CHAPTER 22

CALCULATIONS AND CONVERSIONS

INTRODUCTION

2200. Purpose and Scope

This chapter discusses the use of calculators and computers in navigation and summarizes the formulas the navigator depends on during voyage planning, piloting, celestial navigation, and various related tasks. To fully utilize this chapter, the navigator should be competent in basic mathematics including algebra and trigonometry (See Chapter 21, Navigational Mathematics), and be familiar with the use of a basic scientific calculator. The navigator should choose a calculator based on personal needs, which may vary greatly from person to person according to individual abilities and responsibilities.

2201. Use of Calculators in Navigation

Any common calculator can be used in navigation, even one providing only the four basic arithmetic functions of addition, subtraction, multiplication, and division. Any good scientific calculator can be used for sight reduction, sailings, and other tasks. However, the use of a computer program or handheld calculator specifically designed for navigation will greatly reduce the workload of the navigator, reduce the possibility of errors, and increase the accuracy of results over those obtained by hand calculation.

Calculations of position based on celestial observations are becoming increasingly obsolete as GPS takes its place as a dependable position reference for all modes of navigation. This is especially true since handheld, battery-powered GPS units have become less expensive, and can provide a worldwide backup position reference to more sophisticated systems with far better accuracy and reliability than celestial.

However, for those who still use celestial techniques, a celestial navigation calculator or computer program can improve celestial positions by easily solving numerous sights, and by reducing mathematical and tabular errors inherent in the manual sight reduction process. They can also provide weighted plots of the LOP's from any number of celestial bodies, based on the navigator's subjective analysis of each sight, and calculate the best fix with lat./long. readout.

On a vessel with a laptop or desktop computer convenient to the bridge, a good choice would be a comprehensive computer program to handle all navigational functions such as sight reduction, sailings, tides, and other tasks, backed up by a handheld navigational calculator for basic calculations should the computer fail. Handheld calculators are dependable enough that the navigator can expect to never have to solve celestial sights, sailings, and other problems by tables or calculations.

In using a calculator for any navigational task, it important to remember that the accuracy of the result, even if carried to many decimal places, is only as good as the least accurate entry. If a sextant observation is taken to an accuracy of only a minute, that is the best accuracy of the final solution, regardless of a calculator's ability to solve to 12 decimal places. See Chapter 23, Navigational Errors, for a discussion of the sources of error in navigation.

Some basic calculators require the conversion of degrees, minutes and seconds (or tenths) to decimal degrees before solution. A good navigational calculator, however, should permit entry of degrees, minutes and tenths of minutes directly, and should do conversions at will. Though many non-navigational computer programs have an on-screen calculator, these are generally very simple versions with only the four basic arithmetical functions. They are thus too simple for many navigational problems. Conversely, a good navigational computer program requires no calculator per se, since the desired answer is calculated automatically from the entered data.

The following articles discuss calculations involved in various aspects of navigation.

2202. Calculations of Piloting

- **Hull speed in knots** is found by:

  $$S = 1.34\sqrt{\text{waterline length}}\ \text{(in feet)}.$$

  This is an approximate value which varies with hull shape.

- **Nautical and U.S. survey miles** can be interconverted by the relationships:

  1 nautical mile = 1.15077945 U.S. survey miles.

  1 U.S. survey mile = 0.86897624 nautical miles.

- **The speed of a vessel over a measured mile** can be calculated by the formula:

$$S = \frac{3600}{T}$$

where S is the speed in knots and T is the time in seconds.

- **The distance traveled at a given speed** is computed by the formula:

$$D = \frac{ST}{60}$$

where D is the distance in nautical miles, S is the speed in knots, and T is the time in minutes.

- **Distance to the visible horizon in nautical miles** can be calculated using the formula:

$$D = 1.17\sqrt{h_f}\ \text{, or}$$

$$D = 2.07\sqrt{h_m}$$

depending upon whether the height of eye of the observer above sea level is in feet (h_f) or in meters (h_m).

