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SYSTEMS OF UNITS AND CONVERSION TABLES

By

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von Kármán Gas Dynamics Facility
ARO, Inc.

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ARNOLD ENGINEERING DEVELOPMENT CENTER

AIR FORCE SYSTEMS COMMAND

UNITED STATES AIR FORCE

NOTICES

ERRATA

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Please note following corrections:

Page	Line	Reads	Should Read
ix	12	velocity of light ...., 9.3573 x 10^{8} ft/sec	9.83573 x 10^{8} ft/sec
ix	21	See Table 16	See Table 12
11	21	mass of force	mass or force
25	33	IAS Journal ...., Fegruary	ISA Journal ...., February
33	1	Day to hour- 2.40000	2.40000^{1}
35	3	ft/sec to mile/hr - 6.81818	6.81818^{-1}
38	Col. Heading	Specific gravity H_2O at 9 °C = 1	Specific gravity H_2O at 4 °C = 1
38	7	Specific gravity H_2O at 4 °C = 1 to lb_m/ft^3-6.24262	6.24262^{1}
44	Line 6 & Column 6	Ab Joule/gm	Abs. Joule/gm
46	5	Liter/min to m^3/min - 1.00003^{-2}	1.00003^{-3}
47	3	9.79862	4.72541^{-4}
		2.77465^{5}	1.33808^{1}
		1.0000	1.0000
		4.46818^{5}	2.15478^{1}
		4.46818^{8}	2.15478^{4}
		2.10866^{8}	1.01691^{4}
		1.44000^{2}	6.94444^{-3}
	Column 3	1.02055^{-1}	2.11622^{3}
		3.60405^{-6}	7.47337^{-2}
		1.0000	1.0000
		2.23806^{-6}	4.64084^{-2}
		2.23806^{-9}	4.64084^{-5}
		4.74233^{-9}	9.83370^{-5}
		6.94444^{-3}	1.44000^{2}

On page 1, line 15, existing reads: Chemical reactions take place between the various constituents and the gas, because its ionized nature is affected by electric and magnetic fields. Should read: Chemical reactions take place between the various constituents, and the gas, because of its ionized nature, is affected by electric and magnetic fields.

On pages 51-56: Ab. amp, Ab. coulomb, Ab. volt, Ab. farad, Ab. henry, Ab. ohm. Should read: Abamp, Abcoulomb, Abvolt, Abfarad, Abhenry, and Abohm, respectively.

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[*] Kinslow, Max and Majors, Betty M. "Systems of Units and Conversion Tables." Arnold Engineering Development Center, Arnold Air Force Station, Tennessee. AEDC-TDR-62-6, February 1962.

SYSTEMS OF UNITS AND CONVERSION TABLES

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ARO, Inc.
a subsidiary of Sverdrup and Parcel, Inc.

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ABSTRACT

Some fundamental concepts of units, dimensions, and physical measurements are discussed, and illustrations of the misunderstandings that exist in the literature concerning these concepts are given. The differences between measure and physical equations are outlined, and a simple example is considered. The choice of how many and which units to use as basic is shown to be completely arbitrary, and the choice is usually made to produce maximum accuracy and convenience.

Various mechanical, thermal, and electrical systems of units in common use today are presented, and an engineering (ft-lb_f-amp-sec) system is developed to describe electromagnetic problems. The history of some important physical units is traced, and the latest definitions of these units are used to obtain convenient conversion tables for various physical quantities.

CONTENTS

NOMENCLATURE

A	Area
a	Acceleration
B	Magnetic flux density
C	Capacitance
c	Velocity of light
°C	Degrees Celsius (centigrade)
d	Diameter
E	Potential
e	Energy
F	Faraday's constant
[F]	Dimension of force
°F	Degree Fahrenheit
f	Force
G	Newtonian gravitational constant
g	Local acceleration of gravity
g_c	Group of units from Newton's law of motion
g_{std}	Standard acceleration of gravity
H	Magnetic field intensity
h	Enthalpy
h_p	Planck's constant
I	Current
j	Surface current
k	Constant of proportionality
°K	Degrees Kelvin
L	Inductance
[L]	Dimension of length
ℓ	Length
m	Mass
$\dot{m}$	Mass flow

