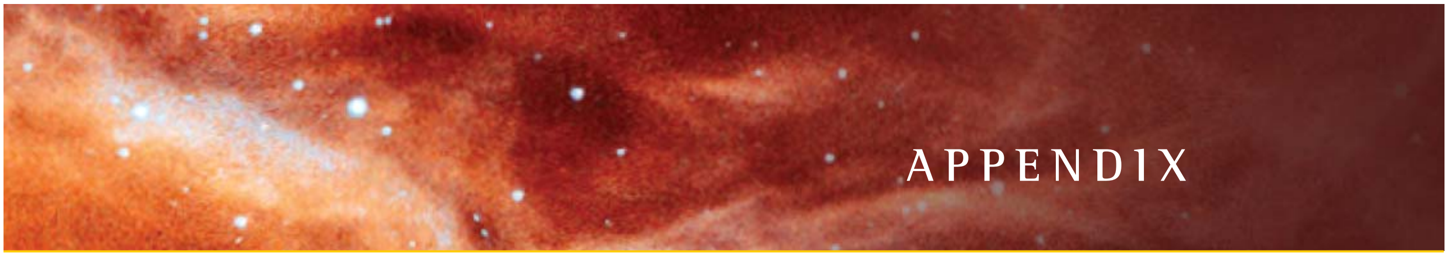


APPENDIX

APPENDIX A: Powers-of-Ten Notation

Astronomy is a science of extremes. As we examine various cosmic environments, we find an astonishing range of conditions—from the incredibly hot, dense centers of stars to the frigid, near-perfect vacuum of interstellar space. To describe such divergent conditions accurately, we need a wide range of both large and small numbers. Astronomers avoid such confusing terms as "a million billion billion" (1,000,000,000,000,000,000,000,000) by using a standard shorthand system. All the cumbersome zeros that accompany such a large number are consolidated into one term consisting of 10 followed by an *exponent,* which is written as a superscript and called the **power of ten.** The exponent merely indicates how many zeros you would need to write out the long form of the number. Thus,

$$10^0 = 1$$

$$10^1 = 10$$

$$10^2 = 100$$

$$10^3 = 1000$$

$$10^4 = 10{,}000$$

and so forth. Equivalently, the exponent tells you how many tens must be multiplied together to yield the desired number. For example, ten thousand can be written as 10^4 ("ten to the fourth") because $10^4 = 10 \times 10 \times 10 \times 10 = 10{,}000$. Similarly, 273,000,000 can be written as 2.73×10^8.

In scientific notation, numbers are written as a figure between 1 and 10 multiplied by the appropriate power of 10. The distance between Earth and the Sun, for example, can be written as 1.5×10^8 km. Once you get used to it, you will find this notation more convenient than writing "150,000,000 kilometers" or "one hundred and fifty million kilometers."

This powers-of-ten system can also be applied to numbers that are less than 1 by using a minus sign in front of the exponent. A negative exponent tells you that the location of the decimal point is as follows:

$$10^0 = 1.0$$

$$10^{-1} = 0.1$$

$$10^{-2} = 0.01$$

$$10^{-3} = 0.001$$

$$10^{-4} = 0.0001$$

and so forth. For example, the diameter of a hydrogen atom approximately is 1.1×10^{-8} cm. That is more convenient than saying "0.000000011 centimeter" or "11 billionths of a centimeter." Similarly, 0.000728 equals 7.28×10^{-4}.

Using the powers-of-ten shorthand, one can write large or small numbers like these compactly:

$$3{,}416{,}000 = 3.416 \times 10^6$$

$$0.000000807 = 8.07 \times 10^{-7}$$

Because powers-of-ten notation bypasses all the cumbersome zeros, a wide range of circumstances can be numerically described conveniently:

$$\text{one thousand} = 10^3$$

$$\text{one million} = 10^6$$

$$\text{one billion} = 10^9$$

$$\text{one trillion} = 10^{12}$$

and also

$$\text{one thousandth} = 10^{-3} = 0.001$$

$$\text{one millionth} = 10^{-6} = 0.000001$$

$$\text{one billionth} = 10^{-9} = 0.000000001$$

$$\text{one trillionth} = 10^{-12} = 0.000000000001$$

Try these questions: Write 3,141,000,000 and 0.0000000031831 in scientific notation. Write 2.718282×10^{10} and 3.67879×10^{-11} in standard notation.

(Answers appear at the end of the book.)

APPENDIX B: Guidelines for Solving Math Problems and Reading Graphs

Astronomy relies on mathematics. Although we have distilled the concepts into words, you can gain further insights into the distances, intensities, and other astronomical quantities from the equations presented in this book. In addition, much scientific information is presented in the form of graphs, a technique that presents data very compactly and often provides a good way to see the trends that the data reveal. This appendix thus provides guidance on three things: setting up problems to be solved analytically (using equations), solving algebra equations, and reading graphs.

Setting Up and Solving Analytical Problems

At the end of most chapters, there are questions, indicated by an asterisk (*), that require mathematical solutions. You will need to translate the question into an equation or two in order to solve for some value. This is best done systematically. In what follows, we will work a question, appropriate to Chapter 2: How fast does a meteoroid (small piece of rocky space debris) of mass 5 kg (kilograms) move if it has a kinetic energy of 10 J ($1 \text{ J} = 1 \text{ kg} \times \text{m}^2/\text{s}^2$)? This approach should work for most of the questions in the book.

Step 1. ***Write down all the information you are given in terms of the variable names used in the book.*** For example, denoting mass by m and kinetic energy by KE, write: mass $m = 5$ kg, kinetic energy $KE = 10$ J.

Step 2. ***Identify and write down the thing you are trying to find in terms of its variable name.*** In this case: speed, $v = ?$.

Step 3. ***Find (usually) one or (sometimes) two equations that are needed to solve for the unknown.*** All the equations presented in the book are listed in Appendix C. For our problem, use the kinetic energy equation $KE = \frac{1}{2}mv^2$, because this equation has the unknown, v, along with only variables and constants that are given, namely KE and m. (As in this case, you will often need only one equation, but sometimes you will have to solve first one equation and then another to get the answer. As an example, you might be given the information above but asked for the value of a momentum, p, of the meteoroid. The equation for momentum, also in Chapter 2, is $p = mv$. First you would solve for the speed, as we are now doing, and then use that v in this last equation.)

Step 4. ***Manipulate the equation(s) until you have the unknown variable on one side and all the other variables and constants on the other side.*** Variables can be added, subtracted, multiplied, and divided in the same way that numbers are combined. For our example, we want to find v, so we start with $KE = \frac{1}{2}mv^2$, multiply by 2, and divide by m. This gives $v^2 = 2\ KE/m$. Because we want v, we now take the square root of both sides or $v = \sqrt{2\ KE/m}$.

Step 5. ***Make sure that all the units match up.*** Units on both sides of the equation must be identical. Period. If you have one value in kilometers (km) and another value in meters (m), then the result you will get by combining numbers is not meaningful. If you end up with inconsistent units on opposite sides of an equation, convert one unit to the other. For example, change kilometers into meters or vice versa. In this case, use the fact that $1 \text{ km} = 10^3 \text{ m}$.

Step 6: ***Plug in all the numbers and solve for the unknown.*** In our case, $v = \sqrt{2 \times 10 \text{ J}/5 \text{ kg}}$ or $v = 2$ m/s.

Reading Graphs

The graphs you will encounter in this book are compact ways of displaying patterns of information relating two variables, like the temperature and luminosity of stars or the temperature at different altitudes in an atmosphere. The relevant values of one of the variables are presented along the horizontal or x axis and the relevant values of the other variable are presented along the vertical or y axis. The word "relevant" here indicates that often graphs do not start at 0. Consider three examples. First is data presented in Chapter 7 concerning the temperature of Venus's atmosphere at different altitudes (**Figure 1**).

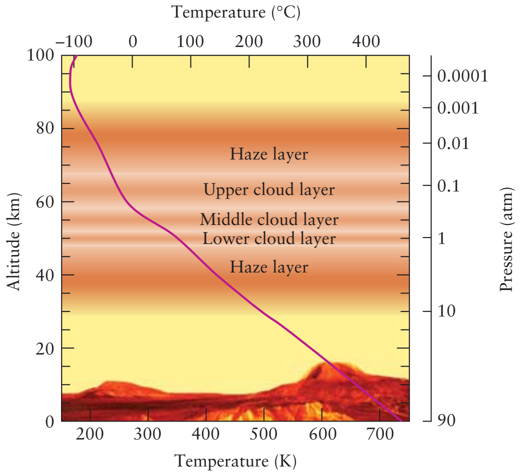


FIGURE 1 Linear Graph

The horizontal axis of the graph indicates the temperature in degrees Kelvin (K). The vertical axis denotes the altitude above Venus's surface in kilometers (km). Note that both axes are always labeled with a name (temperature or altitude, here) and units (K or km, respectively). Bear in mind that some variables in graphs you will see in this book increase to the right or upward (these are more common), but some variables will increase in the opposite directions.

To read a graph, note that a value on the horizontal axis is then transferred directly upward through the graph. For example, all points on the blue line in Figure 1 (which extends upward from 400 K) have a temperature of 400 K. Equivalently, the value given on the vertical axis is transferred to all points horizontally across from this value. All the points on the black line in Figure 1 are at an altitude of about 43 km above Venus's surface. We have interpolated between 40 and 45 to get this value (**Figure 2**).

A curve or a set of points on the graph presents the *relationship* between the variable represented on the horizontal axis and the variable on the vertical axis. Each point on a curve or each separate point relates the two variables. Choose a point, say the dot on Figure 1. It represents the temperature at a certain altitude above Venus's surface. To find the temperature at that point, you slide directly down (along the blue line in this example) from the point and read the value of the horizontal variable under it. To find the altitude for that point, you slide directly over to the side (along the black line) and read the value of the vertical variable there. In our example, sliding along the blue line leads to 400 K on the temperature line. Therefore, this point corresponds to a temperature of 400 K. Moving horizontally from the point, you encounter, by interpolation, the 43 km indicator. Combining the data, you conclude that *the temperature of Venus's atmosphere 43 km above its surface is 400 K.*

The red curve in Figure 1 provides the relationship between altitude and temperature for a wide range of locations above Venus in a representation that is much more informative than a table of heights and temperatures. Specifically, this curve shows you the trend of temperature with altitude.

