CHAPTER 1
MEASUREMENT

This chapter introduces the standards of measurements and how to express them. The metric system is presented along with conversion factors that will be used throughout the text. Three standards of measure are reviewed: length, time and mass. This chapter is substantial in gaining a strong basis for understanding and doing physics.

1-1 Measuring Things

- ❑ Introduction
- ❑ Concepts
- ❑ Sample Problems

Introduction

Physics measures quantities such as length, time, mass, temperature, pressure and electrical resistance. A unit is a measure of quantity which is exactly 1.0. A meter, second and kilogram are unit measures. A standard is a reference to which all other measures of the same type of quantity are compared. By comparing a quantity to it's standard, we are able to then compare it with all other measures of the same quantity. For example, the standard for length is the path traveled by light in a vacuum during a specific time period. The metric system is based on this standard. We can compare the length of a table to the length of a wall by comparing them both to this standard. The standard is one unit of a meter (1.0). If the table is twice this, we say it is 2 meters. If we find the wall to be 3 meters, we know that the table will fit along the wall. Base quantities are the small number of physical quantities which have been chosen by international agreement to have assigned standards. All other physical quantities are measured in terms of these base quantities. An example is speed, a ratio of length to time, which is measured in meters per second (m/s) when the length is in meters and the time in seconds.

Concepts

Base Quantity	Unit	Standard
Mass	Kilogram (kg)	Platinum-iridium cylinder
Length	Meter (m)	Path traveled by light in a vacuum during a specified time interval
Time	Second (s)	Amount of time taken by a specified number of light vibrations emitted by a cesium-133 atom

Other Quantities:

Speed/Velocity: a unit is measured in m/s (meters per second)

Acceleration: a unit is measured in m/s^2 (velocity over time)

Force: a unit is measured in Newtons ($N = kg \bullet m/s^2$)
(kilogram-mass times acceleration)

Sample Problems

1-1(a) A dog chases a cat across a 3 m driveway in .3 s.
What is the dog's speed?

Speed = length/time

$$S = \frac{3m}{.3s} = 10 \, {}^{m}\!/_{s}$$

1-1(b) What is the mass of five platinum-iridium cylinders that are one half the mass of the standard?

Standard = 1 kilogram

$$5 \bullet \frac{1}{2}(1kg) = 2.5kg$$

1-2 The International System of Units

- Introduction
- Concepts

- ❑ Tips and Advice
- ❑ Sample Problems

Introduction

Seven quantities were chosen as base quantities during the 14th General Conference on Weights and Measures. These formed the basis of the International System of Units (SI) known as the metric system. The units (m, kg and s) chosen for the base quantities of length, mass and time are considered to be on a "human scale". Many times we need to use scientific notation which multiplies a number by powers of ten or prefixes before units when trying to express very large or very small quantities.

Concepts

Derived Units: 1 unit of force = 1 Newton = 1 N = 1 $kg\bullet m/s^2$

1 watt = 1 W = 1 $kg\bullet m^2/s^3$

Scientific Notation: 2,340,000,000 kg = 2.34×10^9 kg

0.000000321 m = 3.21×10^{-7} m

0.567 s = 5.67×10^{-1} s

Prefixes: 1.52×10^{-3} s = 1.52 milliseconds = 1.52 ms

3.47×10^{-2} m = 3.47 centimeters = 3.47 cm

5.89×10^3 W = 5.89 kilowatts = 5.89 kW

Commonly Used Prefixes:

Factor	Prefix	Symbol
10^{12}	tera-	T
10^9	giga-	G
10^6	mega-	M
10^3	kilo-	k
10^2	hecto-	h
10^1	deka-	da
10^{-1}	deci-	d
10^{-2}	centi-	c
10^{-3}	milli-	m
10^{-6}	micro-	*m*
10^{-9}	nano-	n
10^{-12}	pico-	p

Tips and Advice

In using scientific notation, the idea is to have at least one significant number to the left of the decimal point. To know what power to raise 10 to is simple: count the number of places the decimal point moves. To know if the power is positive or negative is also simple: if the number is > 1, the decimal point moves to the left and the exponent is positive; if the number is < 1, the decimal point moves to the right and the exponent is negative.

If the number is in scientific notation and you want to write the number in its entirety, simply move the decimal point the same number of places as the exponent. If the exponent is positive, move the decimal point to the right, and if the exponent is negative, move the decimal point to the left.

Sample Problems

1-2(a) Express 40,000 kg in scientific notation.