- **Dip of the visible horizon in minutes of arc** can be calculated using the formula:

$$D = 0.97'\sqrt{h_f}\ \text{, or}$$

$$D = 1.76'\sqrt{h_m}$$

depending upon whether the height of eye of the observer above sea level is in feet (h_f) or in meters (h_m)

- **Distance to the radar horizon** in nautical miles can be calculated using the formula:

$$D = 1.22\sqrt{h_f}\ \text{, or}$$

$$D = 2.21\sqrt{h_m}$$

depending upon whether the height of the antenna above sea level is in feet (h_f) or in meters (h_m).

- **Dip of the sea short of the horizon** can be calculated using the formula:

$$Ds = 60\tan^{-1}\left(\frac{h_f}{6076.1\,d_s} + \frac{d_s}{8268}\right)$$

where Ds is the dip short of the horizon in minutes of arc; h_f is the height of eye of the observer above sea level, in feet and d_s is the distance to the waterline of the object in nautical miles.

- **Distance by vertical angle between the waterline and the top of an object** is computed by solving the right triangle formed between the observer, the top of the object, and the waterline of the object by simple trigonometry. This assumes that the observer is at sea level, the Earth is flat between observer and object, there is no refraction, and the object and its waterline form a right angle. For most cases of practical significance, these assumptions produce no large errors.

$$D = \sqrt{\frac{\tan^2 a}{0.0002419^2} + \frac{H - h}{0.7349}} - \frac{\tan a}{0.0002419}$$

where D is the distance in nautical miles, a is the corrected vertical angle, H is the height of the top of the object above sea level, and h is the observer's height of eye in feet. The constants (0.0002419 and 0.7349) account for refraction.

2203. Tide Calculations

- **The rise and fall of a diurnal tide** can be roughly calculated from the following table, which shows the fraction of the total range the tide rises or falls during flood or ebb.

Hour	Amount of flood/ebb
1	1/12
2	2/12
3	3/12
4	3/12
5	2/12
6	1/12

2204. Calculations of Celestial Navigation

Unlike sight reduction by tables, sight reduction by calculator permits the use of nonintegral values of latitude of the observer, and LHA and declination of the celestial body. Interpolation is not needed, and the sights can be readily reduced from any assumed position. Simultaneous, or nearly simultaneous, observations can be reduced using a single assumed position. Using the observer's DR or MPP for the assumed longitude usually provides a better representation of the circle of equal altitude, particularly at high observed altitudes.

- **The dip correction** is computed in the *Nautical Almanac* using the formula:

$$D = 0.97\sqrt{h}$$

where dip is in minutes of arc and h is height of eye in feet. This correction includes a factor for refraction. The *Air Almanac* uses a different formula intended for air navigation. The differences are of no significance in practical navigation.

- **The computed altitude** (Hc) is calculated using the basic formula for solution of the undivided navigational triangle:

$$\sin h = \sin L \sin d + \cos L \cos d \cos LHA,$$

in which h is the altitude to be computed (Hc), L is the latitude of the assumed position, d is the declination of the celestial body, and LHA is the local hour angle of the body. Meridian angle (t) can be substituted for LHA in the basic formula.
Restated in terms of the inverse trigonometric function:

$$Hc = \sin^{-1}[(\sin L \ \sin d) + (\cos L \cos d \ \cos LHA)].$$

When latitude and declination are of contrary name, declination is treated as a negative quantity. No special sign convention is required for the local hour angle, as in the following azimuth angle calculations.

- **The azimuth angle** (Z) can be calculated using the altitude azimuth formula if the altitude is known. The formula stated in terms of the inverse trigonometric function is:

$$Z = \cos^{-1}\left(\frac{\sin d - (\sin L \sin Hc)}{(\cos L \cos Hc)}\right)$$

If the altitude is unknown or a solution independent of altitude is required, the azimuth angle can be calculated using the time azimuth formula:

$$Z = \tan^{-1}\left(\frac{\sin LHA}{(\cos L \tan d) - (\sin L \cos LHA)}\right)$$

The sign conventions used in the calculations of both azimuth formulas are as follows: (1) if latitude and declination are of contrary name, declination is treated as a negative quantity; (2) if the local hour angle is greater than 180°, it is treated as a negative quantity.
If the azimuth angle as calculated is negative, add 180° to obtain the desired value.