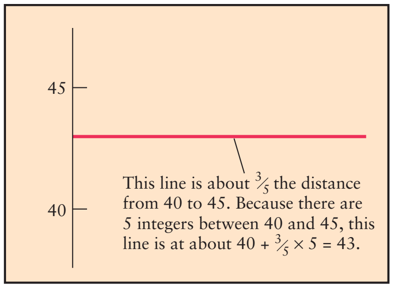


FIGURE 2 Interpolation

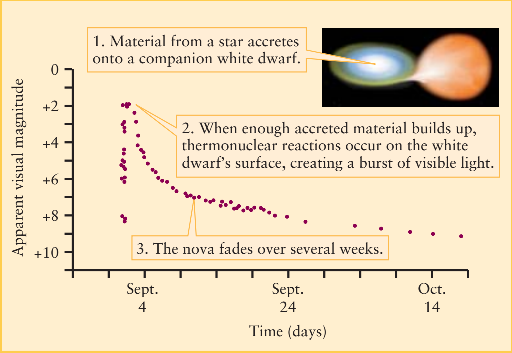


FIGURE 3 The Brightness of a Nova

Try these questions: What is the temperature at 20 km? What is the altitude at which the temperature is 300 K? For most of this graph, what is the general *trend* of the temperature with height? (Answers appear at the end of the book.)

Sometimes, the known information is not a curve, but rather a set of points, as in our second example (**Figure 3**), from Chapter 13. In this case, the graph connects the apparent magnitude of a nova (how bright it appears to be as seen from Earth regardless of its distance or other factors) and time. Each dot indicates how bright the nova (an explosion on the surface of certain stars) was at different times. For example, the peak brightness of the nova was an apparent magnitude of about +2 and it occurred on September 2. Noting that time passes to the right, you can immediately see that the trend of the nova's brightness is to increase rapidly and decrease more slowly.

Try these questions: What is the apparent magnitude on September 24? October 9? On what two days was the apparent magnitude +6? (Answers appear at the end of the book.)

The graphs so far have shown variables that change uniformly along the axes. For example, the distance on Figure 1 from 300 K to 400 K is the same as the distance from 400 K to 500 K, and so on. Many graphs you will encounter have variables that do not change uniformly (that is, linearly) along the axes. That means that the change in value going along each axis varies—there is not the same amount of change per centimeter along the axis. In **Figure 4**, from Chapter 12 and typical of graphs in the second half of the book, the temperature decreases going from left to right nonuniformly and the luminosity (total energy emitted per second) increases upward nonuniformly. These are called logarithmic scales.

The purpose of logarithmic and other nonlinear axes is to present in compact form data that varies very widely in values. For example, the dimmest star

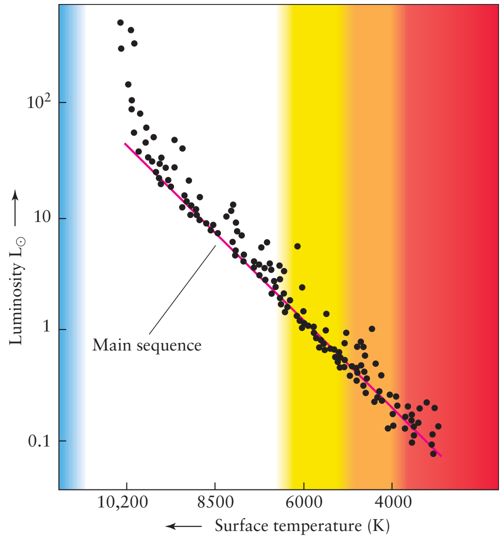


FIGURE 4 Logarithmic Graph

represented in Figure 4 is just less than 0.1 times as luminous as the Sun, while the brightest star is nearly 1000 times as luminous. The process of getting information from logarithmic graphs is the same as linear graphs. You must just be careful not to think of values as doubling or tripling when you go over or up two or three intervals. **Figure 5** shows how a logarithmic scale varies over one decade of values. The same numbering intervals apply for any decade of values, for example, 1 to 10 or 10^5 to 10^6. As you can see, the numbers bunch up near the highest value, so you need to interpolate these graphs more carefully than linear graphs.

Referring to Figure 4, the luminosity of a star with surface temperature of 4000 K is about 0.1 L⊙. Note, also, that some graphs are linear on one axis and logarithmic on the other axis.

Try these questions: Approximately what is the luminosity of a star with surface temperature 8500 K? What is the surface temperature of a star with the same luminosity as the Sun (1 L⊙)? (Answers appear at the end of the book.)

APPENDIX C: Key Formulas

Angular Momentum $L = I\omega$, where L is the angular momentum, I is the object's moment of inertia, and ω is the object's angular velocity (Chapter 2).

Area of a Circle $A = \pi d^2/4$, where π is approximately 3.14, and d is the diameter of the circle (Chapter 3).

Average Density $\rho = m/V$, where ρ is the average density, m is the total mass, and V is the volume of the object (Chapter 5).

Distance from Parallax $d = 1/p$ where d is the distance in parsecs and p is the parallax angle in arcseconds, or $d_{ly} = 3.26/p$, where d_{ly} is the distance in light-years (Chapter 11).

Distance-Magnitude Relationship $M = m - 5 \log(d/10)$, where M is the star's absolute magnitude, m is its apparent magnitude, and d is its distance in parsecs (Chapter 11).

Doppler Shift $\Delta\lambda/\lambda_o = v/c$, where $\Delta\lambda$ is the change in wavelength $(\lambda - \lambda_0)$, λ is the observed wavelength, λ_0 is the wavelength the object emits as seen by someone not moving toward or away from it, v is the speed of the object toward or away from the observer, and c is the speed of light (Chapter 4).

Drake Equation $N = R^* f_p\, n_e\, f_l\, f_i\, f_c\, L$, where N is the number of advanced civilizations in our Galaxy estimated by the equation, R^* is the rate at which solar-type stars form in the Galaxy, f_p is the fraction of stars that have planets, n_e is the number of planets per star system suitable for life, f_l is the fraction of habitable planets on which life arises, f_i is the fraction of lifeforms that develop advanced intelligence, f_c is the frac-

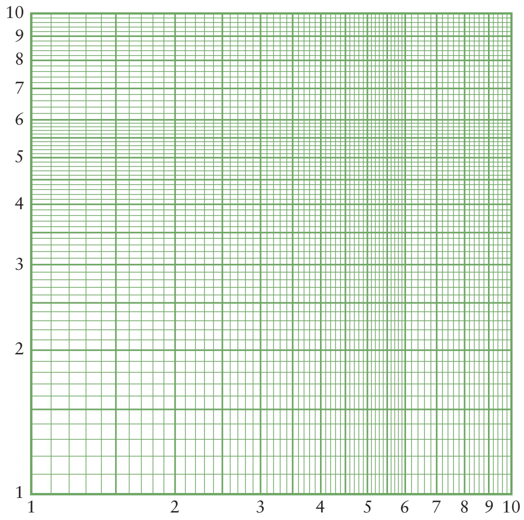


FIGURE 5 Logarithmic Scale

tion of species that develop technology and send signals into space, and L is the lifetime of technological civilizations (Chapter 19).

Energy Flux $F = \sigma T^4$, where σ is Stefan's constant and T is the blackbody's temperature in K (Chapter 4).

Energy-Mass Equation $E = mc^2$, where c is the speed of light and E is the energy released when mass m is converted to energy (Chapter 10).

Gravitational Force $F = G(m_1 m_2/r^2)$, where G is the gravitational constant, m_1 and m_2 are the masses of the two interacting objects, and r is the distance between them (Chapter 2).

Gravitational Potential Energy (always true) $PE = GmM/r$, where PE is the potential energy, G is the gravitational constant, m is the mass of the object whose gravitational potential energy you are measuring, M is the mass of the object creating the gravitational potential, and r is the distance between the centers of the two (Chapter 2).

Gravitational Potential Energy (near Earth) $PE = mgh$, where m is the mass of the object whose gravitational potential energy you are measuring, $g = 9.8$ m/s^2, and h is the height of the object above the Earth's surface (Chapter 2).

Kepler's Third Law $P^2 = a^3$, where P is the sidereal period in Earth years and a is its semimajor axis in AU (Chapter 2).

Kinetic Energy $KE = \frac{1}{2}mv^2 = p^2/2m = L^2/2I$, where KE is its kinetic energy, m is its mass, v is its speed, p is the momentum, L is the angular momentum, and I is the object's moment of inertia. The first two equalities apply if the object is moving in a straight line. The last equality applies if the object is revolving or rotating (Chapter 2).

Luminosity $L = F \cdot 4\pi r^2$, where L is the luminosity (total energy per second) emitted, F is the energy flux, and r is the radius of the object (Chapter 4).

Magnification $M = f_o/f_e$, where f_o is the focal length of the primary mirror or objective lens and f_e is the focal length of the eyepiece (Chapter 3).

Momentum $\mathbf{p} = m\mathbf{v}$, where $\mathbf{p}$ is the momentum, m is the mass, and $\mathbf{v}$ is the velocity (Chapter 2).

Newton's Force Law $\mathbf{F} = m\mathbf{a}$, where F is the force acting on an object, m is its mass, and a is its acceleration ($\mathbf{F}$ and $\mathbf{a}$ are in boldface to denote that they act in some direction or other) (Chapter 2).

Newton's Version of Kepler's Third Law for Binary Star Systems $M_1 + M_2 = a^3/P^2$, where M_1 and M_2 are the masses of the stars, a is the average distance between them, and P is the period of their orbit in years (Chapter 11).

Photon Energy $E = hc/\lambda$, where E is the photon's energy, h is Planck's constant, c is the speed of light, and λ is the wavelength of the light (Chapter 3).

Pressure $P = F/A$, where P is the pressure, F is the force, and A is the area over which the force acts (Chapter 6).

Recessional Velocity of Galaxies $v = H_0 \times d$, where v is the recessional velocity in km/s, H_0 is the Hubble constant, and d is the distance to the galaxy in Mpc (Chapter 16).

Schwarzschild Radius of a Black Hole $R_{\text{Sch}} = 2\,GM/c^2$, where R_{Sch} is the Schwarzschild radius in meters, G is the gravitational constant, M is the mass of the black hole in kg, and c is the speed of light (Chapter 14).

Size of a Distant Object $D = R \times \tan\theta$, where D is the physical diameter of an object, R is the distance to it, and $\tan\theta$ is the tangent of the angle it makes in the sky (Chapter 1).

Wien's law $\lambda_{\text{max}} = 2.9 \times 10^3/T$, where λ_{max} is the peak wavelength of the blackbody and T is the blackbody's temperature in K (Chapter 4).

Work $W = Fd$, where W is the work, F is the force acting, and d is the distance moved in the direction that the force acts (Chapter 2).

APPENDIX D: Temperature Scales

Three temperature scales are in common use. Throughout most of the world, temperatures are expressed in degrees Celsius (°C), named in honor of the Swedish astronomer Anders Celsius, who proposed it in 1742. The **Celsius temperature scale** (also known as the "centigrade scale") is based on the behavior of water, which freezes at 0°C and boils at 100°C at sea level on Earth.

Scientists usually prefer the **Kelvin scale,** named after the British physicist Lord Kelvin (William Thomson), who made many important contributions to our knowledge about heat and temperature. On the Kelvin temperature scale, water freezes at 273 K and boils at 373 K. Note that we do not use the degree symbol with the Kelvin temperature scale.