40,000. kg = 4.0×10^4 kg

The decimal point moves 4 places to the left.

1-2(b) Express 4.0×10^4 kg in megagrams.

$$4.0x10^4\,kg\left(\frac{10^3\,g}{1kg}\right) = 4.0x10^7\,g = 40.0x10^6\,g = 40 megagrams = 40mg$$

1-3 Changing Units

- Introduction
- Concepts
- Tips and Advice
- Sample Problems

Introduction

In doing problems in physics, it is often the case that the information provided is defined as one type of unit and the answer required is of another type of unit. Changing units is done by a method called chain-link conversion. To employ this method, we use conversion factors, that is, a ratio of units that is equal to unity (or one). The number and its unit are considered to be one entity, so that when using conversion factors, the effect is as if we are multiplying by one. The unwanted units cancel, and we are left with the unit we are converting to.

Concepts

Employ chain-link conversions using conversion factors to express a given number and unit as an equivalent number of another unit.

Equivalence	**Conversion Factor**
1 min = 60 s	$\frac{1\min}{60s}\ or\ \frac{60s}{1\min}$
1 km = 1000 m	$\frac{1km}{1000m}\ or\ \frac{1000m}{1km}$
1 mile = 5280 ft	$\frac{1mile}{5280\,ft}\ or\ \frac{5280\,ft}{1mile}$
1 N = 0.2248 lb	$\frac{1N}{0.2248lb}\ or\ \frac{0.2248lb}{1N}$

Tips and Advice

Appendix D in the text contains numerous conversion factors, too many to know and/or memorize. It is best to know several pertinent conversions and multiply succesively to obtain the proper units, thus the idea of chain-link conversions.

When converting squared or cubed units, each unit must be converted. See Sample Problem 1-3(b).

Sample Problems

1-3(a) Express 75 km/h as m/s.

$$75\,{}^{k}\!/_{h}\left(\frac{1000m}{1km}\right)\left(\frac{1h}{3600s}\right)=20.8\,{}^{m}\!/_{s}$$

The conversion factor of $\left(\frac{1h}{3600s}\right)$ could be replaced by several linked conversions such as $\left(\frac{1h}{60\min}\right)\left(\frac{1\min}{60s}\right)$ which yields the same result.

1-3(b) If your car is traveling at a speed of 4.5 km/s^2, how fast are you going in mi/h^2?

$$4.5\,{}^{km}\!/\!_{s^2}\left(\frac{0.6214mi}{1km}\right)\left(\frac{3600s}{1h}\right)\left(\frac{3600s}{1h}\right)=3.62x10^{7}\,{}^{mi}\!/\!_{h^2}$$

1-4 Length

- Introduction
- Concepts
- Tips and Advice
- Sample Problems

Introduction

Scientific precision requires a standard of length that is universal. The definition of a standard of measurement has evolved throughout the centuries. A meter was once defined to be one ten-millionth of the distance from the north pole to the equation. It was then redefined to be the distance between two lines engraved on a platinum-iridium bar located at the International Bureau of Weights and Measures near Paris. This became the standard meter bar that all other secondary standards were compared. With an increase in technology, a more accessible standard was defined based on the wavelengths of orange-red light emitted by atoms of krypton-86 in a gas discharge tube. In 1983, a demand for even higher precision was met by the 17th General Conference on Weights and Measures when the meter was defined as the length of the path traveled by light in a vacuum during a time interval of 1/299,792, 458 of a second. Thus, the speed of light, c, is exactly

c = 299,792,458 m/s.

Concepts

Length Conversion Factors:

1 m = 100 cm = 39.4 in = 2.38 ft

1 mi = 1.61 km = 5280 ft

1 in = 2.54 cm

1 nm = 10^{-9} m

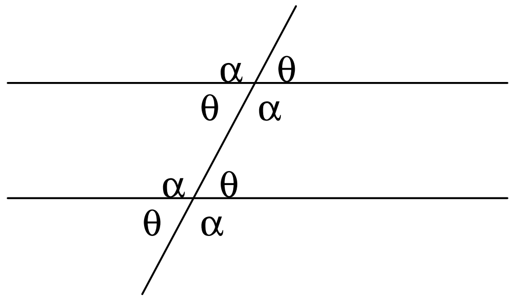
1 pm = 10^{-12} m

1 light-year = 9.46 x 10^{15}

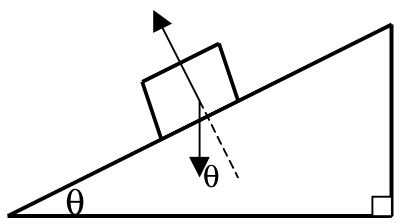
Tips and Advice

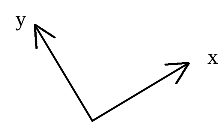
Geometry:

Most of the geometric knowledge needed has to do with identifying angles. One situation involves pairs of congruent angles formed by a line intersecting parallel lines.