$[M]$	Dimension of mass
m_e	Electron rest mass
N	Avogadro's number
P	Power
p	Pressure
q	Charge
q_e	Electron charge
R	Gas constant per unit mass
R	Resistance
$^\circ R$	Degrees Rankine
R_o	Gas constant per mole
T	Temperature
t	Time
V	Volume
$\dot{V}$	Volume flow or pumping speed
v	Velocity
X	Generalized quantities
$\{\ \}_{a,b}$	Measure in system identified by subscript
$[\ ]$	Dimension
$[\ ]_{a,b,}$	Unit in system identified by subscript
α	Angle
ϵ	Permittivity
θ	Temperature
μ	Permeability
μ	Viscosity
ξ	Electric field intensity
ρ	Resistivity
ρ	Density
ρ_{std}	Standard density

τ	Time
ϕ	Magnetic flux

SUBSCRIPTS

a, b	Special cases, described in text
f	Force
m	Mass
n	Particular example
x	Unspecified system of units
1	First, or first case
2	Second, or second case

CONSTANTS

c	Velocity of light, 2.99793×10^{10} cm/sec, 9.3573 [9.83573] $\times 10^{8}$ ft/sec
h_p	Planck's constant, 6.62517×10^{-27} ergs sec, 4.886474×10^{-34} ft lb_f sec
g_{std}	Standard acceleration of gravity, 980.665 cm/sec^2, 32.1740 ft/sec^2
q_e	Electron charge, 1.60206×10^{-19} coulombs, 1.60206×10^{-19} amp sec
m_e	Electron rest mass, 9.1083×10^{-28} grams, 2.00803×10^{-30} lb_m
atm_{std}	Standard atmosphere, 1.013246×10^{6} dynes/cm^2, 2116.22 lb_f/ft^2 (See Table ~~16~~) 12
σ	Stefan-Boltzmann constant, 5.6687×10^{-5} ergs/cm^2 °K^4 sec 4.75502×10^{-13} Btu/ft^2(°R)^4
π	= 3.14159265
e	= 2.7182818
F	Faraday constant, 96516.5 ± 2.1 coulombs/gm mole (physical scale)

k	Boltzmann's constant, 1.38044×10^{-16} erg/°K, $5.65644 \times 10^{-24} \frac{\text{ft lb}_f}{\text{°R}}$
N	Avogadro's number, $6.02486 \times 10^{23} (\text{g mole})^{-1}$, $2.73283 \times 10^{26} (\text{lb}_m \text{ mole})^{-1}$
G	Newtonian gravitational constant, $(6.670 \pm 0.005) \times 10^{-8}$ dyne cm^2 g^{-2}, 3.320792×10^{-10} lb$_f$ ft^2/lb$_m{}^2$
T_{std}	273.15 °K, 491.67 °R

NUMERICAL PREFIXES

Prefixes	Meaning
pico -	1×10^{-12}
nano -	1×10^{-9}
micro -	1×10^{-6}
milli -	1×10^{-3}
centi -	1×10^{-2}
deci -	1×10^{-1}
unity -	1×10^{0}
deka -	1×10^{1}
hecto -	1×10^{2}
kilo -	1×10^{3}
myra -	1×10^{4}
mega -	1×10^{6}
giga -	1×10^{9}
tera -	1×10^{12}

ABBREVIATIONS

Term	Abbreviation	Term	Abbreviation
absolute	abs	joule	j
acre	spell out or A	kilo-	k
ampere	amp	kilocalorie	kcal
Angstrom unit	Å	kilogram	kg
atmosphere	atm	liter	l
British thermal unit	Btu	meter	m
calorie	cal	meter-kilogram-second	mks
centimeter	cm	micro-	μ
centimeter gram second	cgs	micron	μ
chemical	chem	miles per hour	mph
circular	cir	milli	m
cubic	cu	minute	min
degree	deg	minute (angular)	′
degree Celsius (centigrade)	°C	molecular weight	mol. wt
degree Fahrenheit	°F	oersted	oe
degree Kelvin	°K	ohm	Ω
degree Rankine	°R	ounce	oz
electric	elec	pound force	lb_f
farad	f	pound mass	lb_m
foot	ft	pounds per square inch	psi
foot pound second	fps	revolutions per minute	rpm
gallon	gal	second (angle)	″
gauss	gs	second (time)	sec
gram	gm	specific gravity	sp gr
henry	h	square	sq
horsepower	hp	standard	std
hour	hr	temperature	temp
international	int	volt	v
international steam table	I. T.	watt	w
inch	in.	watthour	whr
		yard	yd

1.0 INTRODUCTION

The first physical experiments were qualitative in that they were simply observations of physical phenomena. However, as science progressed, the need for quantitative investigations became apparent. Systems of units were developed by early investigators to describe their results conveniently; and, since most of these researchers worked independently, many systems of measurement were developed.