Because water must be heated by 100 K or 100°C to go from its freezing point to its boiling point, you can see that the size of a Kelvin is the same as the size of a degree Celsius. When considering temperature *changes,* measurements in Kelvins and in degrees Celsius lead to the same number.

A temperature expressed in Kelvins is always equal to the temperature in degrees Celsius plus 273. Scientists prefer the Kelvin scale because it is closely related to the physical meaning of temperature. All substances are made of atoms, which are very tiny (a typical atom has a diameter of about 10^{-10} m) and constantly in motion. The temperature of a substance is directly related to the average speed of its atoms. If something is hot, its atoms are moving at high speeds. If a substance is cold, its atoms are moving much more slowly.

The coldest possible temperature is the temperature at which atoms move as slowly as possible (they can never quite stop completely). This minimum possible temperature, called *absolute zero*, is the starting point for the Kelvin scale. Absolute zero is 0 K, or −273°C. Because it is impossible for anything to be colder than 0 K, there are no negative temperatures on the Kelvin scale.

In the United States, many people still use the now archaic Fahrenheit scale, which expresses temperature in degrees Fahrenheit (°F). When the German physicist Gabriel Fahrenheit introduced this scale in the early 1700s, he intended 0°F to represent the coldest temperature then achievable (with a mixture of ice and saltwater) and 100°F to represent the temperature of a healthy human body. On the Fahrenheit scale, water freezes at 32°F and boils at 212°F. Because there are 180 degrees Fahrenheit between the freezing and boiling points of water, a degree Fahrenheit is only 100/180 (= 5/9) the size of the other scales.

The following equation converts from degrees Fahrenheit to degrees Celsius:

$$T_C = 5/9\,(T_F - 32)$$

To convert from Celsius to Fahrenheit, a simple rearrangement of terms gives the relationship

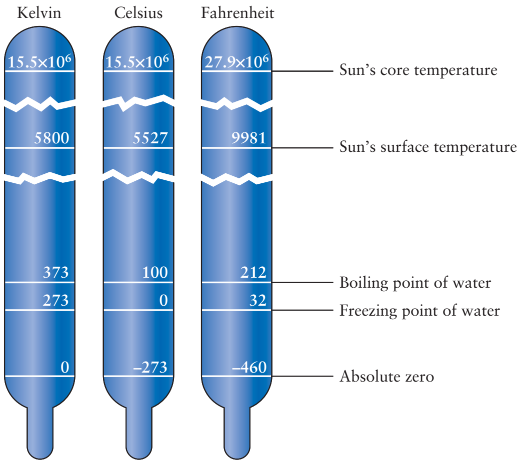
$$T_F = 9/5\,T_C + 32$$

where T_F is the temperature in degrees Fahrenheit and T_C is the temperature in degrees Celsius.

For example, consider a typical room temperature of 68°F. Using the first equation, we can convert this measurement to the Celsius scale as follows:

$$T_C = 5/9\,(68 - 32) = 20°\mathrm{C}$$

To arrive at the Kelvin scale, we simply add 273 degrees to the value in degrees Celsius. Thus, 68°F = 20°C = 293 K. The accompanying figure displays the relationships among these three temperature scales.



Try these questions: The Sun's surface temperature is about 5800 K. What is its temperature in Celsius and Fahrenheit? The temperature of empty space is about 3 K. What is its temperature in Celsius and Fahrenheit? (Answers appear at the end of the book.)

APPENDIX E: Data Tables

TABLE E-1 The Planets: Orbital Data

Planet	Semimajor axis		Sidereal period		Synodic period (day)	Mean orbital speed (km/s)	Orbital eccentricity	Inclination of orbit to ecliptic (°)
	(AU)	(10^6 km)	(year)	(day)				
Mercury	0.3871	57.9	0.2408	87.97	115.88	47.9	0.206	7.00
Venus	0.7233	108.2	0.6152	224.70	583.92	35.0	0.007	3.39
Earth	1.0000	149.6	1.0000	365.26	—	29.8	0.017	0.00
Mars	1.5237	227.9	1.8808	686.98	779.94	24.1	0.093	1.85
Jupiter	5.2034	778.6	11.862	4,332.6	398.9	13.1	0.048	1.31
Saturn	9.5371	1433.5	29.457	10,759	378.1	9.7	0.054	2.48
Uranus	19.1913	2872.5	84.01	30,685	369.7	6.8	0.047	0.77
Neptune	30.0690	4495.1	164.79	60,189	367.5	5.4	0.009	1.77

TABLE E-2 The Planets: Physical Data

Planet	Equatorial diameter		Mass		Mean density (kg/m^3)	Rotation period* (days)	Inclination of equator to orbit (°)	Surface gravity (Earth = 1)	Albedo	Escape speed (km/s)
	(km)	(Earth = 1)	(kg)	(Earth = 1)						
Mercury	4,879	0.383	3.302×10^{23}	0.055	5427	58.646	173.4	0.38	0.106	4.3
Venus	12,104	0.949	4.869×10^{24}	0.815	5243	243.02^{R}	177.4	0.91	0.65	10.4
Earth	12,756	1.000	5.974×10^{24}	1.000	5515	0.996	23.45	1.000	0.37	11.2
Mars	6,794	0.533	6.419×10^{23}	0.107	3933	1.025	25.19	0.38	0.15	5.0
Jupiter	142,984	11.209	1.899×10^{27}	317.83	1326	0.413	3.13	2.5	0.52	59.5
Saturn	120,536	9.449	5.685×10^{26}	95.16	687	0.445	26.73	1.1	0.47	35.5
Uranus	51,118	4.007	8.683×10^{25}	14.54	1270	0.717^{R}	97.77	0.91	0.51	21.3
Neptune	49,528	3.883	1.024×10^{26}	17.147	1638	0.671	28.32	1.1	0.4	23.5

** For Jupiter, Saturn, Uranus, and Neptune, the internal rotation period is given. A superscript* R *means that the rotation is retrograde (opposite the planet's orbital motion).*

TABLE E-3 Satellites of the Planets

Planet	Satellite	Discoverers of planet	Average distance from center (km)	Orbital (sidereal) period* (days)	Orbital eccentricity	Diameter of satellite (km)	Mass (kg)
EARTH	Moon	—	384,400	27.322	0.0549	3476	7.349×10^{22}
MARS	Phobos	Hall (1877)	9,378	0.319	0.02	28 × 23 × 2	1.1×10^{16}
	Deimos	Hall (1877)	23,459	1.262	0.00	16 × 12 × 10	2.4×10^{15}
JUPITER	Metis	Synott (1980)	127,960	0.2948	0.00	44	1×10^{17}
	Adrastea	Jewitt et al. (1979)	128,980	0.2983	0.00	24 × 16 × 20	1.9×10^{16}
	Amalthea	Barnard (1892)	181,300	0.4982	0.00	270 × 170 × 150	7.5×10^{18}
	Thebe	Synott (1979)	221,900	0.6745	0.02	98	8×10^{17}
	Io	Galileo (1610)	421,600	1.769	0.00	3643	8.93×10^{22}
	Europa	Galileo (1610)	670,900	3.551	0.01	3138	4.80×10^{22}
	Ganymede	Galileo (1610)	1,070,000	7.155	0.00	5268	1.48×10^{23}
	Callisto	Galileo (1610)	1,883,000	16.689	0.01	4821	1.08×10^{23}
	Themisto	Kowal (1975)	7,435,000	130.02	0.24	8	(?)
	Leda	Kowal (1974)	11,094,000	238.72	0.15	18	6×10^{15}
	Himalia	Perrine (1904)	11,480,000	250.57	0.16	170	9.5×10^{18}
	Lysithea	Nicholson (1938)	11,720,000	259.22	0.11	38	8×10^{16}
	Elara	Perrine (1905)	11,737,000	259.65	0.21	80	8×10^{17}
	S/2000/J11	Sheppard et al. (2000)	12,654,000	287	0.25	4	(?)
	Euporie	Sheppard et al. (2001)	19,017,000	553.1^{R}	0.16	2	(?)
	Chaldene	Sheppard et al. (2000)	20,375,000	723.8^{R}	0.24	4	(?)
	Iocaste	Sheppard et al. (2000)	20,733,000	632^{R}	0.22	5	(?)
	Kale	Sheppard et al. (2001)	20,804,000	721^{R}	0.48	2	(?)
	Orthosie	Sheppard et al. (2001)	20,876,000	623^{R}	0.27	2	(?)
	Thyone	Sheppard et al. (2001)	20,876,000	632^{R}	0.30	4	(?)
	Euanthe	Sheppard et al. (2001)	20,947,000	620^{R}	0.18	3	(?)
	Harpalyke	Sheppard et al. (2000)	21,019,000	623^{R}	0.23	4	(?)
	Praxidike	Sheppard et al. (2000)	21,162,000	625^{R}	0.22	7	(?)
	Ananke	Nicholson (1951)	21,200,000	631^{R}	0.17	28	4×10^{16}
	Hermippe	Sheppard et al. (2001)	21,376,000	632^{R}	0.25	4	(?)
	Taygete	Sheppard et al. (2000)	21,734,000	732^{R}	0.25	5	(?)
	Erinome	Sheppard et al. (2000)	21,948,000	728^{R}	0.27	3	(?)
	Carme	Nicholson (1938)	22,600,000	692^{R}	0.21	46	9×10^{16}
	Isonoe	Sheppard et al. (2000)	22,806,000	726	0.26	4	(?)
	Pasithee	Sheppard et al. (2001)	22,949,000	715^{R}	0.29	2	(?)
	Eurydome	Sheppard et al. (2001)	23,378,000	721^{R}	0.35	3	(?)
	Aitne	Sheppard et al. (2001)	23,449,000	741^{R}	0.29	3	(?)
	Pasiphae	Melotte (1908)	23,500,000	735^{R}	0.38	36	2×10^{17}
	Megaclite	Sheppard et al. (2000)	23,521,000	753^{R}	0.43	5	(?)
	Sponde	Sheppard et al. (2001)	23,592,000	749^{R}	0.45	2	(?)
	Sinope	Nicholson (1914)	23,700,000	758^{R}	0.28	28	8×10^{16}
	Autonoe	Sheppard et al. (2001)	23,979,000	765^{R}	0.42	4	(?)
	Kalyke	Sheppard et al. (2000)	24,164,000	743^{R}	0.24	5	(?)
	Callirrhoe	Scotti et al. (1999)	24,200,000	759^{R}	0.28	8	(?)