Slightly more complicated analysis is useful in inclined plane problems where the angle of inclination is θ.





Trigonometry:

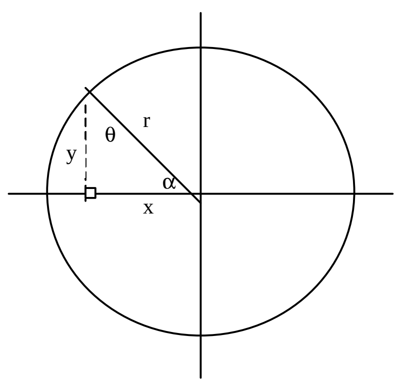
Circular function definitions where θ is any angle:

$r = \sqrt{x^2 + y^2}$

sin θ = x/r, sin α = y/r

cos θ = y/r, cos α = x/r

tan θ = x/y, tan α = y/x



In more general terms:

angle = arcsin (opposite/hypotenuse)

angle = arccos (adjacent/hypotenuse)

angle = arctan (opposite/adjacent)

Taking the first letter of each term yields SOHCAHTOA which can be easily remembered by making up some perverted saying such as:
Some Old Horse Caught Another Horse Taking Oats Away.

Sample Problems

1-4(a) Calculate the number of kilometeres in 20.0 mi unsing only the following conversion factors:
1 mi = 5280 ft, 1 ft = 12 in, 1 in = 2.54 cm,
1 m = 100 cm, and 1 km = 1000 m.

Solution:

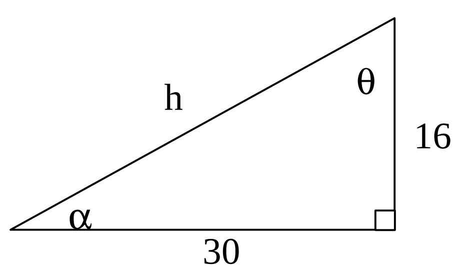
First you start with the given length. Use the conversion factor from miles to feet. So:

Number of feet = $20.0mi\left(\frac{5280\,ft}{1mi}\right)=105600\,ft$

Now continue using conversions until you are left with kilometers:

$$105600\,ft\left(\frac{12in}{1\,ft}\right)\left(\frac{2.54cm}{1in}\right)\left(\frac{1m}{100cm}\right)\left(\frac{1km}{1000m}\right)=32.2km$$

1-4(b) Given a right triangle, find the value of its two angles α and β.



Solution:

First you must find the value of the hypotenuse:

h = $\sqrt{30^2+16^2}=34$

Once you know the length of the hypotenuse you can use any of the trig rules to find the two angles:

For α: $\alpha = \arcsin\left(\frac{16}{34}\right) = 28°$

$$\alpha = \arccos\left(\frac{30}{34}\right) = 28°$$

$$\alpha = \arctan\left(\frac{16}{30}\right) = 28°$$

For β: $\beta = \arcsin\left(\frac{30}{34}\right) = 62°$

$$\beta = \arccos\left(\frac{16}{34}\right) = 62°$$

$$\beta = \arctan\left(\frac{30}{16}\right) = 62°$$

Check: $90° + 28° + 62° = 180°$

1-5 Time

- Concepts
- Sample Problems

Concepts

One second = the time taken by 9,193,631,770 vibrations of the light emitted by a Cesium-133 atom

Conversion Factors:

	Year	Day	Hour	Minute	Second
1 Year	1	365.25	8.766×10^{3}	5.259×10^{5}	3.156×10^{7}
1 Day	2.738×10^{-3}	1	24	1449	8.640×10^{4}
1 Hour	1.141×10^{-4}	4.167×10^{-2}	1	60	3600
1 Minute	1.901×10^{-6}	6.944×10^{-4}	1.667×10^{-2}	1	60
1 Second	3.169×10^{-8}	1.157×10^{-5}	2.778×10^{-4}	1.667×10^{-2}	1

Some Approximate Time Intervals:

TIME INTERVAL	SECONDS
Lifetime of the proton (predicted)	1×10^{39}

Age of the universe	5×10^{17}
Age of the pyramid of Cheops	1×10^{11}
Human life expectancy (U.S.)	2×10^{9}
Length of a day	9×10^{4}
Time between human heartbeats	8×10^{-1}
Lifetime of the muon	2×10^{-6}
Shortest laboratory light pulse (1989)	6×10^{-15}
Lifetime of most unstable particle	1×10^{-23}
The Planck time (earliest time after Big Bang)	1×10^{-43}

Sample Problems

1-5(a) Express the speed of light, 3.0×10^8 m/s in
(a) Feet per nanosecond, and
(b) Millimeters per picosecond.