Although recently there has been agreement, to a certain extent, within each field of science as to preference in units and dimensions, there is still the problem of converting from one system to another. The problem has become more apparent in the last few years because of the overlapping of the various fields of science. For example, the aerodynamicist of today is not limited to problems that can be described by purely mechanical units. Equations that were once totally mechanical now have additional terms because air and other gases at high temperature can no longer be considered inert substances. Chemical reactions take place between the various constituents and the gas, because ~~its~~ of its ionized nature, is affected by electric and magnetic fields. Chemical kinetic and magnetohydrodynamic terms must now be included to describe the gas completely.

The initial motivation for this report was the need for a convenient, accurate, readily available handbook of definitions and conversion factors for units of measurement. It soon became apparent that this could not be provided without some consideration of more basic questions, such as

1. What are the requirements of an ideal unit?
2. What is the minimum number of units needed to define a complete system?
3. What is the difference between a physical and measure equation?
4. What is meant by rationalization?
5. What are the classic and modern viewpoints?

This report attempts to briefly answer these questions and others frequently raised concerning systems of units. Also included are tables to expedite the conversion of quantities measured in one system of units into the units of another system.

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2.0 GENERAL DISCUSSION

2.1 UNITS AND DIMENSIONS

A physical quantity, in the general sense, is any material concept which can be described mathematically. The procedure involved in this mathematical description will be considered in the next section. All that need be said at this time is that a defined physical quantity of the same kind is required. This defined quantity is called a unit.

Units are of two types, basic and derived. A basic or fundamental unit is one that is defined by some arbitrary physical standard, whereas a derived unit is one that is defined by some physical phenomenon in terms of other units. An example of a basic unit is the meter, a unit of length, whereas the dyne, a unit of force, is a derived unit; it is defined in terms of the units of length, mass, and time together with Newton's second law.

Physical quantities that can be expressed in terms of the same unit are said to have the same dimensions. A dimension can be considered merely a name to identify a physical quantity as to kind. For example, length is the name given to that quantity that can be measured with a yardstick. A dimension may describe several different units of the same kind; e. g., the units of inch, centimeter, and mile all have the dimension of length.

Every kind of physical quantity, each of which has its own dimension, can be expressed as a product of powers of a few basic dimensions (Ref. 1). The dimensions of the basic units are usually chosen as these basic dimensions. Thus, while area is a dimension characteristic of a surface, the dimension of area can be conceived and expressed as the dimension of length squared. The brackets are used to represent a dimension; the dimension of area is [A] and that of length [L]. Therefore,

$$[A] = [L]^2$$

Any number of basic units could be chosen from the many kinds of physical quantities. The choice of which units and how many units to use as fundamental depends upon several requirements. An ideal basic unit should fulfill the following requirements:

1. Easily definable
2. Capable of being compared directly with quantities of the same kind

3. Easily reproducible
4. The same order of magnitude as the quantities to be measured (Different units would be required in atomic and astronomical fields.)

Since no unit fully represents the ideal unit, a compromise between the various requirements must be made. The choice of the basic units is usually biased by tradition and custom. However, custom dictates that only quantities that fulfill the second and fourth requirements be used as basic units. On the other hand, these traditional units usually fail to fulfill the first and third requirements.

The requirement of being easily reproducible would indicate that the basic standard could by reproduced anywhere without the need for arbitrarily defined material standards. This suggests that quantitites occurring unchanging in nature be used as primary units. (For example, if velocity were taken as a basic quantity, then the velocity of light in vacuo would be the most obvious unit. The velocity of light, being possibly the easiest definable and reproducible physical constant, is several orders of magnitude larger than most velocities and cannot be compared directly with them.) Although this approach is probably the best from the theoretical point of view, most naturally occurring quantities that are appropriate for units are not suited to accurate measurements. Artificial material standards can usually be compared to other like quantities far more accurately than can natural units. Exceptions are length and time; these will be discussed later.