TABLE E-3 Satellites of the Planets (continued)

Planet	Satellite	Discoverers of planet	Average distance from center (km)	Orbital (sidereal) period* (days)	Orbital eccentricity	Diameter of satellite (km)	Mass (kg)
SATURN	Pan	Showalter (1990)	133,570	0.573	0.00	20	(?)
	Atlas	Terrile (1980)	137,670	0.602	0	40 × 30 × 30	8×10^{17}
	Prometheus	Collins et al. (1980)	139,353	0.613	0.00	140 × 80 × 100	8×10^{17}
	Pandora	Collins et al. (1980)	141,700	0.629	0.00	110 × 70 × 100	2×10^{17}
	Epimetheus	Walker (1966)	151,422	0.694	0.01	140 × 100 × 100	5×10^{17}
	Janus	Dolfuss (1966)	151,472	0.695	0.01	220 × 160 × 200	2×10^{18}
	Mimas	Herschel (1789)	185,520	0.942	0.02	392	3.8×10^{19}
	Enceladus	Herschel (1789)	238,020	1.370	0.00	444	7.3×10^{19}
	Tethys	Cassini (1684)	294,660	1.888	0.00	1050	6.3×10^{20}
	Calypso	Pascu et al. (1980)	294,660	1.888	0 (?)	30 × 20 × 25	8×10^{17}
	Telesto	Smith et al. (1980)	294,660	1.888	0 (?)	24	8×10^{17}
	Dione	Cassini (1684)	377,400	2.737	0.00	1120	1.1×10^{21}
	Helene	Laques et al. (1980)	377,400	2.737	0.01	40 × 30 × 30	8×10^{17}
	Rhea	Cassini (1672)	527,040	4.518	0.00	1528	2.3×10^{21}
	Titan	Huygens (1655)	1,221,830	15.945	0.03	5150	1.3×10^{23}
	Hyperion	Bond et al. (1848)	1,481,100	21.277	0.10	410 × 260 × 220	8×10^{17}
	Iapetus	Cassini (1671)	3,561,300	79.330	0.03	1436	1.6×10^{21}
	Phoebe	Pickering (1898)	12,952,000	550.56^{R}	0.16	220	4×10^{17}
URANUS	Cordelia	*Voyager 2* (1986)	49,752	0.335	0.00	26	8×10^{17}
	Ophelia	*Voyager 2* (1986)	53,763	0.376	0.01	30	8×10^{17}
	Bianca	*Voyager 2* (1986)	59,166	0.435	0.00	42	8×10^{17}
	Cressida	*Voyager 2* (1986)	61,767	0.464	0.00	66	8×10^{17}
	Desdemona	*Voyager 2* (1986)	62,658	0.474	0.00	54	8×10^{17}
	Juliet	*Voyager 2* (1986)	64,358	0.493	0.00	84	8×10^{17}
	Portia	*Voyager 2* (1986)	66,097	0.513	0.00	108	8×10^{17}
	Rosalind	*Voyager 2* (1986)	69,927	0.558	0.00	54	8×10^{17}
	Mab	Showalter et al. (2003)	97,734	(?)	0 (?)	26	(?)
	Belinda	*Voyager 2* (1986)	75,236	0.624	0.00	66	8×10^{17}
	Perdita	*Voyager 2* (1986)	76,420	0.638	0 (?)	20	(?)
	Puck	*Voyager 2* (1986)	86,004	0.762	0.00	144	8×10^{17}
	Cupid	Showalter et al. (2003)	74,800	(?)	0 (?)	10	(?)
	Miranda	Kuiper (1948)	129,872	1.413	0.00	−470	6.6×10^{19}
	Ariel	Lassell (1851)	190,945	2.520	0.00	−1160	1.4×10^{21}
	Umbriel	Lassell (1851)	265,998	4.144	0.01	1169	1.2×10^{21}
	Titania	Herschel (1787)	436,298	8.706	0.00	1578	3.5×10^{21}
	Oberon	Herschel (1787)	583,519	13.463	0.00	1523	3.0×10^{21}
	Caliban	Gladman et al. (1997)	7,169,000	579^{R}	0.16	80	8×10^{17}
	Sycorax	Gladman et al. (1997)	12,213,000	1284^{R}	0.52	160	8×10^{17}
	Stephano	Kavelaars et al. (1999)	>7,979,000	677^{R}	0.23	32	8×10^{17}
	Prospero	Kavelaars et al. (1999)	>16,665,000	1993^{R}	0.43	50	8×10^{17}
	Setebos	Kavelaars et al. (1999)	>17,879,000	2194^{R}	0.59	47	8×10^{17}

TABLE E-3 Satellites of the Planets (continued)

Planet	Satellite	Discoverers of planet	Average distance from center (km)	Orbital (sidereal) period* (days)	Orbital eccentricity	Diameter of satellite (km)	Mass (kg)
NEPTUNE	Naiad	*Voyager 2* (1989)	48,230	0.294	0.00	58	8×10^{17}
	Thalassa	*Voyager 2* (1989)	50,070	0.311	0.00	80	8×10^{17}
	Despina	*Voyager 2* (1989)	52,530	0.335	0.00	148	8×10^{17}
	Galatea	*Voyager 2* (1989)	61,950	0.429	0.05	178	8×10^{17}
	Larissa	*Voyager 2* (1989)	73,550	0.553	0.00	−190	8×10^{17}
	Proteus	*Voyager 2* (1989)	117,650	1.122	0.00	−415	8×10^{17}
	Triton	Lassell (1846)	354,760	5.877^{R}	0.00	2704	2.14×10^{22}
	Nereid	Kuiper (1949)	5,513,400	360.1	0.75	340	2×10^{19}

* *A superscript* R *means that the satellite orbits in a retrograde direction (opposite to the planet's rotation).*

TABLE E-4 Dwarf Planets

	Pluto	Ceres	Eris
Year of Discovery	1930	1801	2003
Semimajor axis (AU)	39.4817	2.766	67.668
Semimajor axis (10^6 km)	5906.4	413.7	10210
Sidereal period (year)	247.7	4.599	557
Sidereal period (day)	90470	1680	2.03×10^{5}
Mean orbital speed (km/s)	4.67	17.88	3.44
Orbital eccentricity	0.249	0.080	0.442
Inclination of orbit to ecliptic (°)	17.14	10.59	44.19
Equatorial diameter (km)	2390	941	2400
Equatorial diameter (Earth = 1)	0.19	0.074	0.19
Mass (kg)	1.3×10^{22}	9.5×10^{20}	1.7×10^{22}
Mass (Earth = 1)	2.2×10^{-3}	1.6×10^{-4}	2.8×10^{-3}
Mean density (kg/m^3)	2030	2080	2100
Rotation period (days)	6.388^{R}	0.3781	?
Inclination of equator to orbit (°)	122.5	4	?
Surface gravity (Earth = 1)	0.06	0.028	0.07
Escape velocity	1.2	0.51	1.3
Location	Kuiper Belt (TNO)	Asteroid Belt	TNO
Number of satellites	3	0	1

TABLE E-5 The Nearest Stars

Name*	Parallax (arcsec)	Distance (ly)	Spectral type	Radial velocity** (km/s)	Proper motion (arcsec/year)	Apparent visual magnitude	Absolute visual magnitude	Luminosity (Sun = 1)
Sun			G2 V			−26.7	+4.85	1.00
Proxima Centauri	0.769	4.22	M5.5 V	−22	3.853	+11.09	+15.53	8.2×10^{-4}
Alpha Centauri A	0.747	4.40	G2 V	−25	3.710	−0.01	+4.38	1.77
Alpha Centauri B	0.747	4.40	K0 V	−21	3.724	+1.34	+5.71	0.55
Barnard's Star	0.547	5.94	M4 V	−111	10.358	+9.53	+13.22	3.6×10^{-3}
Wolf 359	0.419	7.80	M6 V	+13	4.696	+13.44	+16.6	3.5×10^{-4}
Lalande 21185	0.393	8.32	M2 V	−84	4.802	+7.47	+10.44	0.023
L 726-8 A	0.374	8.56	M5.5 V	+29	3.368	+12.54	+15.4	9.4×10^{-4}
L 726-8 B	0.374	8.56	M6 V	+32	3.368	+12.99	+15.9	5.6×10^{-4}
Sirius A	0.380	8.61	A1 V	−9	1.339	−1.43	+1.47	26.1
Sirius B	0.380	8.61	white dwarf	−9	1.339	+8.44	+11.34	2.4×10^{-3}
Ross 154	0.337	9.71	M3.5 V	−12	0.666	+10.43	+13.07	4.1×10^{-3}
Ross 248	0.316	10.32	M5.5 V	−78	1.617	+12.29	+14.8	1.5×10^{-3}
Epsilon Eridani	0.310	10.49	K2 V	+17	0.977	+3.73	+6.19	0.40
Lacaille 9352	0.304	10.73	M1.5 V	+10	6.896	+7.34	+9.75	0.051
Ross 128	0.299	10.87	M4 V	−31	1.361	+11.13	+13.51	2.9×10^{-3}
L 789-6	0.294	11.09	M5 V	−60	3.259	+12.33	+14.7	1.3×10^{-3}
61 Cygni A	0.286	11.36	K5 V	−65	5.281	+5.21	+7.49	0.16
61 Cygni B	0.286	11.44	K7 V	−64	5.172	+6.03	+8.31	0.095
Procyon A	0.286	11.40	F5 IV−V	−4	1.259	+0.38	+2.66	7.73
Procyon B	0.286	11.40	white dwarf	−4	1.259	+10.7	+12.98	5.5×10^{-4}
BD +59° 1915 A	0.281	11.61	M3 V	−1	2.238	+8.94	+11.18	0.020
BD +59° 1915 B	0.281	11.61	M3.5 V	+1	2.313	+9.70	+11.97	0.010
Groombridge 34 A	0.281	11.65	M1.5 V	+12	2.918	+8.08	+10.32	0.030
Groombridge 34 B	0.281	11.65	M3.5 V	+11	2.918	+11.06	+13.3	3.1×10^{-3}
Epsilon Indi	0.276	11.82	K5 V	−40	4.704	+4.69	+6.89	0.27
GJ 1111	0.276	11.82	M6.5 V	−5	1.290	+14.78	+16.98	2.7×10^{-4}
Tau Ceti	0.274	11.90	G8 V	−17	1.922	+3.49	+5.68	0.62
GJ 1061	0.272	12.08	M5.5 V	−20	0.826	+13.09	+15.26	1.0×10^{-3}
L 725-32	0.269	12.12	M4.5 V	+28	1.372	+12.10	+14.25	1.7×10^{-3}
BD +05° 1668	0.263	12.40	M3.5 V	+18	3.738	+9.84	+11.94	0.011
Kapteyn's star	0.255	12.79	M1.5 V	+246	8.670	+8.84	+10.87	0.013
Lacaille 8760	0.253	12.89	M0 V	+28	3.455	+6.67	+8.69	0.094
Krüger 60 A	0.248	13.05	M3 V	−33	0.990	+9.79	+11.76	0.010
Krüger 60 B	0.248	13.05	M4 V	−32	0.990	+11.41	+13.38	3.4×10^{-3}

* *Stars that are components of binary systems are labeled A and B.*

** *A positive radial velocity means the star is receding; a negative radial velocity means the star is approaching.*

Compiled from the Hipparcos General Catalogue *and from data reported by the Research Consortium on Nearby Stars. The table lists all known stars within 4.00 parsecs (13.05 light-years).*