- **Amplitudes** can be computed using the formula:

$$A = \sin^{-1}(\sin d \sec L)$$

this can be stated as

$$A = \sin^{-1}\left(\frac{\sin d}{\cos L}\right)$$

where A is the arc of the horizon between the prime vertical and the body, L is the latitude at the point of observation, and d is the declination of the celestial body.

2205. Calculations of the Sailings

- **Plane sailing** is based on the assumption that the meridian through the point of departure, the parallel through the destination, and the course line form a plane right triangle, as shown in Figure 2205.

From this: $\cos C = \frac{l}{D}$, $\sin C = \frac{p}{D}$, and $\tan C = \frac{p}{l}$.

From this: $l = D \cos C$, $D = l \sec C$, and $p = D \sin C$.

From this, given course and distance (C and D), the difference of latitude (l) and departure (p) can be found, and given the latter, the former can be found, using simple trigonometry. See Chapter 24.

- **Traverse sailing** combines plane sailings with two or more courses, computing course and distance along a series of rhumb lines. See Chapter 24.

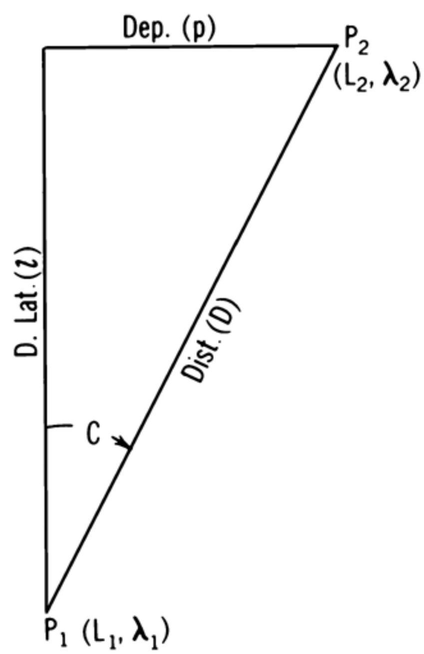

Figure 2205. The plane sailing triangle.

- **Parallel sailing** consists of interconverting departure and difference of longitude. Refer to Figure 2205.

$$DLo = p \sec L, \text{ and } p = DLo \cos L$$

- **Mid-latitude sailing** combines plane and parallel sailing, with certain assumptions. The mean latitude (Lm) is half of the arithmetical sum of the latitudes of two places on the same side of the equator. For places on opposite sides of the equator, the N and S portions are solved separately.

In mid-latitude sailing:

$$DLo = p \sec Lm, \text{ and } p = DLo \cos Lm$$

- **Mercator Sailing** problems are solved graphically on a Mercator chart. For mathematical Mercator solutions the formulas are:

$$\tan C = \frac{DLo}{m} \text{ or } DLo = m \tan C$$

where m is the meridional part from Table 6 in the Tables Part of this volume. Following solution of the course angle by Mercator sailing, the distance is by the plane sailing formula:

$$D = l \sec C.$$

- **Great-circle solutions for distance and initial course angle** can be calculated from the formulas:

$$D = \cos^{-1}[(\sin L_1 \sin L_2 + \cos L_1 \cos L_2 \cos DLo)],$$

and

$$C = \tan^{-1}\left(\frac{\sin DLo}{(\cos L_1 \tan L_2) - (\sin L_1 \cos DLo)}\right)$$

where D is the great-circle distance, C is the initial great-circle course angle, L_1 is the latitude of the point of departure, L_2 is the latitude of the destination, and DLo is the difference of longitude of the points of departure and destination. If the name of the latitude of the destination is contrary to that of the point of departure, it is treated as a negative quantity.

- **The latitude of the vertex**, L_v, is always numerically equal to or greater than L_1 or L_2. If the initial course angle C is less than 90°, the vertex is toward L_2, but if C is greater than 90°, the nearer vertex is in the opposite direction. The vertex nearer L_1 has the same name as L_1.