The number of basic units is completely arbitrary. A physical standard could be chosen for each dimension, thereby eliminating all derived units. There would be a standard for volume, velocity, viscosity, power, etc. This approach would mean that every equation would require an experimentally determined constant.

At the other extreme a system of measurement could be devised with no standards at all (Ref. 2). This concept could be brought about by assuming the constant of proportionality in select physical equations to be unity. This proportionality constant differs from unity only if artificial units are introduced. Inasmuch as physical phenomenon not amenable to accurate measurements would be involved in the definition of this system, the resulting inaccuracies in the measure of quantities would be far greater than that presently obtainable.

Although these two systems of measurements have never been seriously proposed, they serve to illustrate the extremes of systems of units for an adequately defined measuring system.

2.2 MEASUREMENTS

The measurement of any physical quantity involves the comparison of the unknown quantity to some defined quantities of the same kind. This defined quantity, as discussed in the previous section, is called a unit. Since a unit is a defined example of a dimension, it is written symbolically as a subscript on the dimensional symbol. Thus $[L]_a$ is the unit of length in the system defined by the subscript "a". If "a" represents the English system and "b" the metric mks system, then

$$[L]_a = \text{foot}$$

$$[L]_b = \text{meter}$$

The dimensions of the foot and meter are the same, namely that of length.

Let X_n represent the physical quantity that is to be measured; it has generalized dimensions of $[X]$. The subscript "n" is used to identify a particular example of all quantities that have dimensions of $[X]$. $[X]$ could represent length, mass, time, or any other dimension. Suppose X_n is to be measured in the system of units "a". The unit of dimension $[X]$ is therefore $[X]_a$. The measure of X_n is defined as the ratio of the actual physical quantity to that of the unit. This ratio is given the symbol $\{X_n\}_a$. The measure of X_n in the system of units "a" is therefore

$$\{X_n\}_a = \frac{X_n}{[X]_a}$$

Because $\{X_n\}_a$ is the ratio of two quantities of the same kind it is a pure number. Similarly in the system of units defined by "b",

$$\{X_n\}_b = \frac{X_n}{[X]_b}$$

The number that is obtained for the measure of a physical quantity , of course, depends upon the system of units used.

It is shown in Ref. 3 that the symbols representing physical quantities and units can be subjected to mathematical manipulation. Any physical quantity can therefore be written as follows:

$$X_n = \{X_n\}_a\ [X]_a = \{X_n\}_b\ [X]_b$$

In other words, a physical quantity can be expressed as the product of a number and a unit. As an example, suppose X_n represents a length of 1/2 foot, then

$$X_n = \ell_n = \{\ell_n\}_a\ [L]_a = 0.5\ \text{foot}$$

$$\{\ell_n\}_a = 0.5$$

$$[L]_a = \text{foot}$$

in system "b" if

$$[L]_b = \text{meter}$$

then

$$\ell_n = 0.1524 \text{ meter}$$

Since by definition $\frac{\text{foot}}{\text{meter}} = 0.3048$

therefore

$$\{\ell_n\}_b = 0.1524$$

It has been shown that any physical quantity can be measured by comparing it to a defined quantity of the same kind or dimension called a unit. Although this review may at first seem elementary, there is extensive misunderstanding concerning measurement concepts in the literature. In most textbooks, specific gravity is defined as being the dimensionless ratio of the density of an object or substance to the density of water under specified conditions. This definition is the same as that for the measurement of a quantity; in this case, density is the quantity being measured, and the density of water at 4°C is the defined example used as the unit of density. If it is correct to say that specific gravity is dimensionless, then it would be correct to say that length measured in feet is dimensionless since we have taken the ratio of the length to be measured to that of the foot. While it is true that the measure of any quantity is a dimensionless ratio, this fact does not allow for any more generality than a numeric and a dimension. In other words, a measure is not dimensionless in the same general sense as dimensionless variables such as Reynolds number and Mach number. Since length and other basic variables are represented as a product of a pure number and a unit, then for the sake of consistency, quantities such as density when compared to density of water should not be considered dimensionless.