Solution:

(a) 3.0×10^8 m/s = $3.0x10^8\ {}^{m}\!/_{s}\left(3.281\ {}^{ft}\!/_{\min}\right)\left(\frac{1s}{10^9\,ns}\right) = 0.98\ {}^{ft}\!/_{ns}$

(b) 3.0×10^8 m/x = $3.0x10^8\ {}^{m}\!/_{s}\left(10^3\ {}^{mm}\!/_{m}\right)\left(\frac{1s}{10^{12}\ ps}\right) = 0.33\,{}^{mm}\!/_{ps}$

1-5(b) How many seconds are in a year?

Solution:

1 y = $365.25d\left(24\,{}^{h}\!/_{d}\right)\left(60\,{}^{\min}\!/_{h}\right)\left(60\,{}^{s}\!/_{\min}\right) = 3.156x10^7\ s$

1-5(c) An Astonomical Unit (aU) is the average distance of the Earth from the Sun, approximately 1.50×10^8 km. The speed of light is about 3.0×10^8 m/s.
Express the speed of light in terms of Astronomical Units per minute.

Solution:

3.0×10^8 m/s =
$3.0x10^8\ {}^{m}\!/_{s}\left(10^3\ {}^{km}\!/_{\min}\right)\left(\frac{1AU}{1.50x10^8\,km}\right)\left(60\ {}^{s}\!/_{\min}\right) = 0.12\ {}^{AU}\!/_{\min}$

1-5(d) Assuming the length of the day uniformly increases by 0.001 seconds per century, calculate the cumulative effect on the measure of time over 20 centuries. Such slowing of the Earth's rotation is indicated by observations of the occurrences of solar eclipses during this period.

(a) $(20 centuries)\left(0.001\ {}^{s}\!/\!_{centruy}\right) = 0.020$ seconds gained over 20 centuries

(b) Average day increase =

$$\left[\frac{Lastdayof\ 20^{th}\ century - Firstdayof\ 1^{st}\ century}{2}\right] = \left(\frac{0.020s}{2}\right) = 0.010s$$

(c) Time gained =

$$\left(0.010\ {}^{s}\!/\!_{d}\right)\left(365.25\ {}^{d}\!/\!_{y}\right)\left(100\ {}^{y}\!/\!_{century}\right)(20 centuries)\left(\frac{1\min}{60s}\right)\left(\frac{1h}{60\min}\right) = 2.1h$$

1-6 Mass

- Introduction
- Concepts
- Tips and Advice
- Sample Problems

Introduction

Mass is the quantity of matter in a particle. The S.I. unit for mass is the kilogram whose standard is a platinum-iridium cylinder kept by the International Bureau of Weights and Measures. A second mass standard is used for measurements on an atomic scale, so that the masses of smaller particles such as the atom can be compared with greater accuracy. The carbon-12 atom is the international standard given a mass of 12 atomic mass units (u).

Concepts

Conversion Factors:

1 u =1 .6605402 x 10^{-27} kg

1 gram = 1/1000kg

1. Standards are used so that the mass of one particle can be compared to that of the standard and, therefore, to that of another particle.
2. Because some particles are on an extremely small scale(atomic scale), it is necessary to have two different standards.
3. The masses of particles on a human scale are measured in kilograms. Those on a grand scale(universal scale) are measured in kilograms using scientific notation or in grams using a prefix.

Tips and Advice

Assign every number its proper units when working through conversions to avoid confusing the units.

Sample Problems

1-6(a) A proton has a mass of 2 x $^{10-}$27 kg. Convert this to atomic mass units.

Solution:

2 x $^{10-}$27 kg(1u/1.66 x 10^{-27} kg) = 1.2 u

1-6(b) An elephant has a mass of 5 x 10^{6} g. Convert this to kilograms. How could this also be expressed using a prefix?

Solution:

5 x 10^{6} g(1kg/1000g) = 5 x 10^{3} kg = 5 megagrams