The latitude of the vertex can be calculated from the formula:

$$L_v = \cos^{-1}(\cos L_1 \sin C)$$

The difference of longitude of the vertex and the point of departure (DLo_v) can be calculated from the formula:

$$DLo_v = \sin^{-1}\left(\frac{\cos C}{\sin L_v}\right).$$

The distance from the point of departure to the vertex (D_v) can be calculated from the formula:

$$D_v = \sin^{-1}(\cos L_1 \sin DLo_v).$$

- **The latitudes of points on the great-circle track** can be determined for equal DLo intervals each side of the vertex (DLo_{vx}) using the formula:

$$L_x = \tan^{-1}(\cos DLo_{vx} \tan L_v)$$

The DLo_v and D_v of the nearer vertex are never greater than 90°. However, when L_1 and L_2 are of contrary name, the other vertex, 180° away, may be the better one to use in the solution for points on the great-circle track if it is nearer the mid point of the track.

The method of selecting the longitude (or DLo_{vx}), and determining the latitude at which the great-circle crosses the selected meridian, provides shorter legs in higher latitudes and longer legs in lower latitudes. Points at desired distances or desired equal intervals of distance on the great-circle from the vertex (D_{vx}) can be calculated using the formulas:

$$L_x = \sin^{-1}[\sin L_v \cos D_{vx}],$$

and

$$DLo_{vx} = \sin^{-1}\left(\frac{\sin D_{vx}}{\cos L_x}\right).$$

A calculator which converts rectangular to polar coordinates provides easy solutions to plane sailings. However, the user must know whether the difference of latitude corresponds to the calculator's X-coordinate or to the Y-coordinate.

2206. Calculations Of Meteorology And Oceanography

- **Converting thermometer scales** between centigrade, Fahrenheit, and Kelvin scales can be done using the following formulas:

$$C^\circ = \frac{5(F^\circ - 32^\circ)}{9},$$

$$F^\circ = \frac{9}{5}C^\circ + 32^\circ, \text{ and}$$

$$K^\circ = C^\circ + 273.15^\circ.$$

- **Maximum length of sea waves** can be found by the formula:

$$W = 1.5\sqrt{\text{fetch in nautical miles}}.$$

- **Wave height** = 0.026 S^2 where S is the wind speed in knots.
- **Wave speed** in knots

$$= 1.34\sqrt{\text{wavelength in feet}}, \text{ or}$$

$$= 3.03 \times \text{wave period in seconds}.$$

UNIT CONVERSION

Use the conversion tables that appear on the following pages to convert between different systems of units. Conversions followed by an asterisk are exact relationships.

MISCELLANEOUS DATA

Area

1 square inch	= 6.4516 square centimeters*
1 square foot	= 144 square inches*
	= 0.09290304 square meter*
	= 0.000022957 acre
1 square yard	= 9 square feet*
	= 0.83612736 square meter
1 square (statute) mile	= 27,878,400 square feet*
	= 640 acres*
	= 2.589988110336 square kilometers*
1 square centimeter	= 0.1550003 square inch
	= 0.00107639 square foot
1 square meter	= 10.76391 square feet
	= 1.19599005 square yards
1 square kilometer	= 247.1053815 acres
	= 0.38610216 square statute mile
	= 0.29155335 square nautical mile

Astronomy

1 mean solar unit	= 1.00273791 sidereal units
1 sidereal unit	= 0.99726957 mean solar units
1 microsecond	= 0.000001 second*
1 second	= 1,000,000 microseconds*
	= 0.01666667 minute
	= 0.00027778 hour
	= 0.00001157 day
1 minute	= 60 seconds*
	= 0.01666667 hour
	= 0.00069444 day
1 hour	= 3,600 seconds*
	= 60 minutes*
	= 0.04166667 day
1 mean solar day	= $24^h03^m56^s.55536$ of mean sidereal time
	= 1 rotation of Earth with respect to Sun (mean)*
	= 1.00273791 rotations of Earth with respect to vernal equinox (mean)
	= 1.0027378118868 rotations of Earth with respect to stars (mean)