Frequently data are plotted with variables, such as density and pressure, represented as ρ/ρ_{std} and p/p_{std}, respectively. This tends to be misleading (it appears that dimensionless ratios are plotted) when all that is meant is that the density is in amagats and the pressure in atmospheres. One could just as well plot mass as m/m_{std} where m_{std} is defined as the standard kilogram.

2.3 EQUATIONS

A physical law, in order to be applicable to all systems of units, is usually stated as a proportionality. For example, Newton's second law, under normal conditions, is usually stated as: "The acceleration of a body is proportional to the net force acting on the body and inversely proportional to the mass of the body." To use any physical law for a mathematical calculation, the law must be written as an equation.

There are two different views as to how to write a physical law as an equation. The first viewpoint is that by including a constant of proportionality the law may be written as a measure equation. A measure equation, as the name implies, is an equation whose terms are pure numbers representing the measure of the physical quantities involved. It is easily seen that the value of the constant of proportionality will depend upon the system of units used to measure the variables. This viewpoint is called the classic approach.

Contrasted to the classic view is the modern approach wherein a physical law, since it concerns actual quantities, can be written as a quantity equation. A quantity equation is an equation whose terms represent the actual physical quantities, and it is therefore independent of the units used to measure the quantities involved. The only constants that will appear are those caused by geometry or by mathematical operations.

These two differing concepts will be discussed briefly in the following sections. It will be shown that if one considers equations to be relations between measures, he will be unable to appreciate the argument of the modern school.

2.3.1 Classic View

There are two ways to determine the constant of proportionality in a measure equation. First, it may be given any arbitrary value, usually unity. This method permits previously defined units to measure all but one of the physical variables involved. The measure of the remaining quantity is given by the equation with our choice of the constant of proportionality included. This gives us the measure of a physical quantity without defining a unit. The fact that the quantity and its measure are known determines the unit; this is how a derived unit is defined.

An example of this procedure can be taken from Newton's law of motion. This law can be written in system "a" as a measure equation thus,

$$\{f\}_a = k_a \{m\}_a \{a\}_a$$

It is now assumed that $k_a = 1$ and that the subscript a refers to the centimeter, gram, second system of units. When m = 1 gram and a = 1 centimeter per second^2, then $\{m\}_{cgs} = 1$ and $\{a\}_{cgs} = 1$. Therefore, $\{f\}_{cgs} = 1$. Because the measure of the force is unity, the example cited defines the unit of force. This unit of force is called the dyne; it is that force that will give an acceleration of 1 centimeter per second^2 to a mass of 1 gram. Notice that this unit of acceleration is itself a derived unit; it does not have a separate name but retains the basic units from which it was obtained.

If all the units in a measure equation have previously been defined, then the constant of proportionality can be determined from experiment. Newton's law of gravitation furnishes an example of a constant determined in this manner. This law is stated as follows: "The gravitational force between two bodies is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them." Still in the cgs system this law is written as a measure equation in the following manner:

$$\{f\}_{cgs} = k_{cgs} \frac{\{m_1\}_{cgs} \{m_2\}_{cgs}}{\{\ell\}^2_{cgs}}$$

From experiment it is found that

$$k_{cgs} = 6.7 \times 10^{-8}$$

Most books that follow the classic view usually omit the braces, { }, from the symbols that represent a measure of a quantity. A measure equation can usually be recognized by the inclusion of a dimensionless experimental constant in the equation with the units to be used given separate from the equation.

2.3.2 Modern View

For theoretical work the quantity equation is ideal because no units or systems of units need be specified. Newton's second law is written as a quantity equation thus

$$f = ma$$

However, to apply a quantity equation to a physical situation the quantities involved must be measured. Since it has been shown that a physical quantity can be represented by the product of a measure and a unit, Newton's second law can be written as

$$\{f\}_a [F]_a = \{m\}_a [M]_a \{a\}_a [a]_a$$

or

$$\{f\}_a = \frac{[M]_a [a]_a}{[F]_a} \{m\}_a \{a\}_a$$

Notice that this equation is identical with the measure equation given previously if the group of units, $\frac{[M]_a\ [a]_a}{[F]_a}$, is equal to the dimensionless constant of proportionality. This group of units, from the law of motion, is given the symbol g_c.

If the group of units from any physical equation is equal to unity, then the system of units is said to be coherent. In other words, in a coherent system of units, the measure equation and the physical equation will have exactly the same form.