TABLE E-6 The Visually Brightest Stars

Name	Designation	Distance (ly)	Spectral type	Radial velocity* (km/s)	Proper motion (arcsec/year)	Apparent visual magnitude	Apparent visual brightness** (Sirius = 1)	Absolute visual magnitude	Luminosity (Sun = 1)
Sirius A	α CMa A	8.61	A1 V	−9	1.339	−1.43	1.000	+1.47	26.1
Canopus	α Car	313	F0 I	+21	0.031	−0.62	0.470	−5.53	1.4×10^4
Arcturus	α Boo	36.7	K2 III	−5	2.279	−0.05	0.278	−0.31	190
Rigil Kentaurus	α Cen A	4.4	G2 V	−25	3.71	−0.01	0.268	+4.38	1.77
Vega	α Lyr	25.3	A0 V	−14	0.035	+0.03	0.258	+0.58	61.9
Capella	α Aur	42.2	G8 III	+30	0.434	+0.08	0.247	−0.48	180
Rigel	β Ori A	773	B8 Ia	+21	0.002	+0.18	0.225	−6.69	7.0×10^5
Procyon	α CMi A	11.4	F5 IV–V	−4	1.259	+0.38	0.184	+2.66	7.73
Achernar	α Eri	144	B3 IV	+19	0.097	+0.45	0.175	−2.77	5250
Betelgeuse	α Ori	427	M2 Iab	+21	0.029	+0.45	0.175	−5.14	4.1×10^4
Hadar	β Cen	525	B1 II	−12	0.042	+0.61	0.151	−5.42	8.6×10^4
Altair	α Aql	16.8	A7 IV–V	−26	0.661	+0.77	0.132	+2.2	11.8
Aldebaran	α Tau A	65.1	K5 III	+54	0.199	+0.87	0.119	−0.63	370
Spica	α Vir	262	B1 V	+1	0.053	+0.98	0.108	−3.55	2.5×10^4
Antares	α Sco A	604	M1 Ib	−3	0.025	+1.06	0.100	−5.28	3.7×10^4
Pollux	β Gem	33.7	K0 III	+3	0.627	+1.16	0.091	+1.09	46.6
Fomalhaut	α PsA	25.1	A3 V	+7	0.368	+1.17	0.090	+1.74	18.9
Deneb	α Cyg	3230	A2 Ia	−5	0.002	+1.25	0.084	−8.73	3.2×10^5
Mimosa	β Cru	353	B0.5 III	+20	0.05	+1.25	0.084	−3.92	3.4×10^4
Regulus	α Leo A	77.5	B7 V	+4	0.249	+1.36	0.076	−0.52	331

Data in this table was compiled from the Hipparcos General Catalogue.

* *A positive radial velocity means the star is receding; a negative radial velocity means the star is approaching.*

** *This is the ratio of the star's apparent brightness to that of Sirius, the brightest star in the night sky*

Note: Acrux, or α *Cru (the brightest star in Crux, the Southern Cross), appears to the naked eye as a star of apparent magnitude +0.87, the same as Aldebaran, but it does not appear in this table because Acrux is actually a binary star system. The blue-white component stars of this binary system have apparent magnitudes of +1.4 and +1.9, and thus they are dimmer than any of the stars listed here.*

TABLE E-7 The Constellations

Name	Meaning	R.A.	Dec.	Genitive*	Abbreviation
Andromeda	proper name; princess	1	+40	Andromedae	And
Antlia	air pump	10	−35	Antliae	Ant
Apus	bee	16	−75	Apodis	Aps
Aquarius[1,2]	waterman	22	−10	Aquarii	Aqr
Aquila	eagle	20	+15	Aquilae	Aql
Ara	altar	17	−55	Arae	Ara
Aries[2]	ram	3	+20	Arietis	Ari
Auriga	charioteer	6	+40	Aurigae	Aur
Boötes	proper name; herdsman, wagoner	15	+30	Boötis	Boo
Caelum	engraving tool	5	−40	Caeli	Cae
Camelopardalis	giraffe	6	+70	Camelopardalis	Cam
Cancer[2]	crab	8.5	+15	Cancri	Cnc
Canes Venatici	hunting dogs	13	+40	Canum Venaticorum	CVn
Canis Major	larger dog	7	−20	Canis Majoris	CMa
Canis Minor	smaller dog	8	+5	Canis Minoris	CMi
Capricornus[1,2]	water-goat	21	−20	Capricornii	Cap
Carina	keel	9	−60	Carinae	Car
Cassiopeia	proper name; queen	1	+60	Cassiopeiae	Cas
Centaurus	centaur	13	−45	Centauri	Cen
Cepheus	proper name; king	22	+65	Cephei	Cep
Cetus	whale	2	−10	Ceti	Cet
Chamaeleon	chameleon	10	−80	Chamaeleontis	Cha
Circinus	compasses	15	−65	Circini	Cir
Columba	dove	6	−35	Columbae	Col
Coma Berenices	Berenice's hair	13	+20	Comae Berenices	Com
Corona Australis[3]	southern crown	19	+40	Coronae Australis	CrA
Corona Borealis[4]	northern crown	16	+30	Coronae Borealis	CrB
Corvus[5]	crow, raven	12	−20	Corvi	Crv
Crater	cup	11	−15	Crateris	Crt
Crux[6]	southern cross	12	−60	Crucis	Cru
Cygnus	swan	21	+40	Cygni	Cyg
Delphinus[1]	Dolphin	21	+10	Delphini	Del
Dorado[7]	swordfish	6	−55	Doradus	Dor
Draco[8]	dragon	15	+60	Draconis	Dra
Equuleus	little horse	21	+10	Equulei	Equ
Eridanus	proper name; river	4	−30	Eridani	Eri
Fornax	furnace	3	−30	Fornacis	For
Gemini[2]	twins	7	+20	Geminorum	Gem
Grus	crane	22	−45	Gruis	Gru
Hercules[9]	proper name; hero	17	+30	Herculis	Her
Horologium	clock	3	−55	Horologii	Hor

TABLE E-7 The Constellations (continued)

Name	Meaning	R.A.	Dec.	Genitive*	Abbreviation
Hydra	water serpant	12	−25	Hydrae	Hya
Hydrus	water snake	2	−70	Hydri	Hyi
Indus	Indian	22	−70	Indi	Ind
Lacerta	lizard	22	+45	Lacertae	Lac
Leo[2]	lion	11	+15	Leonis	Leo
Leo Minor	smaller lion	10	+35	Leonis Minoris	LMi
Lepus	hare	6	−20	Leporis	Lep
Libra[2,10]	scales	15	−15	Librae	Lib
Lupus	wolf	15	−45	Lupi	Lup
Lynx	lynx	8	+45	Lyncis	Lyn
Lyra[5]	lyre	19	+35	Lyrae	Lyr
Microscopium	microscope	21	−40	Microscopii	Mic
Monoceros	unicorn	7	0	Monocerotis	Mon
Mensa	table	6	−75	Mensae	Men
Musca (Australis)[11]	(southern) fly	12	−70	Muscae	Mus
Norma	square	16	−50	Normae	Nor
Octans[12]	octant	—	−90	Octantis	Oct
Ophiuchus[13]	serpent-bearer	17	0	Ophiuchi	Oph
Orion	proper name; hunter, giant	6	0	Orionis	Ori
Pavo	peacock	20	−70	Pavonis	Pav
Pegasus	proper name; winged horse	23	+20	Pegasi	Peg
Perseus	proper name; hero	3	+45	Persei	Per
Phoenix	phoenix	1	−50	Phoenicis	Phe
Pictor	easel	6	−55	Pictoris	Pic
Pices[1,2]	fishes	1	+10	Piscium	Psc
Piscis Austrinus[1]	southern fish	22	−30	Piscis Austrini	PsA
Puppis	stern	8	−30	Puppis	Pup
Pyxis	compass	9	−30	Pyxidis	Pyx
Reticulum	net	4	−60	Reticuli	Ret
Sagitta	arrow	20	+20	Sagittae	Sge
Sagittarius[2,14]	archer	19	−25	Sagittarii	Sgr
Scorpius[2]	scorpion	17	−30	Scorpii	Sco
Sculptor[15]	sculptor's workshop	1	−30	Sculptoris	Scl
Scutum[16]	shield	19	−10	Scuti	Sct
Serpens[13]	serpent	17	0	Serpentis	Ser
Sextans	sextant	10	0	Sextantis	Sex
Taurus[2]	bull	5	+20	Tauri	Tau
Telescopium	telescope	19	−50	Telescopii	Tel
Triangulum	triangle	2	+30	Trianguli	Tri
Triangulum Australe	southern triangle	16	−65	Trianguli Australis	TrA
Tucana[17]	toucan	0	−65	Tucanae	Tuc
Ursa Major	larger bear	11	+60	Ursae Majoris	UMa
Ursa Minor[18]	smaller bear	16	+80	Ursae Minoris	UMi

TABLE E-7 The Constellations (continued)

Name	Meaning	R.A.	Dec.	Genitive*	Abbreviation
Vela	sails	10	−45	Velorum	Vel
Virgo[2]	Virgin	13	0	Virginis	Vir
Volans	flying fish	8	−70	Volantis	Vol
Vulpecula	fox	20	+25	Vulpeculae	Vul

** Genitive is the grammatical case denoting possession. For example, astronomers denote the brightest or α (alpha) star in Orion (Betelgeuse) as α Orionis.*

[1] *Constellations of the area of the sky known as the wet quarter for its many watery images.*

[2] *A zodiac constellation.*

[3] *Sometimes considered as Sagittarius's crown.*

[4] *Ariadne's crown.*

[5] *Corvus was Orpheus's companion, Lyra his harp.*

[6] *Originally a part of Centaurus.*

[7] *Contains the Large Magellanic Cloud and the south ecliptic pole.*

[8] *Contains the north ecliptic pole.*

[9] *One of the oldest constellations known.*

[10] *Originally the claws of Scorpius.*

[11] *Originally named Musca Australis to distinguish it from Musca Borealis, the northern fly, which is now defunct; "Australis" is now dropped.*

[12] *Contains the south celestial pole.*

[13] *Ophiucus is identified with the physician Aesculapius, and Serpens with the caduceus.*

[14] *Contains the galactic center.*

[15] *Originally named by Lacaille l'Atelier du Sculpteur (in Latin, Apparatus Sculptoris); now known simply as Sculptor. Contains the south galactic pole.*