1 mean sidereal day	= $23^{h}56^{m}04^{s}09054$ of mean solar time
1 sidereal month	= 27.321661 days
	= $27^{d}07^{h}43^{m}11^{s}.5$
1 synodical month	= 29.530588 days
	= $29^{d}12^{h}44^{m}02^{s}.8$
1 tropical (ordinary) year	= 31,556,925.975 seconds
	= 525,948.766 minutes
	= 8,765.8128 hours
	= $365^{d}.24219879 - 0^{d}.0000000614(t-1900)$,
	where t = the year (date)
	= $365^{d}05^{h}48^{m}46^{s}$ (–) $0^{s}.0053(t-1900)$
1 sidereal year	= $365^{d}.25636042 + 0.0000000011(t-1900)$,
	where t = the year (date)
	= $365^{d}06^{h}09^{m}09^{s}.5$ (+) $0^{s}.0001(t-1900)$
1 calendar year (common)	= 31,536,000 seconds*
	= 525,600 minutes*
	= 8,760 hours*
	= 365 days*
1 calendar year (leap)	= 31,622,400 seconds*
	= 527,040 minutes*
	= 8,784 hours*
	= 366 days
1 light-year	= 9,460,000,000,000 kilometers
	= 5,880,000,000,000 statute miles
	= 5,110,000,000,000 nautical miles
	= 63,240 astronomical units
	= 0.3066 parsecs
1 parsec	= 30,860,000,000,000 kilometers
	= 19,170,000,000,000 statute miles
	= 16,660,000,000,000 nautical miles
	= 206,300 astronomical units
	= 3.262 light years
1 astronomical unit	= 149,600,000 kilometers
	= 92,960,000 statute miles
	= 80,780,000 nautical miles
	= $499^{s}.012$ light-time
	= mean distance, Earth to Sun
Mean distance, Earth to Moon	= 384,400 kilometers
	= 238,855 statute miles
	= 207,559 nautical miles
Mean distance, Earth to Sun	= 149,600,000 kilometers
	= 92,957,000 statute miles
	= 80,780,000 nautical miles
	= 1 astronomical unit
Sun's diameter	= 1,392,000 kilometers
	= 865,000 statute miles
	= 752,000 nautical miles
Sun's mass	= 1,987,000,000,000,000,000,000,000,000,000,000 grams
	= 2,200,000,000,000,000,000,000,000,000 short tons
	= 2,000,000,000,000,000,000,000,000,000 long tons
Speed of Sun relative to neighboring stars	= 19.4 kilometers per second
	= 12.1 statute miles per second
	= 10.5 nautical miles per second
Orbital speed of Earth	= 29.8 kilometers per second
	= 18.5 statute miles per second
	= 16.1 nautical miles per second
Obliquity of the ecliptic	= $23°27'08''.26 - 0''.4684\ (t-1900)$,
	where t = the year (date)
General precession of the equinoxes	= $50''.2564 + 0''.000222\ (t-1900)$, per year,
	where t = the year (date)
Precession of the equinoxes in right ascension	= $46''.0850 + 0''.000279\ (t-1900)$, per year,
	where t = the year (date)

Precession of the equinoxes in declination	= 20″.0468 – 0″.000085 (*t*–1900), per year, where *t* = the year (date)
Magnitude ratio	= 2.512
	= $\sqrt[5]{100}$*

Charts

Nautical miles per inch	= reciprocal of natural scale ÷ 72,913.39
Statute miles per inch	= reciprocal of natural scale ÷ 63,360*
Inches per nautical mile	= 72,913.39 × natural scale
Inches per statute mile	= 63,360 × natural scale*
Natural scale	= 1:72,913.39 × nautical miles per inch
	= 1:63,360 × statute miles per inch*

Earth

Acceleration due to gravity (standard)	= 980.665 centimeters per second per second
	= 32.1740 feet per second per second
Mass-ratio—Sun/Earth	= 332,958
Mass-ratio—Sun/(Earth & Moon)	= 328,912
Mass-ratio—Earth/Moon	= 81.30
Mean density	= 5.517 grams per cubic centimeter
Velocity of escape	= 6.94 statute miles per second
Curvature of surface	= 0.8 foot per nautical mile