A group of units from a physical equation is dimensionless only when applied to the physical phenomena from which it was derived unless, by definition, we assign it the attribute of being universally dimensionless. This last choice eliminates at least one unit from the group as being fundamental. Regardless of how we evaluate a units group, by definition or experiment, it can be considered dimensionless in the equation from which it was derived. To illustrate, still using Newton's law of motion, we find that when

$$f = 1\ lb_f$$

and

$$m = 1\ lb_m$$

that

$$a = 32.2\ ft/sec^2$$

Therefore,

$$[M]_a = lb_m \qquad \{m\}_a = 1$$

$$[F]_a = lb_f \qquad \{f\}_a = 1$$

$$[a]_a = ft/sec^2 \qquad \{a\}_a = 32.2$$

and hence

$$\frac{f}{ma} = \frac{lb_f\ sec^2}{32.2\ lb_m\ ft} = 1$$

We can now miltiply the physical equation f = ma by unity, i. e. $\frac{lb_f\ sec^2}{32.2\ lb_m\ ft}$, which gives $f = \frac{lb_f\ sec^2}{32.2\ lb_m\ ft}\ ma$. This equation is still a physical equation, but now evaluation is simpler because one need not resort to experimentation or definition.

Suppose now we wish to use this equation in the metric cgs system. We have a mass of 1 gram and a force of 2 dynes. What is the acceleration, measured in cm/sec^2?

Given that

$$f = 2 \text{ dynes}$$

$$m = 1 \text{ gram}$$

$$a = \{a\}_{cgs} [a]_{cgs}$$

where

$$[a]_{cgs} = \text{cm/sec}^2$$

Substituting these values in the equation

$$f = \frac{\text{lb}_f \ \text{sec}^2}{32.2 \ \text{lb}_m \ \text{ft}} \ ma$$

gives

$$\{a\}_{cgs} = \frac{2 \text{ dyne}}{\text{lb}_f} \ \frac{\text{lb}_m}{1 \text{ gram}} \ 32.2 \ \frac{\text{ft}}{\text{cm}} \ \frac{\text{sec}^2}{\text{sec}^2}$$

All that is now required is to use the conversion tables to evaluate the ratio of like quantities.

$$\{a\}_{cgs} = (2)\ (2.248 \times 10^{-6})\ (453.6)\ (32.2)\ (30.48)$$

$$= 2.00$$

While this result could have been obtained more easily from the definitions of the dyne, it serves to illustrate the method.

One problem in the modern school of thought that becomes immediately apparent is--to which physical phenomenon is the simplest form of a physical equation applied? To illustrate this question, the simplest equation relating area and length is: $A = \ell^2$. This equation is usually applied to the relation between the side of a square and its area. However, one might argue that the circle is the simplest geometric figure and, therefore, its area should be given by $A = d^2$. Let us assume a hypothetical case where these two views both persist. Subscript "a" represents the system where the square is considered basic. Subscript "b" represents the circle point of view. The units of length and area are the foot and the square foot, respectively, in both cases. Undoubtedly advocates of the circle system put up much resistance to the use of the "square" foot as a unit of area.

The defining physical equation and the resulting relations between units and measures in each of these assumed systems is demonstrated on the following page.

	System a	System b
Defining equations:		
	$A_{\text{square}} = \ell^2$	$A_{\text{circle}} = d^2$
	$\{A_{sq}\}_a [A]_a = \{\ell\}_a^2 [L]_a^2$	$\{A_{cir}\}_b [A]_b = \{d\}_b^2 [L]_b^2$
Units:		
	$[A]_a = \text{sq ft}$	$[A]_b = \text{sq ft}$
	$[L]_a = \text{ft}$	$[L]_b = \text{ft}$
When,		
	$\{\ell\}_a = 1$	$\{d\}_b = 1$
then,	$\{A\}_a = 1$	$\{A\}_b = \frac{\pi}{4}$
therefore,	$[A]_a = [L]_a^2$	$[A]_b = 4 \frac{[L]_b^2}{\pi}$
or,	$\text{sq ft} = \text{ft}^2$	$\text{sq ft} = \frac{4}{\pi} \text{ft}^2$
hence, the measure equation is:		
	$\{A\}_a = \{\ell\}_a^2$	$\{A\}_b = \frac{\pi}{4} \{d\}_b^2$

System a is a coherent system of units whereas system b is not.

