1

MEASUREMENTS IN PHYSICS

CONCEPTUAL QUESTIONS

1. **SOLVE** An advantage of using AU is that astronomical distances can be expressed as simple multiples of AUs.
REFLECT An astronomical unit (abbreviated as AU) is a unit of length equal to the mean distance between the Earth and the Sun. One AU is 149.6 million kilometers (approximately 93 million miles). Some astronomical distances in AU are given below:
The Earth is 1.00 ± 0.02 AU from the Sun.
The Moon is 0.0026 ± 0.0001 AU from the Earth.
Mars is 1.52 ± 0.14 AU from the Sun.
Jupiter is 5.20 ± 0.05 AU from the Sun.
Pluto is 39.5 ± 9.8 AU from the Sun.
108 AU: As of November 16, 2008, Voyager 1 is the farthest of any human-made objects from the Sun.

2. **SOLVE** Sometimes it's advantageous to use non-SI units to describe familiar everyday life situations. Furthermore, occasionally it's useful to use non-SI units when SI values would be extremely large or small.
REFLECT For example in a country that uses the English system of units like the United States, people are more familiar with expressing the speed limit in miles per hour and the temperature in Fahrenheit. Astronomical distances and atomic properties are examples of very large and small SI values, respectively.

3. **SOLVE** The disadvantage of using a prototype, a standard piece of metal for the standard kilogram is the fact that the mass of the piece could change its mass over time.
REFLECT Alternative options for a standard of mass are under consideration.

4. **SOLVE** The term *nanotechnology* was chosen since it describes the study of the control of matter on an atomic and molecular scale.
REFLECT Generally, nanotechnology deals with structures of the size of 100 nanometers or smaller, and involves developing materials or devices within that size.

5. **SOLVE** Different units can describe a quantity with the same dimension. For example speed has the dimensions of distance per time, and can be expressed as m/s, miles/hour, or any other units of distance per time. Units reveal the dimensions of physical quantities.
REFLECT A dimension analysis of a calculated physical property is very helpful for identifying errors in a calculation. For example, if an area was supposed to be calculated, and the units of the answer are m or m^3, it's clear that a mistake was made.

6. **SOLVE** Based on the average distance between Earth and Saturn of 1.2 billion km, there will be a time delay between the moment a radio signal is sent and the time the spacecraft receives the signal:

$$t = \frac{\left(1.2\times10^{12}\ \text{m}\right)}{\left(299792458\ \text{m s}^{-1}\right)} = 4002.8\ \text{s} = 66.7\ \text{min}$$

Furthermore, the radio frequency signals travel on a straight pass, therefore, communication with the spacecraft will be lost when it is on the opposite side of Saturn.
REFLECT On July 1, 2004, the Cassini–Huygens spacecraft performed the SOI (Saturn Orbit Insertion) maneuver and entered into orbit around Saturn. Before the SOI, Cassini had already studied the system extensively. In June

2004, it had conducted a close flyby of Phoebe, sending back high-resolution images and data. Cassini's flyby of Saturn's largest moon, Titan, has captured radar images of large lakes and their coastlines with numerous islands and mountains. The orbiter completed two Titan flybys before releasing the Huygens probe on December 25, 2004. Huygens descended onto the surface of Titan on January 14, 2005, sending a flood of data during the atmospheric descent and after the landing. During 2005, Cassini conducted multiple flybys of Titan and icy satellites. Cassini's last Titan flyby commenced on March 23, 2008.

7. **SOLVE** Physical quantities with different units have to be converted to the same units in order to properly add and subtract them.

REFLECT In 1999, the Mars climate orbiter spacecraft was lost due a navigation error, which was tracked to different scientific teams using different unit systems.

8. **SOLVE** The number 2 in $\sqrt{2}$ is exact, therefore the number can be expressed in as many figures as desired.

REFLECT In a calculation, don't round off too early. Wait until the last step, when the final answer is calculated.

MULTIPLE-CHOICE PROBLEMS

9. **SOLVE** The answer is (b). Ten million kg are $10\times10^{6}\ \text{kg}\times\left(\dfrac{1000\ \text{g}}{1\ \text{kg}}\right)=10^{10}\ \text{g}$.

REFLECT The aircraft carrier USS Ronald Reagan has an overall length of 1,092 ft or 333 m and weighs around 20628 tons (2.0628×10^{10} g!). It can carry more than 80 aircraft and 5500 sailors at one time.

10. **SOLVE** The answer is (d).

The SI unit for speed is m/s.

REFLECT The land speed record (or absolute land speed record) is the fastest speed achieved by any wheeled vehicle on land. There is no single body for validation and regulation; what is used in practice is the Category C ("Special Vehicles") flying start regulations, officiated by regional or national organizations under the auspices of the Fédération Internationale de l'Automobile. The record is standardized as the speed over a course of fixed length, averaged over two runs (commonly called "passes") in opposite directions within one hour. A new record mark must exceed the previous one by 1% to be validated. There are numerous other class records for cars, and motorcycles fall into another, separate, class. The current absolute record holder is *ThrustSSC*, a twin turbofan-powered car which achieved 763 miles per hour (1,228 km/h) for the mile (1.6 km), breaking the sound barrier.

11. **SOLVE** The answer is (c).

$$13.7\ \text{Gy}=13.7\times10^{9}\ \text{y}=13.7\times10^{9}\ \text{y}\times\frac{3600\ \text{s}}{1\ \text{h}}\times\frac{24\ \text{h}}{1\ \text{day}}\times\frac{365\ \text{d}}{1\ \text{y}}=4.32\times10^{17}\ \text{s}$$

REFLECT Expressing the time in years gives us a better feel for the magnitude of the immense time period, whereas it is difficult to comprehend that large number of seconds, the SI units of time. For everyday events, it is sometimes more convenient to use non-SI units.

12. **SOLVE** The answer is (c).

$$8.25\frac{\text{g}}{\text{cm}^3}=8.25\frac{\text{g}}{\text{cm}^3}\times\frac{1\ \text{kg}}{1000\ \text{g}}\times\frac{1\times10^{6}\ \text{cm}^3}{1\ \text{m}^3}=8250\frac{\text{kg}}{\text{m}^3}$$

REFLECT The density in the core of the sun is about 150000 kg m^{-3}!

13. **SOLVE** The answer is (a).

$$85\frac{\text{mi}}{\text{h}}=85\frac{\text{mi}}{\text{h}}\times\frac{1602\ \text{m}}{1\ \text{mi}}\times\frac{1\ \text{h}}{3600\ \text{s}}=38\frac{\text{m}}{\text{s}}$$

REFLECT A very important point for any driver to remember is that if you double your speed–say from 30 mph to 60 mph–your braking distance does not become twice as long, it becomes *four times* as far.

14. **SOLVE** The answer is (c).

$$v = 500\ \text{mi} \times \frac{1602\ \text{m}}{1\ \text{mi}} \times \frac{1}{\left[\left(3\ \text{h} \times \frac{3600\ \text{s}}{1\ \text{h}}\right) + \left(8\ \text{min} \times \frac{60\ \text{s}}{1\ \text{min}}\right)\right]} = 71.0\ \frac{\text{m}}{\text{s}}$$

REFLECT The Indianapolis 500-Mile Race, often shortened to Indianapolis 500 or Indy 500 or commonly known simply as The 500, is an American automobile race, held annually over the Memorial Day weekend at the Indianapolis Motor Speedway in Speedway, Indiana. The event lends its name to the IndyCar class of formula, or open-wheel, race cars that have competed in it. The fastest winning average speed at the Indy 500 of 185.981 mi/h (299.307 km/h) was achieved by Arie Luyendyk in 1990.