World Geodetic System (WGS) Ellipsoid of 1984

Equatorial radius (a)	= 6,378,137 meters
	= 3,443.918 nautical miles
Polar radius (b)	= 6,356,752.314 meters
	= 3432.372 nautical miles
Mean radius (2a + b)/3	= 6,371,008.770 meters
	= 3440.069 nautical miles
Flattening or ellipticity (f = 1 – b/a)	= 1/298.257223563
	= 0.003352811
Eccentricity ($e = (2f - f^2)^{1/2}$)	= 0.081819191
Eccentricity squared (e^2)	= 0.006694380

Length

1 inch	= 25.4 millimeters*
	= 2.54 centimeters*
1 foot (U.S.)	= 12 inches*
	= 1 British foot
	= $^1/_3$ yard*
	= 0.3048 meter*
	= $^1/_6$ fathom*
1 foot (U.S. Survey)	= 0.30480061 meter
1 yard	= 36 inches*
	= 3 feet*
	= 0.9144 meter*
1 fathom	= 6 feet*
	= 2 yards*
	= 1.8288 meters*
1 cable	= 720 feet*
	= 240 yards*
	= 219.4560 meters*
1 cable (British)	= 0.1 nautical mile
1 statute mile	= 5,280 feet*
	= 1,760 yards*
	= 1,609.344 meters*
	= 1.609344 kilometers*
	= 0.86897624 nautical mile
1 nautical mile	= 6,076.11548556 feet
	= 2,025.37182852 yards
	= 1,852 meters*

	= 1.852 kilometers*
	= 1.150779448 statute miles
1 meter	= 100 centimeters*
	= 39.370079 inches
	= 3.28083990 feet
	= 1.09361330 yards
	= 0.54680665 fathom
	= 0.00062137 statute mile
	= 0.00053996 nautical mile
1 kilometer	= 3,280.83990 feet
	= 1,093.61330 yards
	= 1,000 meters*
	= 0.62137119 statute mile
	= 0.53995680 nautical mile

Mass

1 ounce	= 437.5 grains*
	= 28.349523125 grams*
	= 0.0625 pound*
	= 0.028349523125 kilogram*
1 pound	= 7,000 grains*
	= 16 ounces*
	= 0.45359237 kilogram*
1 short ton	= 2,000 pounds*
	= 907.18474 kilograms*
	= 0.90718474 metric ton*
	= 0.8928571 long ton
1 long ton	= 2,240 pounds*
	= 1,016.0469088 kilograms*
	= 1.12 short tons*
	= 1.0160469088 metric tons*
1 kilogram	= 2.204623 pounds
	= 0.00110231 short ton
	= 0.0009842065 long ton
1 metric ton	= 2,204.623 pounds
	= 1,000 kilograms*
	= 1.102311 short tons
	= 0.9842065 long ton

Mathematics

π	= 3.1415926535897932384626433832795028841971
π^2	= 9.8696044011
$\sqrt{\pi}$	= 1.7724538509
Base of Naperian logarithms (e)	= 2.718281828459
Modulus of common logarithms ($\log_{10}e$)	= 0.4342944819032518
1 radian	= 206,264.″80625
	= 3,437′.7467707849
	= 57°.2957795131
	= 57°17′44″.80625
1 circle	= 1,296,000″*
	= 21,600′*
	= 360°*
	= 2π radians*
180°	= π radians*
1°	= 3600″*
	= 60′*
	= 0.0174532925199432957666 radian
1′	= 60″*
	= 0.000290888208665721596 radian
1″	= 0.0000048481368110953599 33 radian
Sine of 1′	= 0.0002908882045634246 0
Sine of 1″	= 0.0000048481368110763 7

Meteorology

Atmosphere (dry air)

Nitrogen	= 78.08%
Oxygen	= 20.95%
Argon	= 0.93%
Carbon dioxide	= 0.03%
	$\}$ 99.99%
Neon	= 0.0018%
Helium	= 0.000524%
Krypton	= 0.0001%
Hydrogen	= 0.00005%
Xenon	= 0.0000087%
Ozone	= 0 to 0.000007% (increasing with altitude)
Radon	= 0.0000000000000000006% (decreasing with altitude)
Standard atmospheric pressure at sea level	= 1,013.250 dynes per square centimeter
	= 1,033.227 grams per square centimeter
	= 1,033.227 centimeters of water
	= 1,013.250 hectopascals (millibars)*
	= 760 millimeters of mercury
	= 76 centimeters of mercury
	= 33.8985 feet of water
	= 29.92126 inches of mercury
	= 14.6960 pounds per square inch
	= 1.033227 kilograms per square centimeter
	= 1.013250 bars*
Absolute zero	= (–)273.16°C
	= (–)459.69°F