[16] *Shield of the Polish hero John Sobieski.*

[17] *Contains the Small Magellanic Cloud.*

[18] *Contains the north celestial pole.*

TABLE E-8 Some Useful Astronomical Quantities

Astronomical unit:	$1\ \text{AU} = 1.496 \times 10^{11}\ \text{m}$
Light-year:	$1\ \text{ly} = 9.461 \times 10^{15}\ \text{m}$ $= 63{,}240\ \text{AU}$
Parsec:	$1\ \text{pc} = 3.086 \times 10^{16}\ \text{m}$ $= 3.262\ \text{ly}$
Solar mass:	$1\ M_\odot = 1.989 \times 10^{30}\ \text{kg}$
Solar radius:	$1\ R_\odot = 6.960 \times 10^{8}\ \text{m}$
Solar luminosity:	$1\ L_\odot = 3.827 \times 10^{26}\ \text{W}$
Earth's mass:	$1\ M_\oplus = 5.974 \times 10^{24}\ \text{kg}$
Earth's equatorial radius:	$1\ R_\oplus = 6.378 \times 10^{6}\ \text{m}$
Moon's mass:	$1\ M_{\text{Moon}} = 7.349 \times 10^{22}\ \text{kg}$
Moon's equatorial radius:	$1\ R_{\text{Moon}} = 1.738 \times 10^{6}\ \text{m}$

TABLE E-9 Some Useful Physical Constants

Speed of light:	$c = 2.998 \times 10^{8}\ \text{m/s}$
Gravitational constant:	$G = 6.668 \times 10^{-11}\ \text{N m}^2\ \text{kg}^{-2}$
Planck constant:	$h = 6.626 \times 10^{-34}\ \text{J s}$ $= 4.136 \times 10^{-15}\ \text{eV s}$
Boltzmann constant:	$k = 1.380 \times 10^{-23}\ \text{J K}^{-1}$ $= 8.617 \times 10^{-5}\ \text{eV K}^{-1}$
Stefan–Boltzmann constant:	$\sigma = 5.670 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$
Mass of electron:	$m_e = 9.109 \times 10^{-31}\ \text{kg}$
Mass of 1H atom:	$m_H = 1.673 \times 10^{-27}\ \text{kg}$

TABLE E-10 Common Conversions between British and Metric Units

1 inch = 2.54 centimeters (cm)
1 cm = 0.394 inch (in)
1 yard = 0.914 meter (m)
1 meter = 1.09 yards = 39.37 inches
1 mile = 1.61 kilometers (km)
1 km = 0.621 mile (mi)

TABLE E-11 Spiral Galaxies and Interacting Galaxies

Spiral galaxy	R.A.	Decl.	Hubble type	Interacting galaxies	R.A.	Decl.
M31 (NGC 224)	0^h 42.7^m	+41° 16′	Sb	M51 (NGC 5194)	13^h 29.9^m	+47°12′
M58 (NGC 4579)	12 37.7	+11 49	Sb	NGC 5195	13 30.0	+47 16
M61 (NGC 4303)	12 21.9	+ 4 28	Sc	M65 (NGC 3623)	11 18.9	+13 05
M63 (NGC 5055)	13 15.8	+42 02	Sb	M66 (NGC 3627)	11 20.2	+12 59
M64 (NGC 4826)	12 56.7	+21 41	Sb	M81 (NGC 3031)	9 55.6	+69 04
M74 (NGC 628)	1 36.7	+15 47	Sc	M82 (NGC 3034)	9 55.8	+69 41
M83 (NGC 5236)	13 37.0	−29 52	Sc	M95 (NGC 3351)	10 44.0	+11 42
M88 (NGC 4501)	12 32.0	+14 25	Sb	M96 (NGC 3368)	10 46.8	+11 49
M90 (NGC 4569)	12 36.8	+13 10	Sb	M105 (NGC 3379)	10 47.8	+12 35
M94 (NGC 4736)	12 50.9	+41 07	Sb			
M98 (NGC 4192)	12 13.8	+14 54	Sb			
M99 (NGC 4254)	12 18.8	+14 25	Sc			
M100 (NGC 4321)	12 22.9	+15 49	Sc			
M101 (NGC 5457)	14 03.2	+54 21	Sc			
M104 (NGC 4594)	12 40.0	−11 37	Sa			
M108 (NGC 3556)	11 11.5	+55 40	Sc			

TABLE E-12 Mass and Energy Inventory for the Universe

	Individual Contribution	Section Total
Dark matter and dark energy contributions		0.954 ± 0.003*
Dark Energy	0.72 ± 0.03	
Dark Matter	0.23 ± 0.03	
Primeval Graviational Radiation	$\leq 10^{-10}$	
Contributions from Big Bang era		0.0010 ± 0.0005
Electromagnetic Radiation	$10^{-4.3 \pm 0.000001}$	
Neutrinos	$10^{-2.9 \pm 0.1}$	
Normal Particle (Baryon) Rest Mass		0.045 ± 0.003
Charged particles (plasma) between stars and galaxies	0.0418 ± 0.003	
Main sequence stars in elliptical galaxies and nuclear bulges	0.0015 ± 0.0004	
Neutral hydrogen & helium	0.00062 ± 0.00010	
Main sequence stars in galactic disks and in irregular galaxies	0.00055 ± 0.00014	
White dwarfs	0.00036 ± 0.00008	
Molecular gas	0.00016 ± 0.00006	
Substellar objects	0.00014 ± 0.00007	
Black holes	0.00007 ± 0.00002	
Neutron stars	0.00005 ± 0.00002	
Planets	$10^{-6 \pm 0.1}$	

**The numbers after the plus or minus (±) symbol indicate the possible errors in the given numbers.*
This table lists the major contributions to the mass and energy of the universe.

APPENDIX F: More to Know

For expanded coverage of these key concepts in the text, visit our More to Know resource at www.whfreeman.com/dtu8e.

Understanding Astronomy

Chapter 1

- Earth Satellites
- Stars' Technical Names
- Height of the Sun
- Maximum Number of Eclipses Annually

Chapter 2

- The Conservation of Angular Momentum

Chapter 3

- Seeing Nonvisible Radiation

Chapter 4

- Radioactive Age-Dating

Understanding the Solar System

Chapter 5

- Computer Simulations of Planet Formation
- Spectra

Chapter 6

- Waves in and on the Earth
- The Origin of the Earth's Magnetic Field
- Radioactive Age-Dating

Chapter 7

- *Mariner 10* and the Exploration of Mercury
- Radar Doppler Measurements

Chapter 8

- Roche Limit

Chapter 9

- Orbital Resonances
- Discovering Comets
- Meteors

Chapter 10

- Zeeman Effect
- Fusion

Understanding the Stars

Chapter 11

- Exact Spectra
- Stellar Sizes

Chapter 13

- Origins of Cosmic Rays
- Brightest Planetary Nebulae

Chapter 14

- Gravitational Waves

Understanding the Universe

Chapter 16

- Computers in Astronomical Research

Chapter 17

- Black Hole Masses or How Plausible Are Extremely Massive Black Holes?

APPENDIX G: Using the *Starry Night Enthusiast*™ CD-ROM

The *Starry Night Manual* is available on the *Starry Night Enthusiast*™CD-ROM. It contains detailed instructions on how to install the *Starry Night Enthusiast*™ software and how to use its various features. Once the software has been installed, this manual is available from the Help menu.

It might be useful, and it is certainly good scientific practice, to keep a notebook specifically for these exercises in which you can write down the date and time of each observation as well as notes on set-up procedures as you become familiar with them. This appendix introduces some of the major features of the software to jumpstart your effective use of it for making astronomical observations.

The first time that you launch *Starry Night Enthusiast*™ after installing it, you will be prompted to select a home location. Once selected, the program will use this home location as the default viewing location when the program opens or a new file is generated. You can use the **File > Set Home Location. . .** menu command to change the default home location whenever necessary. The Home Location dialog window allows you to select your default viewing location by selecting from a list of cities, clicking points on a map, or entering a specific latitude and longitude.

Once the Home Location has been set, the default behavior of *Starry Night Enthusiast*™ when it opens is to present a dialog with a list of interesting astronomical events that may be visible from your home location. You can explore these events with the **View Event** button. To dismiss the dialog window click the **Close** button.

The *Starry Night Enthusiast*™ screen contains four sections:

1. The menu bar across the top of the screen, which contains commands for handling and opening files and altering various options in the display.
2. The toolbar, which is below the menu bar. The toolbar displays the various parameters that are in effect for the current view such as the time, date, viewing location, gaze direction and field of view as well as controls for changing these parameters and for animating the view at various speeds.
3. The main view window comprises the majority of the screen and shows a virtual view of the sky consistent with the parameters indicated in the toolbar.
4. The tabs on the left edge of the main view window open side panes from which you can quickly find objects in the sky, adjust various viewing options, expedite file handling and obtain more information about the parameters of the observation and details on astronomical objects. You can also obtain further assistance in using the *Starry Night Enthusiast*™ interface through guided tutorials from the appropriate side pane.

Starry Night Enthusiast™ opens with an image of the ground and sky centered on your home location at the date and time specified by the system clock of your computer. You control the time of day or night with the **Time and Date** information on the toolbar and the rate of time flow with the buttons in the Time Flow Rate section of it. The buttons allow you to stop time flow, run time forward (the Play button) or backward, step time forward or backward in specific intervals, and change the rate of time flow. A list of time options will appear when you click the downward pointing arrow to the right of the Time Flow Rate display. You should experiment with these controls.

Clicking a field in the **Time and Date** section of the toolbar allows you to change its value directly from the keyboard or increment and decrement the value with the + and − keys. The **Viewing Location** section of the toolbar contains a panel indicating the current location from which you are observing the sky. The up and down wedge buttons below the viewing location display decrease and increase the current elevation of your viewing location, respectively. The **Home** button resets the view to the current date and time from your home location. Clicking the − and + buttons in the **Zoom** section at the right of the toolbar allow you to zoom in and out.

To find a specific astronomical object in the sky, select **Edit > Find. . .** from the menu or click the **Find** tab on the left of the main view window to open the **Find** pane. The Find pane contains a list of solar system objects when the edit box at the top of the pane is empty. A button containing a + sign to the left of the name of an object in the list indicates that the list for that object can be expanded by clicking the button. To the extreme left of an entry in the object list is a blue button with a downward pointing arrowhead. This menu button contains several important menu commands that allow you to locate and center the object in the view and **Magnify** the object in the view as well as several other interesting commands. To find an object in the sky that is not in the list, type its name in the search box at the top of the **Find** pane.

There are several ways to adjust the view directly from the main view window by using the mouse. The default mouse icon is the Hand Tool. When this mouse icon is visible, you can grab the screen by clicking the mouse (left button on a PC) and dragging the view. You can change the behavior of the mouse by holding down the Shift key on the keyboard. The mouse cursor changes to a small square of four arrowheads to become the Location Scroller. To use the location scroller, click the mouse button (left button on a PC) and drag the mouse while holding down the **Shift** key. Unlike the hand tool, which changes the view by altering the gaze direction, rather like turning your head, the Location Scroller changes the view by altering the viewing location. As you move the four arrowheads with the mouse, you can see your viewing location change on the toolbar.