15. **ORGANIZE AND PLAN** The two surface areas are given by: $A_1 = 4\pi r_1^2$ and $A_2 = 4\pi r_2^2$

Setting $A_1 = 4 \times A_2$ $A_1 = 4 \times A_2$ we obtain for A_1:

$$4A_2 = 4\pi r_1^2$$
$$A_2 = \pi r_1^2$$

Therefore, we obtain for the relationship between the two radii:

$$\pi r_1^2 = 4\pi r_2^2$$
$$r_1 = 2r_2$$

SOLVE And then for the volume ratio:

$$V_1 = \frac{4}{3}\pi r_1^3 \text{ and } V_2 = \frac{4}{3}\pi r_2^3$$

$$\frac{V_1}{V_2} = \frac{(2r_2)^3}{r_2^3} = 2^3 = 8$$

The answer is (c).

REFLECT The exponent of 3 that the doubling of the radius has to be raised with to calculate the ratio of the volumes reflects the dimension of volume, i.e., distance cubed.

16. **SOLVE** The answer is (d).

REFLECT Zeroes after a decimal point are significant.

17. **SOLVE** The answer is (a).

REFLECT Zeroes before a decimal point are not significant.

18. **SOLVE** The answer is (a).

REFLECT Following the rule that when multiplying or dividing quantities, the answer should be reported with a number of significant figures equal to the smallest number of significant figures among the quantities given.

PROBLEMS

19. **SOLVE** Expressing in scientific notation: (a) 1.3950×10^4 m (b) 2.46×10^{-5} kg (c) 3.49×10^{-8} s (d) 1.28×10^9 s

REFLECT Scientific notation helps you to manage very large and small numbers.

20. **SOLVE** Express the quantities in the preceding problem using SI units and prefixes with no power of 10:
(a) 13.95 km (b) 24.6 μg (c) 0.349 μs (d) 1.28 Gs

REFLECT SI prefixes and units were designed so we can measure everyday things with numbers that are not too large or too small.

21. **SOLVE** We convert from megatons to kg:

$$1\ \text{megaton} = 10^6\ \text{tons} = \frac{1000\ \text{kg}}{1\ \text{ton}} = 10^9\ \text{kg}$$

22. **SOLVE** The speed of light is $v\ (\text{light}) = 299{,}792{,}458\ \text{m/s}^{-1}$. We need to convert m to $\mu\text{m}\ \left(10^{-6}\ \text{m}\right)$ and s to fs $\left(10^{-15}\ \text{s}\right)$:

$$v(\text{light}) = \left(299{,}792{,}458\ \frac{\text{m}}{\text{s}}\right) \times \left(\frac{\mu\text{m}}{10^{-6}\text{m}}\right) \times \left(\frac{10^{-15}\text{s}}{\text{fs}}\right) = 0.2998 \frac{\mu\text{m}}{\text{fs}}$$

REFLECT Using SI prefixes, μ and f, it's difficult to gauge the actual incredible speed of light.

23. **ORGANIZE AND PLAN** In part (a), we use the volume of a sphere, which is given by $V(\text{sphere}) = \frac{4}{3}\pi r^3$, where r is the radius of the sphere. In part (b), we consider that density is defined as mass per volume.

SOLVE (a) For Earth we obtain:

$$V(\text{Earth}) = \frac{4}{3}\pi\ \left(6.371\times10^{6}\ \text{m}\right)^{3} = 1.083\times10^{21}\ \text{m}^3$$

(b) We use the volume from part (a) and the mass given to calculate the average density of Earth, $\bar{\rho}$ (Earth) :

$$\bar{\rho}\ (\text{Earth}) = \frac{m(\text{Earth})}{V(\text{Earth})} = \frac{\left(5.97\times10^{24}\ \text{kg}\right)}{\left(1.083\times10^{21}\ \text{m}^3\right)} = 5511.44\ \frac{\text{kg}}{\text{m}^3}$$

The average density of Earth is approximately 5.5 times the density of water.

REFLECT The interior of the Earth, like that of the other terrestrial planets, is divided into layers by their chemical or physical (rheological) properties. The outer layer of the Earth is a chemically-distinct silicate solid crust, which is underlain by a highly viscous solid mantle. The crust is separated from the mantle by the Mohorovičić discontinuity, and the thickness of the crust varies: averaging 6 km under the oceans and 30–50 km on the continents. The crust and the cold, rigid, top of the upper mantle are collectively known as the lithosphere, and it is of the lithosphere that the tectonic plates are comprised. Beneath the lithosphere is the asthenosphere, a relatively low-viscosity layer on which the lithosphere rides.

24. **ORGANIZE AND PLAN** Velocity is defined as distance per time:

$$v = \frac{d}{t}$$

SOLVE We solve the equation for t and double the distance from Earth to the Moon to consider the distance for the light's roundtrip, and obtain the time:

$$t(\text{roundtrip}) = \frac{2\times d\ (\text{Earth to Moon})}{v\ (\text{light})} = \frac{2\times\left(385{,}000\times10^{3}\ \text{m}\right)}{\left(299{,}792{,}458\ \text{m s}^{-1}\right)} = 2.57\ \text{s}$$

REFLECT The short travel time reflects the incomprehensible speed of light.

25. **SOLVE** The ratio of Earth's radius and the height of Mount Everest's summit is:

$$\frac{h(\text{Mount Everest})}{r(\text{Earth})} = \frac{\left(8847\ \text{m}\right)}{\left(6.371\times10^{6}\ \text{m}\right)} = 1.39\times10^{-3}$$

REFLECT The height of Mount Everest makes up only about 0.1% of Earth's radius.

SOLVE (a) The number of Earth's diameters to make up the distance from Earth to the Moon is:

$$\frac{d(\text{Earth to Moon})}{d(\text{Earth diameter})} = \frac{d(\text{Earth to Moon})}{2\times r(\text{Earth radius})} = \frac{\left(3.85\times10^{8}\ \text{m}\right)}{2\times\left(6.371\times10^{6}\ \text{m}\right)} = 30.2$$

(b) The number of Earth's diameters to make up the distance from Earth to the Sun is:

$$\frac{d(\text{Earth to Sun})}{d(\text{Earth diameter})} = \frac{d(\text{Earth to Sun})}{2\times r(\text{Earth radius})} = \frac{\left(1.496\times10^{11}\ \text{m}\right)}{2\times\left(6.371\times10^{6}\ \text{m}\right)} = 11740$$

REFLECT Earth is the third planet from the Sun, and the largest of the terrestrial planets in the Solar System in terms of diameter, mass, and density.

26. **SOLVE** We use the SI prefixes given in Table 1.4 to express the units:
(a) The distance traveled by light in a year (ly): 1 ly = 9.5×1015 m = 9.5 Pm

(b) The time since the formation of the solar system:

$$\text{age of solar system} = 1.6\times 1017\ \text{s} = 16\times 1018\ \text{s} = 16\ \text{Es} = 160\ \text{Ps}$$

(c) The mass of a typical dust particle:

$$m\ (\text{dust particle}) = 1.0\times 10^{-14}\ \text{kg} = 10\times 10^{-15}\ \text{kg} = 10\ \text{Fkg}$$

REFLECT Using SI prefixes makes it easier to work with very small or large numbers.

27. **SOLVE** We need to convert mi to m and h to s:

$$v(\text{cheetah}) = \left(70\frac{\text{mi}}{\text{h}}\right)\times\left(\frac{\text{h}}{3600\ \text{s}}\right)\times\left(\frac{1609\ \text{m}}{\text{mi}}\right) = 31.3\frac{\text{m}}{\text{s}}$$

REFLECT Below is a list with the next 4 fastest animals:
Pronghorn Antelope 61 mph (98 km per hour)
Wildebeest 50 mph (80 km per hour)
Lion 50 mph (80 km per hour)
Thomson's Gazelle 50 mph (80 km per hour)

28. **SOLVE** We need to convert g to kg and cm^3 to m^3:

$$d\ (\text{Al}) = \left(2.70\ \frac{\text{g}}{\text{cm}^3}\right)\times\left(\frac{\text{kg}}{1000\ \text{g}}\right) = 2.7\times 10^{-3}\ \frac{\text{kg}}{\text{m}^3}$$

REFLECT The density of Osmium, the metal with the highest density, is 22610 kg m^3.