Pressure

1 dyne per square centimeter	= 0.001 hectopascal (millibar)*
	= 0.000001 bar*
1 gram per square centimeter	= 1 centimeter of water
	= 0.980665 hectopascal (millibar)*
	= 0.07355592 centimeter of mercury
	= 0.0289590 inch of mercury
	= 0.0142233 pound per square inch
	= 0.001 kilogram per square centimeter*
	= 0.000967841 atmosphere
1 hectopascal (millibar)	= 1,000 dynes per square centimeter*
	= 1.01971621 grams per square centimeter
	= 0.7500617 millimeter of mercury
	= 0.03345526 foot of water
	= 0.02952998 inch of mercury
	= 0.01450377 pound per square inch
	= 0.001 bar*
	= 0.00098692 atmosphere
1 millimeter of mercury	= 1.35951 grams per square centimeter
	= 1.3332237 hectopascals (millibars)
	= 0.1 centimeter of mercury*
	= 0.04460334 foot of water
	= 0.039370079 inch of mercury
	= 0.01933677 pound per square inch
	= 0.001315790 atmosphere
1 centimeter of mercury	= 10 millimeters of mercury*
1 inch of mercury	= 34.53155 grams per square centimeter
	= 33.86389 hectopascals (millibars)
	= 25.4 millimeters of mercury*
	= 1.132925 feet of water
	= 0.4911541 pound per square inch
	= 0.03342106 atmosphere
1 centimeter of water	= 1 gram per square centimeter
	= 0.001 kilogram per square centimeter
1 foot of water	= 30.48000 grams per square centimeter
	= 29.89067 hectopascals (millibars)
	= 2.241985 centimeters of mercury
	= 0.882671 inch of mercury
	= 0.4335275 pound per square inch
	= 0.02949980 atmosphere
1 pound per square inch	= 68,947.57 dynes per square centimeter
	= 70.30696 grams per square centimeter

	= 70.30696 centimeters of water
	= 68.94757 hectopascals (millibars)
	= 51.71493 millimeters of mercury
	= 5.171493 centimeters of mercury
	= 2.306659 feet of water
	= 2.036021 inches of mercury
	= 0.07030696 kilogram per square centimeter
	= 0.06894757 bar
	= 0.06804596 atmosphere
1 kilogram per square centimeter _ _ _ _ _ _	= 1,000 grams per square centimeter*
	= 1,000 centimeters of water
1 bar _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	= 1,000,000 dynes per square centimeter*
	= 1,000 hectopascals (millibars)*

Speed

1 foot per minute _ _ _ _ _ _ _ _ _ _ _ _	= 0.01666667 foot per second
	= 0.00508 meter per second*
1 yard per minute _ _ _ _ _ _ _ _ _ _ _ _	= 3 feet per minute*
	= 0.05 foot per second*
	= 0.03409091 statute mile per hour
	= 0.02962419 knot
	= 0.01524 meter per second*
1 foot per second _ _ _ _ _ _ _ _ _ _ _ _	= 60 feet per minute*
	= 20 yards per minute*
	= 1.09728 kilometers per hour*
	= 0.68181818 statute mile per hour
	= 0.59248380 knot
	= 0.3048 meter per second*
1 statute mile per hour _ _ _ _ _ _ _ _ _ _	= 88 feet per minute*
	= 29.33333333 yards per minute
	= 1.609344 kilometers per hour*
	= 1.46666667 feet per second
	= 0.86897624 knot
	= 0.44704 meter per second*
1 knot _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	= 101.26859143 feet per minute
	= 33.75619714 yards per minute
	= 1.852 kilometers per hour*
	= 1.68780986 feet per second
	= 1.15077945 statute miles per hour
	= 0.51444444 meter per second
1 kilometer per hour _ _ _ _ _ _ _ _ _ _ _	= 0.62137119 statute mile per hour
	= 0.53995680 knot
1 meter per second _ _ _ _ _ _ _ _ _ _ _ _	= 196.85039340 feet per minute
	= 65.6167978 yards per minute
	= 3.6 kilometers per hour*
	= 3.28083990 feet per second
	= 2.23693632 statute miles per hour
	= 1.94384449 knots
Light in vacuum _ _ _ _ _ _ _ _ _ _ _ _ _	= 299,792.5 kilometers per second
	= 186,282 statute miles per second
	= 161,875 nautical miles per second
	= 983.570 feet per microsecond
Light in air _ _ _ _ _ _ _ _ _ _ _ _ _ _ _	= 299,708 kilometers per second
	= 186,230 statute miles per second
	= 161,829 nautical miles per second
	= 983.294 feet per microsecond
Sound in dry air at 59°F or 15°C and standard sea level pressure _ _ _ _ _	= 1,116.45 feet per second
	= 761.22 statute miles per hour
	= 661.48 knots
	= 340.29 meters per second
Sound in 3.485 percent saltwater at 60°F _ _ _	= 4,945.37 feet per second
	= 3,371.85 statute miles per hour