When the mouse cursor is over a specific object in the sky, it changes its appearance to an arrow with an attached list. Clicking the mouse button (right mouse button on a PC) when the mouse icon is an arrow allows you, among other things, to label and select the specific object at which the mouse is pointing. Pressing **ctrl** when the mouse icon is an arrow reveals details about the object you are viewing. If you click and hold the mouse button (left mouse button on a PC) when it is an arrow and drag the mouse, the Selection Tool can be used to measure angular and physical distances between objects in the sky.

Try the practice exercises below to help to familiarize yourself with the *Starry Night Enthusiast*™ interface.

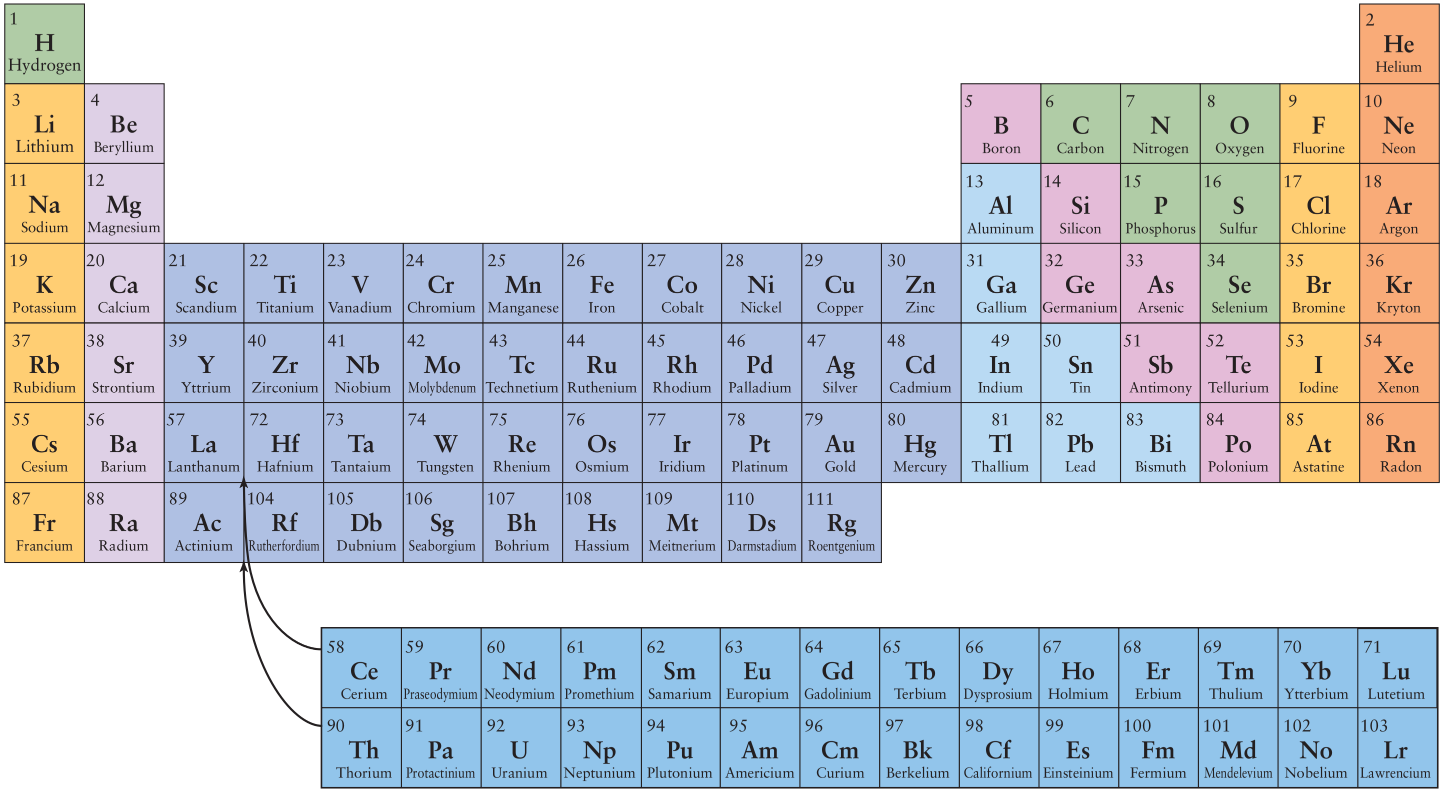
1. Click the **Home** button to reset the view. **Stop time** and then change the **Time** in the toolbar to **11:00:00 PM** on today's date. Select **Labels > Planets-Moons** from the menu. Use the Hand Tool to look around the sky. Will any planets be visible from your home location tonight at 11 PM? If you are using a notebook, record the date and time of your observation and the planets that are visible.

2. Click the **Home** button to reset the view and **Stop time.** Click and hold the **Increase current elevation** button (the second button from the left in the **Viewing Location** section of the toolbar) until the Viewing Location panel indicates that you are about **0.001 au** above your home location. Earth should be visible near the bottom of the view. Position the mouse cursor over the image of Earth so that the cursor changes from the Hand Tool to the Selection Tool. Open the object contextual menu by right-clicking the Selection Tool (Ctrl-click on a Mac) and select Centre from the list of commands. This will center Earth in the view. Select **Labels > Planets-Moons** from the menu. Now use the Location Scroller (hold down the Shift key while clicking and dragging the mouse) to roll Earth around like a ball in the view until the Moon becomes visible in the view. Position the mouse cursor over the Moon so that it turns into a Selection Tool. Now click and hold the mouse button (the left button on a PC) and drag the mouse from the Moon toward Earth. The Selection Tool will draw a line from the Moon to Earth and display the angular distance between Earth and the Moon from your current viewing location as well as the actual physical distance separating the two bodies. Use the Location Scroller to change your viewing location and repeat the measurement of the angular and physical distances between Earth and the Moon. Which of these values has changed and why?

3. Click the **Home** button to reset the view. **Stop time.** Find the Andromeda Galaxy by opening the **Find** pane and typing "Andromeda Galaxy" into the edit box at the top of the pane. The list will narrow down as you type. Double-click the entry for the Andromeda Galaxy in the Found items list. The view will label and center this object. Use the **Zoom in** button to change the field of view to about 2° wide. Position the mouse cursor over any other interesting objects that you see in this magnified view and use the information displayed on the screen when you position the mouse cursor over these objects to identify them. What are the names of these objects? Use the object contextual menu over these objects to select the **Show Info** command. This will open the Info side pane in which a description and other data on the object are displayed. What types of objects are those that you identified?

4. Click the **Home** button to reset the view. **Stop time.** Click and hold the **Increase current elevation** button (the second button from the left in the **Viewing Location** section of the toolbar) until the Viewing Location panel indicates that you are about **0.001 au** above your home location, as you did in section 2 above. Now continue to increase your altitude above Earth in factors of about 10 as you move away from our location in the universe, noting first the local stars in our neighborhood, then the Milky Way galaxy in which the solar system is located, then the nearby galaxies and finally move outward into the realm of galaxies and note the soap-bubble structure formed by these very distant galaxies. You can stop at any distance and center upon an object and use the location scroller to move around the selected object to see its overall shape.

APPENDIX H: Periodic Table of the Elements



1 **H** Hydrogen																	2 **He** Helium
3 **Li** Lithium	4 **Be** Beryllium											5 **B** Boron	6 **C** Carbon	7 **N** Nitrogen	8 **O** Oxygen	9 **F** Fluorine	10 **Ne** Neon
11 **Na** Sodium	12 **Mg** Magnesium											13 **Al** Aluminum	14 **Si** Silicon	15 **P** Phosphorus	16 **S** Sulfur	17 **Cl** Chlorine	18 **Ar** Argon
19 **K** Potassium	20 **Ca** Calcium	21 **Sc** Scandium	22 **Ti** Titanium	23 **V** Vanadium	24 **Cr** Chromium	25 **Mn** Manganese	26 **Fe** Iron	27 **Co** Cobalt	28 **Ni** Nickel	29 **Cu** Copper	30 **Zn** Zinc	31 **Ga** Gallium	32 **Ge** Germanium	33 **As** Arsenic	34 **Se** Selenium	35 **Br** Bromine	36 **Kr** Kryton
37 **Rb** Rubidium	38 **Sr** Strontium	39 **Y** Yttrium	40 **Zr** Zirconium	41 **Nb** Niobium	42 **Mo** Molybdenum	43 **Tc** Technetium	44 **Ru** Ruthenium	45 **Rh** Rhodium	46 **Pd** Palladium	47 **Ag** Silver	48 **Cd** Cadmium	49 **In** Indium	50 **Sn** Tin	51 **Sb** Antimony	52 **Te** Tellurium	53 **I** Iodine	54 **Xe** Xenon
55 **Cs** Cesium	56 **Ba** Barium	57 **La** Lanthanum	72 **Hf** Hafnium	73 **Ta** Tantaium	74 **W** Tungsten	75 **Re** Rhenium	76 **Os** Osmium	77 **Ir** Iridium	78 **Pt** Platinum	79 **Au** Gold	80 **Hg** Mercury	81 **Tl** Thallium	82 **Pb** Lead	83 **Bi** Bismuth	84 **Po** Polonium	85 **At** Astatine	86 **Rn** Radon
87 **Fr** Francium	88 **Ra** Radium	89 **Ac** Actinium	104 **Rf** Rutherfordium	105 **Db** Dubnium	106 **Sg** Seaborgium	107 **Bh** Bohrium	108 **Hs** Hassium	109 **Mt** Meitnerium	110 **Ds** Darmstadium	111 **Rg** Roentgenium							
				58 **Ce** Cerium	59 **Pr** Praseodymium	60 **Nd** Neodymium	61 **Pm** Promethium	62 **Sm** Samarium	63 **Eu** Europium	64 **Gd** Gadolinium	65 **Tb** Terbium	66 **Dy** Dysprosium	67 **Ho** Holmium	68 **Er** Erbium	69 **Tm** Thulium	70 **Yb** Ytterbium	71 **Lu** Lutetium
				90 **Th** Thorium	91 **Pa** Protactinium	92 **U** Uranium	93 **Np** Neptunium	94 **Pu** Plutonium	95 **Am** Americium	96 **Cm** Curium	97 **Bk** Berkelium	98 **Cf** Californium	99 **Es** Einsteinium	100 **Fm** Fermium	101 **Md** Mendelevium	102 **No** Nobelium	103 **Lr** Lawrencium

APPENDIX 1: Changing Pluto's Status as a Planet

Pluto has been removed from the pantheon of planets and relegated to the status of a "dwarf planet," leaving eight surviving planets. Although this change requires everyone to re-learn the number of planets, it places Pluto into a new category that will eventually help astronomers better understand all the types of bodies that orbit the Sun.