29. **SOLVE** We need to convert feet and inches to m and add the lengths:

$$\text{height (Yao)} = 7\ \text{feet} + 6\ \text{inches} = \left(7\ \text{feet}\times\frac{0.3048\ \text{m}}{\text{feet}}\right) + \left(6\ \text{inches}\times\frac{0.0254\ \text{m}}{\text{inches}}\right) = 2.286\ \text{m}$$

REFLECT Robert Wadlow is confirmed as the tallest male person by the *Guinness Book of World Records* at 8'11.1" (2.72 m).

30. **ORGANIZE AND PLAN** We use the equation for the velocity:

$$v = \frac{d}{t}$$

SOLVE We obtain for the average velocity of Lance Armstrong in the 2004 Tour de France:

$$\bar{v}(\text{Lance Armstrong}) = \frac{\left(3395\times 10^3\ \text{m}\right)}{\left(\left(83\ \text{h}\times\frac{3600\ \text{s}}{\text{h}}\right) + \left(36\ \text{min}\times\frac{60\ \text{s}}{\text{min}}\right) + 2\ \text{s}\right)} = 11.28\frac{\text{m}}{\text{s}}$$

REFLECT This velocity is equivalent to approximately 25 miles per hour!

31. **SOLVE** Converting inches to meters gives for the average annual rainfall:

$$\text{average rainfall} = \left(200\ \text{inches}\times\frac{0.0254\ \text{m}}{\text{inch}}\right) = 5.08\ \text{m}$$

REFLECT The most annual rainfall on Earth is in the Amazon at about 20 m per year!

32. **ORGANIZE AND PLAN** We use the equation for velocity:

$$v = \frac{d}{t}$$

SOLVE We convert miles to meters and 2 minutes and 2 s to seconds and obtain the average speed for the winner of the Kentucky Derby:

$$\bar{v}(\text{winner}) = \frac{\left(1.25\ \text{min} \times \dfrac{1609\ \text{m}}{\text{mi}}\right)}{\left(\left(2\ \text{min} \times \dfrac{60\ \text{s}}{1\ \text{min}}\right) + 2\ \text{s}\right)} = 16.49\frac{\text{m}}{\text{s}}$$

REFLECT The speed of the Kentucky Derby winner is about 1.6 times the speed of a short distance sprinter.

33. **SOLVE** (a) The number of Earth's diameters to make up the distance from Earth to the Moon is:

$$\frac{d(\text{Earth to Moon})}{d(\text{Earth diameter})} = \frac{d(\text{Earth to Moon})}{2 \times r(\text{Earth radius})} = \frac{(3.85 \times 10^8\ \text{m})}{2 \times (6.371 \times 10^6\ \text{m})} = 30.2$$

(b) The number of Earth's diameters to make up the distance from Earth to the Sun is:

$$\frac{d(\text{Earth to Sun})}{d(\text{Earth diameter})} = \frac{d(\text{Earth to Sun})}{2 \times r(\text{Earth radius})} = \frac{(1.496 \times 10^{11}\ \text{m})}{2 \times (6.371 \times 10^6\ \text{m})} = 11740$$

REFLECT Earth is the third planet from the Sun, and the largest of the terrestrial planets in the Solar System in terms of diameter, mass, and density.

34. **SOLVE** The average number of seconds in a year, $\bar{t}_1$, is given by:

$$\bar{t}_1 = 365.24\ \text{days} \times \left(\frac{(24 \times 60 \times 60\ \text{s})}{\text{day}}\right) = 3.1536 \times 10^7\ \text{s}$$

Or by the approximation, $\bar{t}_2$:

$$\bar{t}_2 = \pi \times 10^7\ \text{s} = 3.1416 \times 10^7$$

The percentage difference between the two numbers is given by:

$$\%\text{diff} = 100\% \times \frac{(\bar{t}_1 - \bar{t}_2)}{\bar{t}_1} = 100\% \times \frac{(3.1536 \times 10^7\ \text{s} - 3.1416 \times 10^7\ \text{s})}{(3.1416 \times 10^7\ \text{s})} = 0.38\ \%$$

REFLECT The 0.4% difference between the two numbers corresponds to 120000 s (about 33.3 h)!

35. **SOLVE** The mass for a ^{12}C atom is given by:

$$m(^{12}\text{C atom}) = 12\frac{\text{g}}{\text{mol}} \times \frac{\text{mol}}{6.02 \times 10^{23}} = 1.99 \times 10^{-23}\,\text{g}$$

REFLECT The mass of one ^{238}U atom, the heaviest naturally occurring atom, is 3.95×10^{-22} g.

36. **ORGANIZE AND PLAN** Using the mass of one water molecule and the density of water, we can calculate the number of molecules in 1 L of water.

SOLVE From the density we know that 1 L of water weighs 1 kg. Therefore:

$$\text{number of water molecules} = \frac{(1\ \text{kg L}^{-1})}{(3.0 \times 10^{-26}\ \text{kg molecule}^{-1})} = 3.33 \times 10^{25}$$

REFLECT If you could count two water molecules per second, it would take you 5.28×10^{17} years to count all the water molecules in one liter!

37. **SOLVE** (a) To convert from mi to km we use the fact that 1609 m are 1 mile and 1000 m are in 1 km:

$$(\text{factor mi} \to \text{km}) = \frac{(1602\ \text{m mi}^{-1})}{(1000\ \text{m km}^{-1})} = 1.602\ \text{km mi}^{-1}$$

(b) To convert from kg to μg we use the fact that 1000 g are 1 kg and 10^{-6} g are in 1 μg :

$$(\text{factor kg} \to \mu\text{g}) = \left(1000\frac{\text{g}}{\text{kg}}\right) \times \left(\frac{1\ \mu\text{g}}{10^{-1}\ \text{g}}\right) = 10^{-1}\ \mu\text{g kg}^{-1}$$

(c) To convert from km/h to m/s we have to convert km to m and h to s:

$$\left(\text{factor } \frac{\text{km}}{\text{h}} \rightarrow \frac{\text{m}}{\text{s}}\right) = \left(1000\frac{\text{m}}{\text{km}}\right)\times\left(\frac{1\text{ h}}{3600\text{ s}}\right) = 0.2778\text{ m h s}^{-1}\text{ km}^{-1}$$

(d) To convert from ft^3 to m^3 we use that 0.3048 m is 1 foot:

$$\left(\text{factor ft}^3 \rightarrow \text{m}^3\right) = \left(\frac{0.3048\text{ m}}{1\text{ ft}}\right)^3 = 0.0283\text{ m}^3\text{ ft}^{-3}$$

REFLECT Always convert all physical properties to the same unit system before you use the corresponding numbers in your calculations.

38. **SOLVE** We convert micro century to s:

$$1\text{ micro century} = 10^{-6}\times 100\text{ y} = 10^{-6}\times 100\text{ y}\times\left(\frac{60\text{ min}}{1\text{ h}}\right)\times\left(\frac{24\text{ h}}{1\text{ d}}\right)\times\left(\frac{365\text{ d}}{1\text{ y}}\right) = 52.56\text{ min}$$

A typical college class lasts a little less than an hour.