	= 2,930.05 knots
	= 1,507.35 meters per second

Volume

1 cubic inch	= 16.387064 cubic centimeters*
	= 0.016387064 liter*
	= 0.004329004 gallon
1 cubic foot	= 1,728 cubic inches*
	= 28.316846592 liters*
	= 7.480519 U.S. gallons
	= 6.228822 imperial (British) gallons
	= 0.028316846592 cubic meter*
1 cubic yard	= 46,656 cubic inches*
	= 764.554857984 liters*
	= 201.974026 U.S. gallons
	= 168.1782 imperial (British) gallons
	= 27 cubic feet*
	= 0.764554857984 cubic meter*
1 milliliter	= 0.06102374 cubic inch
	= 0.0002641721 U.S. gallon
	= 0.00021997 imperial (British) gallon
1 cubic meter	= 264.172035 U.S. gallons
	= 219.96878 imperial (British) gallons
	= 35.31467 cubic feet
	= 1.307951 cubic yards
1 quart (U.S.)	= 57.75 cubic inches*
	= 32 fluid ounces*
	= 2 pints*
	= 0.9463529 liter
	= 0.25 gallon*
1 gallon (U.S.)	= 3,785.412 milliliters
	= 231 cubic inches*
	= 0.1336806 cubic foot
	= 4 quarts*
	= 3.785412 liters
	= 0.8326725 imperial (British) gallon
1 liter	= 1,000 milliliters
	= 61.02374 cubic inches
	= 1.056688 quarts
	= 0.2641721 gallon
1 register ton	= 100 cubic feet*
	= 2.8316846592 cubic meters*
1 measurement ton	= 40 cubic feet*
	= 1 freight ton*
1 freight ton	= 40 cubic feet*
	= 1 measurement ton*

Volume-Mass

1 cubic foot of seawater	= 64 pounds
1 cubic foot of freshwater	= 62.428 pounds at temperature of maximum density (4°C = 39°.2F)
1 cubic foot of ice	= 56 pounds
1 displacement ton	= 35 cubic feet of seawater*
	= 1 long ton

Prefixes to Form Decimal Multiples and Sub-Multiples of International System of Units (SI)

Multiplying factor		Prefix	Symbol
1 000 000 000 000	$= 10^{12}$	tera	T
1 000 000 000	$= 10^{9}$	giga	G
1 000 000	$= 10^{6}$	mega	M
1 000	$= 10^{3}$	kilo	k
100	$= 10^{2}$	hecto	h
10	$= 10^{1}$	deka	da
0. 1	$= 10^{-1}$	deci	d
0. 01	$= 10^{-2}$	centi	c
0. 001	$= 10^{-3}$	milli	m
0. 000 001	$= 10^{-6}$	micro	μ
0. 000 000 001	$= 10^{-9}$	nano	n
0. 000 000 000 001	$= 10^{-12}$	pico	p
0. 000 000 000 000 001	$= 10^{-15}$	femto	f
0. 000 000 000 000 000 001	$= 10^{-18}$	atto	a