Changing categories in astronomy is not new. Imagine that the year is 1780. Six planets are known: Mercury, Venus, Earth, Mars, Jupiter, and Saturn. Now move ahead a year: Uranus has just been discovered, requiring people to learn that there are seven planets, not six. Fast forward nineteen years. . . . It is New Year's Day, 1801 and the Swiss/Italian amateur astronomer Giuseppe Piazzi discovers the eighth planet, which he names *Ceres* (**Figure 1**). It is located between Mars and Jupiter. During the following year, German astronomer H. Wilhelm Olbers discovers the ninth planet, *Pallas,* in the same region of the solar system. The discovery of *Pallas* is followed within five years by the discovery of the tenth and eleventh planets—*Juno* by German astronomer Karl Harding and *Vesta* by Olbers (**Figure 2**). These bodies (Ceres, Pallas, Juno, and Vesta) also orbit the Sun between Mars and Jupiter.

The fifth such body, *Astraea,* is located between Mars and Jupiter and was discovered in 1845 by amateur German astronomer Karl Hencke. It is significantly smaller than any previously-discovered planet, just like all but one[1] of the next eighteen planets discovered by 1852.

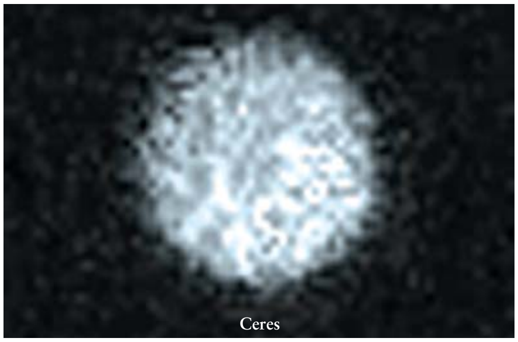


FIGURE 1 Ceres, the Largest Asteroid in Orbit between Mars and Jupiter (NASA, ESA, J. Parker [Southwest Research Institute], P. Thomas [Cornell University], L. McFadden [University of Maryland, College Park], and M. Mutchler and Z. Levay [STScI])

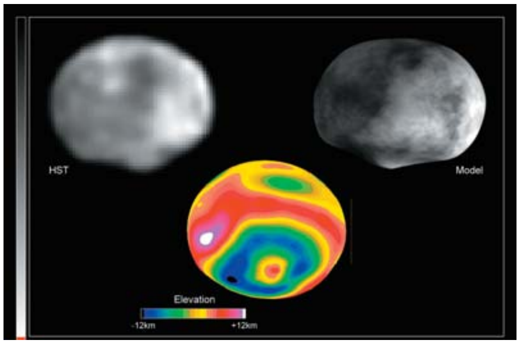


FIGURE 2 Asteroid Vesta, between Mars and Jupiter (Ben Zellner [Georgia Southern Univ.], Peter Thomas [Cornell Univ.], and NASA)

Furthermore, all these smaller bodies are located in the same general region of the solar system—between Mars and Jupiter. Seeing a physically meaningful pattern emerging, some astronomers began listing in journals the bodies smaller than *Vesta* (namely, *Astraea* and all the subsequently-discovered small bodies) as *asteroids,* or equivalently, *minor planets* or *planetoids.* The terms *Asteroids* and *minor planets* are still in common use today.

Prior to 1855, the sizes of *Ceres, Pallas, Juno,* and *Vesta* had been grossly over-estimated. During that year, another measurement scheme was used that actually underestimated their sizes. Based on these smaller sizes, these four bodies were added to the list of asteroids, which resulted in classifying eight bodies as planets: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, and Neptune. This categorization supports the idea that the smaller objects—the asteroids—are fundamentally different than the eight planets.[2]

Modern observational techniques have finally established the sizes of the four largest asteroids as being smaller than the sizes originally measured and larger than the sizes measured in 1855. Nevertheless, these asteroids are all very small compared to even the smallest of the eight planets, Mercury. Indeed, the largest of the asteroids, *Ceres,* is only a quarter the diameter of our Moon.

Zoom ahead to 1930. During that year, Pluto is discovered by American astronomer Clyde Tombaugh. Pluto was considered to be at the edge of the known solar system and has an orbit that sometimes takes it closer to the Sun than Neptune. Indeed, Pluto's orbit is much more elliptical than the orbits of the eight planets, but similar to the very elliptical orbits of many asteroids.

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[1] The one exception is giant Neptune, discovered in 1847 out beyond Uranus.

[2] We honestly don't yet know all the differences between planets and asteroids or between the various asteroids.

FIGURE 3 Pluto and Its Moon Charon (Dr. R. Albrecht, ESA/ESO Space Telescope European Coordinating Facility; NASA)

However, unlike the asteroids, Pluto is not located between Mars and Jupiter. Pluto's size is decidedly unusual, too. With a diameter eighteen percent that of Earth, just less than half that of Mercury, just two-thirds that of our Moon, and just four times that of *Ceres*, Pluto doesn't fit well as a planet or as an asteroid. It was grouped with the eight planets, despite debate about whether it was more like them or like the ever-growing number of known asteroids.

Although asteroids continued to be discovered throughout the twentieth century, the status of Pluto as a planet was unthreatened until 1978, when Pluto was discovered to have a moon, Charon, which is almost as large as Pluto (**Figure 3**). (Pluto has a diameter of 2300 km while Charon has a diameter of 1190 km.) For comparison, Earth and our Moon, which are the pair of planet and moon that is most similar to Pluto and Charon, have diameters of 12,800 km and 3500 km, respectively. Pluto and Charon are a pair of nearly equal mass bodies orbiting each other, which is unique in the solar system. The status of Pluto as a planet was further questioned as similar-sized bodies, such as *Sedna* and *Eris*, were discovered in the same remote area of the solar system.

Over a hundred thousand asteroids and bodies orbiting beyond Neptune have now been identified. Their sizes and locations suggest that they are all quite different from eight planets and similar to Pluto. Pluto's size is more similar to the larger asteroids than to any planet and its orbit is more similar to those of other bodies orbiting the Sun in space beyond Neptune than to the orbit of any planet. Pluto has finally been reclassified to better reflect these connections. These classifications were done during the summer of 2006 at a meeting of the International Astronomical Union, where the group was charged with classifying and naming objects in space. That meeting was filled with tension, as numerous competing definitions of planets and other objects in the solar system were proposed and rejected. In the end, the following definitions were adopted.

A **planet** is a celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its own gravity to overcome rigid body forces so that it assumes a *hydrostatic equilibrium* (i.e., the object is nearly spherical), and (c) it has cleared the neighborhood around its orbit (of smaller bodies).

Although (a) is self-explanatory and Pluto indeed orbits the Sun, the conditions, (b) and (c), deserve some explanation. If an object has its shape because of the bonds between its atoms, then it can have essentially any shape. Rocks look like rocks, potatoes look like potatoes, and you and I look as we do because of such bonding. However, if an object has enough mass, then the gravitational attraction between its particles are strong enough to reshape the object—pulling down high places and pushing up low ones—until the object becomes nearly spherical. The resulting balance between the force of gravity pulling inward and the pressure created by the matter pressing on itself resulting in the matter pushing outward is called hydrostatic equilibrium. There are about three dozen objects in the solar system that meet this criterion, including Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, Pluto, the asteroid Ceres, our Moon, several moons of each of the large planets, Pluto's moon Charon, and several of the Pluto-like objects orbiting beyond Neptune that have been discovered, including Sedna and Eris. Conversely, there are over a hundred thousand objects in the solar system that look more like potatoes than anything else. These bodies include most of the moons and asteroids and all of the comets.

The third condition to be considered a planet, (c) above, means that the object must also have enough gravitational attraction to pull onto itself, or to fling far away, the myriad smaller pieces of debris that orbit in its neighborhood. The inner eight planets satisfy this condition, but observations reveal numerous objects still in Pluto's vicinity. Pluto does not have enough gravitational attraction to clear its surrounding area; so, by using the new criteria for determining planets, Pluto is not a planet.

Nevertheless, Pluto and numerous other objects are still a part of the solar system, so they need to be classified. Because we know very little about the chemical compositions of these bodies (including Pluto), we don't yet know if they are a single class of objects or several distinct classes of objects. For example, some of them may be composed mostly of rock and metal, while others may be mostly rock and ice; some may have sheaths of ice, while others have rocky surfaces. Until such details are known, all the other spherical objects orbit-

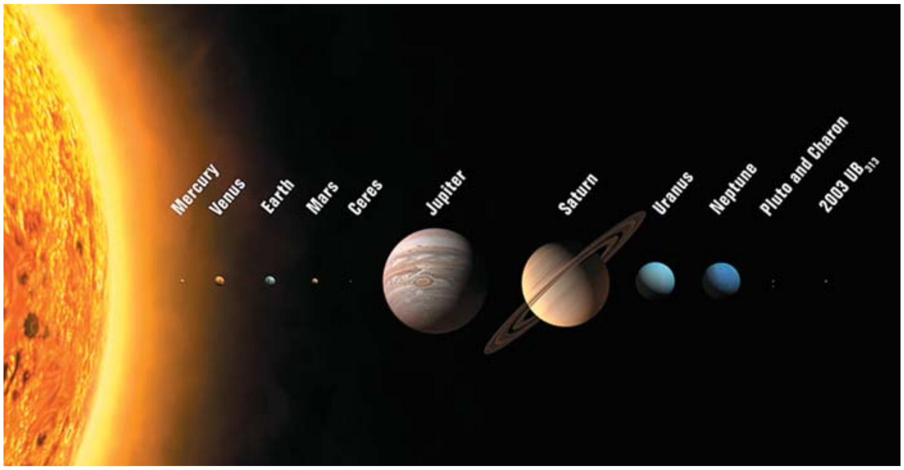

FIGURE 4 Scales of the Solar System All these bodies are presented to scale. The two insets compare the size of Mercury, the smallest planet, with Pluto, now classified a dwarf planet. (International Astronomical Union/NASA)

ing the Sun that have *not* cleared their neighborhoods in space of debris and that are not satellites[3] of other bodies are classified as **dwarf planets.** Pluto is a dwarf planet, but its moon Charon is *not* because Charon orbits the slightly larger body, Pluto. The asteroid Ceres is now considered a dwarf planet.

Finally, the panoply of nonsatellite, nonspherical objects in the solar system are called **small solar-system bodies** (**SSSBs**). Neither this name nor the name dwarf planets is very satisfying. The four inner planets, Mercury, Venus, Earth, and Mars, are much smaller than the four outer planets, so it is easy to confuse the inner "terrestrial planets" with "dwarf planets." Just as the name planetoid was dropped in favor of asteroid, the two names—dwarf planets and small solar-system bodies—may eventually be changed to better reflect the objects they represent.

As has occurred several times since the eighteenth century, people now have to go through the uncomfortable process of learning new names for old astronomical objects. Clearly, changing Pluto's designation to "dwarf planet (134340) Pluto" does not change it physical properties. Indeed, astronomers hope that the new designations will *better* represent Pluto's properties, along with the properties of the other small objects orbiting the Sun. Although the renaming will be confusing for a while, it will eventually help clarify our perception of the solar system (**Figure 4**).

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[3] i.e., moons