REFLECT An academic quarter (German: *Akademisches Viertel*, Swedish: *akademisk kvart (ak* or *aq*) is the quarter-hour (15 minute) period of time discrepancy between the defined start time for a lecture or lesson ("per schema") and the actual starting time, at some universities in Austria, Switzerland, Finland, Romania, Scandinavia, and Germany. The quarter system dates back to the days when the ringing of the church bell was the general method of time keeping. When the bell rang full hour, students had 15 minutes to attend the lecture. Thus a lecture with a defined start time of 10:00 would start at 10:15. In the German university system, lectures scheduled at a certain hour, with or without the addition "c.t." (*cum tempore*, Latin for "with time"), usually start 15 minutes after the full hour. If this is not the case, usually "s.t." (*sine tempore*, Latin for "without time") is added to indicate that the lecture will begin at the exact time.

39. **ORGANIZE AND PLAN** To solve the problem we use the fact the speed has the dimensions of distance per time. Furthermore, the circumference, Cf, of a circle with radius, r, is given by Cf = 2 π r.

SOLVE Therefore, we obtain for the speed of the spacecraft with converting the units appropriately:

$$v = \frac{d}{t} = \frac{2\,\pi\,\left(6378\text{ km} + 100\text{ km}\right)\times 10^3\left(\frac{\text{m}}{\text{km}}\right)}{86.5\text{ min}\times\left(\frac{60\text{ s}}{\text{min}}\right)} = 7842.5\frac{\text{m}}{\text{s}}$$

REFLECT The speed of the spacecraft corresponds to an incredible 17542 miles/hour!

40. **ORGANIZE AND PLAN** To answer the question we first determine the price of 1 L in \$US. Then we calculate how much \$US you would need to spend in Canada to purchase 1 L of gasoline in Canada using the exchange rate.

SOLVE We use the conversion factor from gallons to liter:

$$\text{price in US} = 4.30\frac{\$\text{US}}{\text{gallon}}\times\left(\frac{\text{gallon}}{3.785\text{ L}}\right) = 1.136\ \frac{\$\text{US}}{\text{L}}$$

That means you have to spend 1.136 \$US to purchase 1 L of gasoline in the US. How much \$US you would need to spent in Canada to purchase 1 L of gasoline in Canada using the exchange rate is then:

$$\text{price in Can} = 1.36\frac{\$\text{Can}}{\text{L}}\times\frac{1}{1.07}\frac{\$\text{US}}{\$\text{Can}} = 1.271\frac{\$\text{US}}{\text{L}}$$

This means that it would be cheaper for you to buy the gasoline in the US.

REFLECT As a comparison, the price for 1 gallon of gasoline in Germany is about 7.5 Euros!

41. **SOLVE** To convert the astronomic distances, d, to AU we use the definition of 1 AU = 1.496×10^{11} m:

(a) Mercury

$$d = 5.76\times 10^{10}\times\left(\frac{1\text{ AU}}{1.496\times 10^{11}\text{ m}}\right) = 0.385\text{ AU}$$

(b) Mars

$$d = 2.28\times10^{10}\times\left(\frac{1\text{ AU}}{1.496\times10^{11}\text{ m}}\right) = 1.524\text{ AU}$$

(c) Jupiter

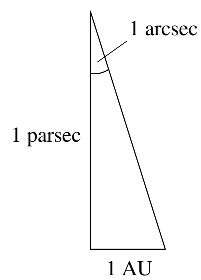
$$d = 7.78\times10^{11}\times\left(\frac{1\text{ AU}}{1.496\times10^{11}\text{ m}}\right) = 5.200\text{ AU}$$

(d) Neptune

$$d = 4.50\times10^{12}\times\left(\frac{1\text{ AU}}{1.496\times10^{11}\text{ m}}\right) = 30.080\text{ AU}$$

REFLECT Using AUs, astronomical distances can easily be expressed as multiples and fractions of the average distance between the Earth and Sun.

42. **ORGANIZE AND PLAN** (a) From the description in the problem we can construct the following rectangular triangle:



From trigonometry we know that:

$$\tan(1\text{ arcsec}) = \frac{1\text{ AU}}{1\text{ parsec}}$$

Finally, we use the conversion factors given to convert from arcsec to degrees.

SOLVE

$$1\text{ arcsec}\times\left(\frac{1\text{ arcmin}}{60\text{ arcsec}}\right)\times\left(\frac{1\text{ degree}}{60\text{ arcmin}}\right) = 2.778\times10^{-4}\text{ degree}$$

$$1\text{ parsec} = \frac{1\text{ AU}}{\tan(1\text{ arcsec})} = \frac{1\text{ AU}}{\tan(\ 2.778\times10^{-4}\text{ degree})} = 206.26\times10^{3}\text{ AU}$$

(b) We use the result from a) and the definition of AU:

$$1\text{ parsec} = 206.26\times10^{3}\text{ AU}\times\left(1.496\times10^{11}\frac{\text{m}}{\text{AU}}\right) = 3.086\times10^{16}\text{ m}$$

REFLECT The first direct measurements of an object at interstellar distances were undertaken by German astronomer Friedrich Wilhelm Bessel in 1838, who used the width of the Earth's orbit as a baseline to calculate the distance of 61 Cygni using parallax and trigonometry. The parallax of a star is half of the angular distance a star appears to move relative to the celestial sphere as Earth orbits around the Sun; or, reciprocally, it is the subtended angle, from that star's perspective, of the semi-major axis of Earth's orbit. The use of the parsec as a unit of distance follows naturally from Bessel's method, since distance (in parsecs) is simply the reciprocal of the parallax angle (in arcseconds). That is, it is the distance at which the semi-major axis of the Earth's orbit would subtend an angle of one second of arc. Though it had probably been used before, the term *parsec* was first mentioned in an astronomical publication in 1913, when Astronomer Royal Frank Watson Dyson expressed his concern for the need of a name for that unit of distance: he proposes the name *astron*, but mentions that Carl Charlier had suggested *siriometer*, and Herbert Hall Turner had suggested *parsec* (parallax second).

43. **SOLVE** (a) We set up two equations for the surface areas of planets A and B, and replace the radius of planet A, r_A with 2 $r_B r_B$:

$$A_A = 4\pi r_A{}^2 = 4\pi \left(2r_B\right)^2 = 16\pi r_B{}^2$$

$$A_B = 4\pi r_B{}^2$$

We now Solve both equations for $r_B{}^2$ and set them equal to obtain the ratio of the surface areas:

$$r_B{}^2 = \frac{A_A}{16\pi} \quad \text{and} \quad r_B{}^2 = \frac{A_B}{4\pi}$$

Then:

$$\frac{A_A}{16\pi} = \frac{A_B}{4\pi}$$
$$A_A = 4A_B$$

(b) We use an equivalent scheme as in a) to obtain the ratio of the volumes, using the equation for the volume of a sphere:

$$V_A = \frac{4}{3}\pi r_A{}^3 = \frac{4}{3}\pi\left(2\ r_B\right)^3 = \frac{32}{3}\pi r_B{}^3$$

$$V_B = \frac{4}{3}\pi r_B{}^3$$

Then:

$$r_B{}^3 = \frac{3V_A}{32\pi} \quad \text{and} \quad r_B{}^3 = \frac{3V_B}{4\pi}$$

$$\frac{3V_A}{32\pi} = \frac{3V_B}{4\pi}$$
$$V_A = 8V_B$$

REFLECT The ratio of the planet's volumes is twice the ratio of their surfaces.

44. **SOLVE** (a) The dimensions of density are mass per volume. (b) The SI units of density are kg per m^3.
REFLECT In a well-known story, Archimedes was given the task of determining whether King Hiero's goldsmith was embezzling gold during the manufacture of a wreath dedicated to the gods and replacing it with another, cheaper alloy. Archimedes knew that the irregularly shaped wreath could be crushed into a cube whose volume could be calculated easily and compared with the weight; but the king did not approve of this. Baffled, Archimedes took a relaxing bath and observed from the rise of the warm water upon entering that he could calculate the volume of the gold crown through the displacement of the water. Allegedly, upon this discovery, he went running naked through the streets shouting, "Eureka! Eureka!" (Greek "I found it"). As a result, the term "eureka" entered common parlance and is used today to indicate a moment of enlightenment. This story first appeared in written form in Vitruvius' books of architecture, two centuries after it supposedly took place. Some scholars have doubted the accuracy of this tale, saying among other things that the method would have required precise measurements that would have been difficult to make at the time.

