}\ kg)(8.64 \times 10^4\ s)^2}{4\pi^2}\right]^{1/3} = 4.22 \times 10^7\ m$$

In Earth radii: $$\frac{4.22 \times 10^7\ m}{6.38 \times 10^6\ m/radius} = 6.62\ radii$$

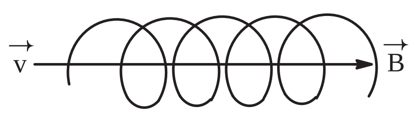
13. A black body absorbs all radiation falling on it. No light reflects, hence it is black. By Kirchhoff's law, a body which completely absorbs all wavelengths emits all wavelengths. So we have come to speak of "black body radiation" as that radiation which has all wavelengths in accord with Planck's law.

Chapter 4

1. $F = qvB = \frac{mv^2}{R}$ $\qquad v = 400\frac{km}{s} = 4 \times 10^5\frac{m}{s}$

$$R = \frac{mv}{qB} = \frac{(1.67 \times 10^{-27})(4 \times 10^5)}{(1.6 \times 10^{-19})(1 \times 10^{-7})} = 41,750\ m\ or\ 41.8km$$

With a component of velocity along $\vec{B}$ field lines, the motion will be corkscrew-like:



2. Fluctuations in the solar wind cause large voltages to be induced in the magnetosphere. Part of this EMF causes currents to flow along magnetic field lines between the magnetosphere and ionosphere. As solar wind intensity changes, so does the strength of this current. This varying current has its own magnetic field which combines with Earth's field to produce a changing magnetic field of the surface of the Earth. Such a changing field induces currents in any conductors, such as power lines or pipe lines.

3. Magnetic reconnection is the joining of the Sun's and the Earth's magnetic fields, and occurs most readily when the two fields are antiparallel. When the fields are joined, solar wind material can more readily enter the magnetosphere, enhancing the energy input to the magnetosphere.

4. Low-orbiting satellites can be engulfed in the Earth's atmosphere as it expands due heating from increased radiation levels from the Sun. This encounter with the atmosphere causes a frictional drag on satellites, which causes them to drop in their orbits, and possibly fall to Earth prematurely. High-orbiting satellites are often exposed to energetic particles during intervals of high solar activity. These particles can cause damaging charge buildups, degrading solar panel output and can destroy or damage microelectronic devices.

5. Magnetohydrodynamics (MHD) is a study which combines features of fluid dynamics and Maxwell's Equations. It is hoped that MHD can provide a model which can be used to predict solar activity and its resulting effects on Earth.