45. **ORGANIZE AND PLAN** To obtain the travel times we use the equation for speed, v, defined as distance per time, and solve for time:

$$v = \frac{d}{t}$$

$$t = \frac{d}{v}$$

We use the speed of light given in the text.

SOLVE (a) The distance between the Moon and Earth is given in Problem 24. With converting the units properly we obtain:

$$t=\frac{d}{v}=\frac{385{,}000\text{ km}\times\left(\frac{1000\text{ m}}{\text{km}}\right)}{299{,}792{,}458\text{ m s}^{-1}}=1.28\text{ s}$$

(b) The distance from the Sun to Earth is given in Table 1.1. With converting the units properly we obtain:

$$t=\frac{d}{v}=\frac{1.5\times10^{11}\text{ m}}{299{,}792{,}458\text{ m s}^{-1}}=500.3\text{ s}$$

(c) The distance from the Sun to Neptune is given in Problem 41. With converting the units properly we obtain:

$$t=\frac{d}{v}=\frac{4.50\times10^{12}\text{ m}}{299{,}792{,}458\text{ m s}^{-1}}=15{,}010.4\text{ s}=15{,}010.4\text{ s}\times\left(\frac{\text{h}}{3600\text{ s}}\right)=4.2\text{ h}$$

REFLECT Considering the incredible speed of light, the 4.2 h of travel time of light from Earth to Neptune indicates the immense size of our solar system.

46. **SOLVE** Using the dimensions given for acceleration, *a,* and force, *F,* and solving the equation for force for *L*, we obtain:

$$a=\frac{L}{T^2}\text{ and }F=\frac{M\,L}{T^2}$$

$$L=\frac{F\,T^2}{M}$$

Now we can substitute *L* in the equation for acceleration and obtain:

$$a=\frac{L}{T^2}=\frac{F\,T^2}{T^2\,M}=\frac{F}{M}$$

A dimension analysis shows that acceleration depends on the ratio of force over mass.

REFLECT Always check the dimensions of an answer you calculate to make sure they match with the dimensions of the property calculated.

47. **SOLVE** To answer the question we analyze the dimensions of the constant and solve for time to obtain:

$$k=\frac{m}{t^2}$$

$$t=\sqrt{\frac{m}{k}}$$

This means that the period depends on the square root of the ratio of mass over the constant.

REFLECT In mechanics, and physics, Hooke's law of elasticity is an approximation that states that the extension of a spring is in direct proportion with the load added to it as long as this load does not exceed the elastic limit. Materials for which Hooke's law is a useful approximation are known as linear-elastic or "Hookean" materials.

48. **SOLVE** In analogy to 47 we obtain:

$$g=\left[\frac{L}{T^2}\right]$$

$$T=\left[\sqrt{\frac{L}{g}}\right]=\left[\sqrt{\frac{LT^2}{L}}\right]=\left[T\right]$$

This means that the period depends on the square root of the ratio of length over the gravity acceleration.

REFLECT The simple gravity pendulum is an idealized mathematical model of a pendulum. This is a weight on the end of a massless cord suspended from a pivot, without friction. When given an initial push, it will swing back and forth at a constant amplitude. Real pendulums are subject to friction and air drag, so the amplitude of their swings declines.

49. **ORGANIZE AND PLAN** We know that velocity has dimensions of length per time:

$$v = \left[\frac{L}{T}\right]$$

Therefore, we must combine the height and gravitational constant to produce the dimensions of length per time.

SOLVE

$$v = \left[\frac{L}{T}\right] = \left[\sqrt{gh}\right] = \left[\sqrt{\frac{L}{T^2}L}\right] = \left[\frac{L}{T}\right]$$

REFLECT Gravitation is a natural phenomenon by which objects with mass attract one another. In everyday life, gravitation is most commonly thought of as the agency which lends weight to objects with mass. Gravitation compels dispersed matter to coalesce, thus it accounts for the very existence of the Earth, the Sun, and most of the macroscopic objects in the universe. It is responsible for keeping the Earth and the other planets in their orbits around the Sun; for keeping the Moon in its orbit around the Earth, for the formation of tides; for convection (by which fluid flow occurs under the influence of a temperature gradient and gravity); for heating the interiors of forming stars and planets to very high temperatures; and for various other phenomena that we observe. Modern physics describes gravitation using the general theory of relativity, in which gravitation is a consequence of the curvature of spacetime which governs the motion of inertial objects. The simpler Newton's law of universal gravitation provides an excellent approximation for most calculations.

50. **ORGANIZE AND PLAN** Zeros are only used to mark the decimal point and are not counted as significant figures.

SOLVE (a) four, (b) four, (c) two, and (d) three

REFLECT Significant figures in calculations are very important for reporting results.

51. **SOLVE** (a) one, (b) three, (c) three, and (d) five.

REFLECT The final answer to a given problem should be rounded to the appropriate number of figures.

52. **ORGANIZE AND PLAN** The area of the room is given by: $A_{\text{room}} = \text{side 1} \times \text{side 2}$

SOLVE $A_{\text{room}} = 9.7\text{ m} \times 14.5\text{ m} = 1.4\times10^2\text{ m}^2$

REFLECT The result of multiplying and dividing two numbers should be rounded to the smaller number of significant figures in the product or fraction. When adding and subtracting numbers, the result should be reported with the number of decimal places equal to the smallest number of decimal places in any of the starting values.

53. **ORGANIZE AND PLAN** Labeling the longest side of the right triangle with 25.0 cm of length, c, and the other two shorter sides with lengths 15.0 cm and 20.0 cm, a and b, we obtain for the area of the right triangle:

$$A_{\text{right triangle}} = \frac{1}{2}(\text{a} \times \text{b})$$

SOLVE $A_{\text{room}} = \frac{1}{2}(15.0\text{ cm} \times 20.0\text{ cm}) = 150\text{ m}$

REFLECT We apply the same rules for rounding to significant figures when multiplying numbers as described in Problem 52.

54. **ORGANIZE AND PLAN** (a) The density is given by mass per volume:

$$\rho = \frac{m}{V}$$

(b) We expand the equation from a) for the density by introducing the equation for the volume of a sphere:

$$\rho = \frac{m}{V} = \frac{m}{\left(\frac{4}{3}\pi r^3\right)} = \frac{3m}{4\pi r^3}$$

SOLVE (a) We can solve that equation for the volume, V, and obtain for the volume:

$$V = \frac{m}{\rho} = \frac{14.00\text{ kg}}{8194\text{ kg m}^{-3}} = 1.7086\times10^{-3}\text{ m}^3$$

(b) Solving for r yields:

$$r = \sqrt[3]{\frac{3\ \text{m}}{4\ \pi\ \rho}} = \sqrt[3]{\frac{3\ (14.00\ \text{kg})}{4\ \pi\ (8194\ \text{kg m}^{-3})}} = 0.074\ \text{m}\ =\ 7.4\ \text{cm}$$

REFLECT Steel is an alloy consisting mostly of iron, with a carbon content between 0.2% and 2.14% by weight, depending on grade. Carbon is the most cost-effective alloying material for iron, but various other alloying elements are used such as manganese, chromium, vanadium, and tungsten. Carbon and other elements act as a hardening agent, preventing dislocations in the iron atom crystal lattice from sliding past one another. Varying the amount of alloying elements and form of their presence in the steel (solute elements, precipitated phase) controls qualities such as the hardness, ductility, and tensile strength of the resulting steel. Steel with increased carbon content can be made harder and stronger than iron, but is also more brittle.

55. **ORGANIZE AND PLAN** The volume of a cylinder is given by: $V = \pi r^2 h$.

SOLVE We expand the equation for the density by introducing the equation for the volume of a cylinder:

$$\rho = \frac{m}{V} = \frac{m}{(\pi r^2 h)} = \frac{m}{\left(\pi\left(\frac{d}{2}\right)^2 h\right)} = \frac{27.13\ \text{g}}{8.625\ \text{cm}\ \pi\left(\frac{1.218\ \text{cm}}{2}\right)^2} = 2.6996\ \text{g cm}^{-3}$$

REFLECT A dimension analysis of our answer indicates that the equation to solve the problem was set up correctly.

56. **ORGANIZE AND PLAN** The time it takes to fall is given by:

$t = \sqrt{\frac{2\ \text{s}}{g}}$, where s is the height and g is the acceleration due to Earth's gravitational field. After we calculated the time, we can simply calculate the speed as distance per time.

SOLVE (a) The time is $t = \sqrt{\frac{2\ \text{s}}{g}} = \sqrt{\frac{2\ (1\ \text{m})}{(9.81\ \text{m/s}^{-2})}} = 0.451\ \text{s}$

The speed is: $v = \sqrt{2g\text{s}} = \sqrt{2(9.81\ \text{m/s}^{-2})(1\ \text{m})} = 4.43\ \text{m/s}^{-1}$

The fall takes in the order of four tens of a second and the speed he has when he hits the water is in the order of $2\ \text{m/s}^{-1}$.

(b) The time is $t = \sqrt{\frac{2\ \text{s}}{g}} = \sqrt{\frac{2\ (10\ \text{m})}{(9.81\ \text{m/s}^{-2})}} = 1.428\ \text{s}$

The speed is: $v = \frac{\text{s}}{t} = \frac{10\ \text{m}}{1.428\ \text{s}} = 7.004\ \text{m/s}^{-1}$

The fall takes in the order of 1.5 s and the speed he has when he hits the water is in the order of $7\ \text{m/s}^{-1}$.

REFLECT When the height the ball drops increases by a factor of 10, the time it takes for the fall increases by $\sqrt{10}$.

57. **ORGANIZE AND PLAN** We use the average number of heart beats per minute of 70 from Problem 68, and then use a series of conversion factors to estimate the number of heart beats per lifetime. We further assume an average lifetime of 80 years.

SOLVE $70\frac{\text{beats}}{\text{min}} \times \frac{60\ \text{min}}{\text{h}} \times \frac{24\ \text{h}}{\text{day}} \times \frac{365\ \text{days}}{\text{yr}} \times \frac{80\ \text{yr}}{\text{lifetime}} = 2.94 \times 10^9\ \frac{\text{yr}}{\text{lifetime}}$

The number of heart beats is in the order of 10^9.

REFLECT Humans live on average 31.99 years in Swaziland and on average 81 years in Japan (2008 est.). The oldest confirmed recorded age for any human is 122 years (see Jeanne Calment), though some people are reported to have lived longer. This is referred to as the life span, which is the upper boundary of life, the maximum number of years an individual can live.The following information is derived from the *Encyclopaedia Britannica*, 1961, as well as other sources and represents estimates of the life expectancies of the population as a whole. In many instances life expectancy varied considerably according to class and gender. It is important to note that life expectancy rises sharply in all cases for those who reach puberty. A pre-20th Century individual who lived past the teenage years could expect to live to an age close to the life expectancy of today. The ages listed below are an average that includes infant mortalities, but not miscarriage or abortion. This table also rejects certain beliefs that the ancient humans had life expectancy of hundreds of years.

58. **ORGANIZE AND PLAN** (a) The Earth, with an approximate weight of 6.0×10^{24} kg, mostly consists of iron, silicon, and oxygen. Assuming the presence of equal amounts we can calculate an average molecular weight, using the molecular weights of those elements. Then we use Avogadro's number to calculate the number of atoms, N_{atoms}.
(b) We use the same approximate composition of Earth and the number of protons in the corresponding elements to calculate an average number of protons per element. Then we use the average approximate number of protons per element and the result from a) to get the approximate number of protons on Earth, N_{protons}.

SOLVE (a)

$$N_{\text{atoms}} = \frac{m}{M} \times N_A = \frac{\left(6.0\times10^{24}\ \text{kg}\right)}{\left[\left(\frac{1}{3}\times56\times10^{-3}\ \frac{\text{kg}}{\text{mol}}\right)+\left(\frac{1}{3}\times28\times10^{-3}\ \frac{\text{kg}}{\text{mol}}\right)+\left(\frac{1}{3}\times16\times10^{-3}\ \frac{\text{kg}}{\text{mol}}\right)\right]}\times\left(6.022\times10^{23}\ \text{mol}^{-1}\right)$$

$$\text{N}_{\text{atoms}} = 1.09\times10^{50}$$

There are approximately in the order of 10^{50} number of atoms in Earth.

(b)

$$N_{\text{protons}} = \left[\left(\frac{1}{3}\ \times8\ \frac{\text{protons}}{\text{O atom}}\right)+\left(\frac{1}{3}\times14\ \frac{\text{protons}}{\text{Si atom}}\right)+\left(\frac{1}{3}\times26\ \frac{\text{protons}}{\text{Fe atom}}\right)\right]\times\left(1.09\times10^{50}\ \text{atoms on Earth}\right)$$

$$N_{\text{protons}} = 1.74\times10^{51}$$

There are approximately in the order of 10^{51} number of protons in Earth.

REFLECT The mass of the Earth is approximately 5.98×10^{24} kg. It is composed mostly of iron (32.1%), oxygen (30.1%), silicon (15.1%), magnesium (13.9%), sulfur (2.9%), nickel (1.8%), calcium (1.5%), and aluminium (1.4%); with the remaining 1.2% consisting of trace amounts of other elements. Due to mass segregation, the core region is believed to be primarily composed of iron (88.8%), with smaller amounts of nickel (5.8%), sulfur (4.5%), and less than 1% trace elements.

59. **ORGANIZE AND PLAN** We use the thickness of the entire book and divide by the number of pages to estimate the thickness of one page.

SOLVE $\text{thickness of page} = \dfrac{\text{thickness of book}}{\text{number of pages}} = \dfrac{2.5\ \text{cm}}{400} = 6.25\times10^{-3}\ \text{cm}$

The thickness of a page in a 400-page book with a total thickness of 2.5 cm is in the order of 10^{-3} cm.

REFLECT The term *e-book* is a contraction of "electronic book"; it refers to a digital version of a conventional print book. An e-book is usually made available through the internet, but also on CD-ROM and other forms. E-books are read by means of a physical book display device known as an e-book reader, such as the Sony Reader or the Amazon Kindle. These devices attempt to mimic the experience of reading a print book.

60. **ORGANIZE AND PLAN** (a) We might make the following assumptions:
(1) There are approximately 5,000,000 people living in Chicago.
(2) On average, there are two persons in each household in Chicago.
(3) Roughly one household in twenty has a piano that is tuned regularly.
(4) Pianos that are tuned regularly are tuned on average about once per year.
(5) It takes a piano tuner about two hours to tune a piano, including travel time.

(6) Each piano tuner works eight hours in a day, five days in a week, and 50 weeks in a year.
From these assumptions we can compute the number of piano tunings in a single year in Chicago. And we can similarly calculate the average tunings a piano tuner performs. Dividing the two numbers gives us an estimate.
(b) We use an equivalent approach for the repair shops in Los Angeles.

SOLVE (a)

$$\frac{5{,}000{,}000 \text{ persons in Chicago}}{2 \text{ persons per household}} \times \frac{1 \text{ piano}}{20 \text{ households}} \times \frac{1 \text{ piano tuning}}{\text{piano and year}} = 125{,}000 \ \frac{\text{piano tunings}}{\text{year}}$$

$$\frac{50 \text{ weeks}}{\text{year}} \times \frac{5 \text{ days}}{\text{weeks}} \times \frac{8 \text{ hours}}{\text{day}} \times \frac{1 \text{ piano tuning}}{2 \text{ hours and tuner}} = 1000 \ \frac{\text{piano tunings}}{\text{year and tuner}}$$

$$\frac{125{,}000 \ \frac{\text{piano tunings}}{\text{year}}}{1000 \ \frac{\text{piano tunings}}{\text{year and tuner}}} = 125 \text{ piano tuners in Chicago}$$

(b) We use an equivalent approach for the repair shops in Los Angeles:

$$\frac{4{,}000{,}000 \text{ persons in LA}}{2 \text{ persons per household}} \times \frac{1 \text{ shop}}{50 \text{ households}} \times \frac{2000 \text{ shop visits}}{\text{shop and year}} = 8.0 \times 10^7 \ \frac{\text{shop visits}}{\text{year}}$$

$$\frac{50 \text{ weeks}}{\text{year}} \times \frac{5 \text{ days}}{\text{weeks}} \times \frac{8 \text{ hours}}{\text{day}} \times \frac{5 \text{ shop visit}}{1 \text{ hours and shop}} = 10{,}000 \ \frac{\text{shop visits}}{\text{year and shop}}$$

$$\frac{8.0 \times 10^7 \ \frac{\text{shop visits}}{\text{year}}}{10{,}000 \ \frac{\text{shop visits}}{\text{year and shop}}} = 8000 \text{ shops in LA}$$

REFLECT A famous example of a Fermi problem–like estimate is the Drake equation, which seeks to estimate the number of intelligent civilizations in the galaxy. The basic question of why, if there are a significant number of such civilizations, ours has never encountered any others is called the Fermi paradox.

61. **ORGANIZE AND PLAN** We use the equation for density and substitute the ratios given for plant's masses and radii.

SOLVE

$$\rho = \frac{m}{V} \text{ with } m_{\mathrm{E}} = 1.23 \times m_{\mathrm{E}} \text{ and } r_{\mathrm{E}} = 1.05 \times r_{\mathrm{V}}$$

$$\frac{\rho_{\mathrm{E}}}{\rho_{\mathrm{V}}} = \frac{\left(\frac{m_{\mathrm{E}}}{V_{\mathrm{E}}}\right)}{\left(\frac{m_{\mathrm{V}}}{V_{\mathrm{V}}}\right)} = \frac{\left(\frac{m_{\mathrm{E}}}{\frac{4}{3}\pi r_{\mathrm{E}}^3}\right)}{\left(\frac{m_{\mathrm{V}}}{\frac{4}{3}\pi r_{\mathrm{V}}^3}\right)} = \frac{\left(\frac{1.23 \times m_{\mathrm{V}}}{\frac{4}{3}\pi \left(1.05 \times r_{\mathrm{V}}\right)^3}\right)}{\left(\frac{m_{\mathrm{V}}}{\frac{4}{3}\pi r_{\mathrm{V}}^3}\right)} = \frac{1.23}{1.05} = 1.06$$

REFLECT The Solar System consists of the Sun and those celestial objects bound to it by gravity, all of which formed from the collapse of a giant molecular cloud approximately 4.5 billion years ago. The Sun's retinue of objects circle it in a nearly flat disc called the ecliptic plane, in which most of the mass is contained within eight relatively solitary planets whose orbits are nearly circular. The four smaller inner planets, Mercury, Venus, Earth and Mars, also called the terrestrial planets, are primarily composed of rock and metal. The four outer planets, Jupiter, Saturn, Uranus and Neptune, also called the gas giants, are composed largely of hydrogen and helium and are far more massive than the terrestrials.

62. **ORGANIZE AND PLAN** (a) To obtain the average daily growth rate of a fetus we convert 39 weeks to days and divide the birth weight by the number of days. (b) We use the definition of density as mass per volume.

SOLVE (a) $\text{birth rate} = \dfrac{3.3\ \text{kg}}{\left(39\ \text{wks} \times \dfrac{7\ \text{d}}{1\ \text{wk}}\right)} = \dfrac{3.3\ \text{kg}}{273\ \text{d}} = 0.012\ \text{kg d}^{-1}$

The fetus gains about 12 g per day in the womb.

(b) The average density that is gained each day can be obtained by:

$$V = \frac{m}{\rho} = \frac{\left(0.012\ \text{kg d}^{-1}\right)}{\left(1020\ \text{kg m}^{-3}\right)} \times \frac{10^6\,\text{cm}^3}{\text{m}^3} = 11.76\ \text{cm}^3\ \text{d}^{-1}$$

The fetus gains about 11.76 cm^3 per day in the womb.

REFLECT In humans, the fetal stage of prenatal development begins about eight weeks after fertilization, when the major structures and organ systems have formed, and lasts until birth.

63. **SOLVE** (a) To calculate the average density of Saturn we use the equation for density:

$$\rho_S = \frac{m_S}{\frac{4}{3}\pi r_S^3} = \frac{\left(5.69\times10^{26}\ \text{kg}\right)}{\frac{4}{3}\pi\left(6.03\times10^{7}\ \text{m}\right)^3} = 619.543\ \text{kg m}^{-3}$$

(b) The density of Saturn is only about 60% of the density of water, reflecting the predominantly gaseous nature of the planet.

REFLECT The planet Saturn is composed of hydrogen, with small proportions of helium and trace elements. The interior consists of a small core of rock and ice, surrounded by a thick layer of metallic hydrogen and a gaseous outer layer. The outer atmosphere is generally bland in appearance, although long-lived features can appear. Wind speeds on Saturn can reach 1,800 km/h, significantly faster than those on Jupiter. Saturn has a planetary magnetic field intermediate in strength between that of Earth and the more powerful field around Jupiter.

64. **SOLVE** To calculate the minutes in a 365-day year we convert days to minutes and obtain:

$$\text{minutes per year} = 365\ \text{d} \times \left(\frac{24\ \text{h}}{1\ \text{d}}\right) \times \left(\frac{60\ \text{min}}{1\ \text{h}}\right) = 525{,}600\ \text{min}$$

REFLECT ”Seasons of Love” is a song from the Broadway musical *Rent*, written and composed by Jonathan Larson. The song starts with an ostinato piano motif, which provides the harmonic framework for the cast to sing “Five hundred twenty-five thousand six hundred minutes” (the number of minutes in a common non-leap-calendar year). The main instruments used throughout the song are piano, vocals, guitar, and drums. Both in the musical and in the 2005 film, the song is performed by the entire cast. The main question asked is, “How do you measure a year?” Various answers are suggested, from points of the day (“Daylights,” “Sunsets,” “Midnights”) to units of measure (“inches,” “miles”), to everyday events (“cups of coffee”) to more symbolic concepts (“laughter,” “strife”). In the chorus, the song reaches the conclusion that love is the only proper measure of a year in a human life. In the stage production, the song is sung at the opening of the second act. The cast stands downstage in a straight line facing the audience.

65. **ORGANIZE AND PLAN** The average speed is distance per time.

SOLVE (a) We convert the units given to the SI units of distance and time, m and s, and obtain:

$$v = \frac{s}{t} = \frac{1.5\ \text{mil} \times \left(\dfrac{1\,609.344\ \text{m}}{1\ \text{mil}}\right)}{\left(2\ \text{min} \times \left(\dfrac{60\ \text{s}}{1\ \text{min}}\right) + 24\ \text{s}\right)} = 16.76\ \text{m/s}^{-1}$$

Secretariat ran the race at an amazingly average speed of $16.76\ \text{m/s}^{-1}$.

(b) Repeating the average speed calculation for a human sprinter yields:

$$v = \frac{s}{t} = \frac{100\text{ m}}{9.8\text{ s}} = 10.20\text{ m/s}^{-1}$$

Therefore, the ratio of Secretariat's speed and the speed of a human sprinter is:

$$\frac{v_{\text{Secretariat}}}{v_{\text{humnan sprinter}}} = \frac{16.76\text{ m/s}^{-1}}{10.20\text{ m/s}^{-1}} = 1.64$$

REFLECT Secretariat (March 30, 1970 – October 4, 1989) was an American thoroughbred racehorse. When Secretariat won the 1973 Triple Crown, he became the first Triple Crown winner in 25 years, and set still-standing track records in two of the three races in the Series, the Kentucky Derby (1:59 2/5), and the Belmont Stakes (2:24). Like the famous Man o' War, Secretariat was a large chestnut colt and was given the same nickname, "Big Red."

66. **ORGANIZE AND PLAN** We use the relationship between the distance on the circumference of a circle, b, and the radius of a circle, r, and solve for r. We then convert stades to meters and consider that the diameter is twice the radius.

SOLVE (a) $\text{b} = \theta \dfrac{\pi}{180°} r$, with θ in degrees

$$d = 2r = 2\times\frac{\text{b}}{\left(\theta\dfrac{\pi}{180°}\right)} = 2\times\frac{5000\text{ stades}\times\left(\dfrac{500\text{ ft}}{1\text{ stade}}\right)\times\left(\dfrac{0.3048\text{ m}}{1\text{ ft}}\right)}{\left(7.2°\dfrac{\pi}{180°}\right)} = 12.128\times10^{6}\text{ m} = 12.128\text{ Mn}$$

(b) Comparing the estimation from part (a) to the accepted value for the Earth's diameter yields:

$$\text{deviation of estimate} = 100\times\frac{(12.7\text{ Mm} - 12.128\text{ Mm})}{12.7\text{ Mm}} = 4.5\%$$

REFLECT Eratosthenes of Cyrene was a Greek mathematician, poet, athlete, geographer, and astronomer. He made several discoveries and inventions including a system of latitude and longitude. He was the first Greek to calculate the circumference of the Earth (with remarkable accuracy), and the tilt of the earth's axis (also with remarkable accuracy); he may also have accurately calculated the distance from the earth to the sun and invented the leap day. He also created a map of the world based on the available geographical knowledge of the era. Eratosthenes was also the founder of scientific chronology; he endeavored to fix the dates of the chief literary and political events from the conquest of Troy.

67. **SOLVE** To get the number of water molecules in a water bottle containing 0.500 L we combine the equations for density and molecular mass:

$$\rho = \frac{m}{V} \quad\Rightarrow\quad m = \rho V$$

$$M = \frac{m}{n} \quad\Rightarrow\quad m = nM$$

Therefore:

$$V\rho = nM$$
$$n = \frac{V\rho}{M}$$

The units for density and volume have to be made equivalent, and then finally, to convert from moles to actual water molecules we need to multiply with Avogadro's number:

$$\text{number of molecules} = \frac{3V\rho N_{\text{A}}}{M}$$

$$\text{number of molecules} = \frac{3(0.500\text{ L})\times\left(\dfrac{0.001\text{ m}^{3}}{1\text{ L}}\right)\times(1000\text{ kg m}^{-3})\times(6.022\times10^{23}\text{ mol}^{-1})}{0.01802\text{ kg mol}^{-1}} = 5.0127\times10^{25}$$

REFLECT More than 83 moles of water molecules are in the 0.5 L bottle.

68. **ORGANIZE AND PLAN** To obtain the flow rate in SI units we have to convert L to m^3 and min to s.

SOLVE (a) The dimensions of flow rate are $L^3 \times T^{-1}$.

(b) The SI units are $m^3 \times s^{-1}$.

(c) $\text{rate} = 5.0 \text{ L min}^{-1} \times \left(\dfrac{0.001 \text{ m}^3}{1 \text{ L}}\right) \times \left(\dfrac{1 \text{ min}}{60 \text{ s}}\right) = 8.33 \times 10^{-5} \text{ m}^3\text{s}^{-1}$

(d) To obtain the volume of blood that flows through the heart in each beat we divide the rate calculated in part (c) by the number of beats per seconds.

$$\text{volume per beat} = \frac{\left(8.33 \times 10^{-5} \text{ m}^3\text{s}^{-1}\right)}{70 \text{ min}^{-1} \times \left(\dfrac{1 \text{ min}}{60 \text{ s}}\right)} = 7.14 \times 10^{-5} \text{m}^3 = 0.0714 \text{ L}$$

REFLECT The heart is a muscular organ in all vertebrates responsible for pumping blood through the blood vessels by repeated, rhythmic contractions, or a similar structure in annelids, mollusks, and arthropods. The term *cardiac* (as in cardiology) means "related to the heart." The heart of a vertebrate is composed of cardiac muscle, an involuntary muscle tissue which is found only within this organ. The average human heart, beating at 72 beats per minute, will beat approximately 2.5 billion times during a lifetime (about 66 years). It weighs on average 250 g to 300 g in females and 300 g to 350 g in males.

69. **ORGANIZE AND PLAN** (a) We use the definition of density and solve for mass:

$$\rho = \frac{m}{V} \Rightarrow m = \rho V$$

Then we convert units appropriately, include the rate of 15 breaths per minute, and consider that air contains 23% O_2. (b) To get the number of O_2 molecules we use:

$$M = \frac{m}{n} \Rightarrow n = \frac{m}{M}$$

$$\text{number of molecules} = nN_A = \frac{m}{M} N_A$$

SOLVE (a)

$$\text{mass } O_2 \text{ per day} = 1.29 \text{ kg m}^{-3} \times 400 \frac{\text{mL}}{\text{breath}} \times \left(\frac{1 \text{ m}^3}{10^6 \text{ mL}}\right) \times 15 \frac{\text{breaths}}{\text{min}} \times \left(\frac{60 \text{ min}}{1 \text{ h}}\right) \times \left(\frac{24 \text{ h}}{1 \text{ d}}\right) \times 0.23$$

$$\text{mass } O_2 \text{ per day} = 2.5635 \text{ kg d}^{-1}$$

(b) $\text{number of molecules} = \dfrac{\left(2.5635 \text{ kg d}^{-1}\right)}{\left(0.032 \text{ kg mol}^{-1}\right)} \times \left(6.022 \times 10^{23} \text{ mol}^{-1}\right) = 4.824 \times 10^{25} \text{ d}^{-1}$

REFLECT In nature, free oxygen is produced by the light-driven splitting of water during oxygenic photosynthesis. Green algae and cyanobacteria in marine environments provide about 70% of the free oxygen produced on earth and the rest is produced by terrestrial plants.

70. **SOLVE** (a) We use Pythagoras's equation for a rectangular triangle:

$$\text{diag}^2 = \text{side}^2 + \text{side}^2$$

$$\text{diag} = \sqrt{2 \text{ side}^2} = \sqrt{2} \times \text{side} = \sqrt{2} \times 90 \text{ ft} = 127.28 \text{ ft}$$

(b) The half point of the diagonal is at 127.28 ft / 2 = 63.64 ft. That means that the pitcher stands in front of the line connecting first and third base looking from home plate.

REFLECT Fans, researchers, historians and even the players argue all the time about who was the fastest pitcher of all-time. The most widely quoted response is Nolan Ryan, whose fastball was "officially" clocked by the *Guinness Book of World Records* at 100.9 miles per hour in a game played on August 20, 1974 versus the Chicago White Sox. A record that's still included in the book.