To the classicist who views an equation as a relation between measures, the defining equations would immediately indicate that different units would be required. He considers the equation for the area of a circle in system b to mean that the unit of area should be circular feet. We can see that if one does not differentiate between a measure equation and a physical equation, general confusion results. This hypothetical problem is analogous to what has happened in the field of electromagnetism. These two possible approaches, when applied to electromagnetic equations, are called rationalized and unrationalized units.

One can find in a "modern" text the statement, 1 oersted = 1000 ampere-turn per meter, while the oersted in a "classic" work is equated to $1000/4\pi$ ampere-turn per meter. The units in both cases are identical. These definitions are parallel to those derived for the square foot in our assumed example. For a more thorough discussion on this subject, see Refs. 4 and 5.

3.0 SYSTEM OF UNITS

Physical measurements are, as a general rule, divided into three classifications; mechanical, thermal, and electrical. Because mechanical units were the first to be developed, they persist throughout the other divisions. In the following sections, important quantities under these classifications will be discussed.

3.1 MECHANICAL

Mechanical problems involve the motion of material bodies within a time-space coordinate system. Therefore, time and length are universally accepted as basic dimensions. Other quantities frequently appearing in physical situations are mass and force. One or both of these is usually chosen as an additional basic dimension. In fields where force plays the major role, such as in structures, the additional basic dimension used is force. Those that are more frequently concerned with mass assume it to be basic. In some fields of engineering such as thermodynamics, both mass and force are considered fundamental. The following table gives the units of various mechanical quantities in several different systems. Also given are the values of g_c, the units group from Newton's law of motion. When g_c is defined as dimensionless and unity in a system of units, it is in the same general sense as sq ft/ft^2 and can therefore be used to eliminate the units of mass ~~of~~ or force from physical equations.

SYSTEMS OF MECHANICAL UNITS

Quantity	mks	cgs	ft-lb$_m$-sec	ft-lb$_f$-sec	ft-lb$_m$-lb$_f$-sec	cm-gm$_m$-gm$_f$-sec
Length	meter	cm	foot	foot	foot	cm
Mass	kilogram	gram	lb$_m$	slug	lb$_m$	gm$_f$
Time	sec	sec	sec	sec	sec	sec
Force	Newton	dyne	poundal	lb$_f$	lb$_f$	gm$_f$
Density	kg/m^3	gm/cm^3	lb$_m$/ft^3	slug/ft^3	lb$_m$/ft^3	gm$_m$
Pressure	Newton/m^2	dyne/cm^2	poundal/ft^2	lb$_f$/ft^2	lb$_f$/ft^2	gm$_f$/cm^2
Work (Energy)	Joule	erg	ft poundal	ft lb$_f$	ft lb$_f$	gm$_f$ cm
Power	watt	erg/sec	ft poundal/sec	ft lb$_f$/sec	ft lb$_f$/sec	gm$_f$ cm/sec
gc	unity = $\frac{\text{kg m}}{\text{Newton sec}^2}$	unity = $\frac{\text{gm cm}}{\text{dyne sec}^2}$	unity = $\frac{\text{lb}_m\text{ ft}}{\text{poundal sec}^2}$	unity = $\frac{\text{slug ft}}{\text{lb}_f\text{ sec}^2}$	$32.174\frac{\text{lbm ft}}{\text{lbf sec}^2}$	$980.665\frac{\text{gm}_m\text{ cm}}{\text{gm}_f\text{ sec}^2}$

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

Many authors introduce a force-mass-length-time system and then proceed to eliminate force or mass by using a dimensionless g_c from some other system. The result is that the four dimensional system has been replaced by a three dimensional system. In the same way the universal gravitational constant, G, could be assumed unity; thus, both mass and force would be eliminated. While this latter possibility is not used, it serves to illustrate the possibilities if one is intent on eliminating basic units.

Some of the more important mechanical dimensions will be discussed in the following sections.

3.1.1 Length

The basic unit of length before October 1960, was the meter bar located at the International Bureau of Weights and Measures at Sèvres, France. In 1795 the original meter bar was constructed of platinum. Its length at 0°C was supposedly one ten-millionth of the earth's meridian quadrant at sea level. In 1875 a new meter bar was constructed of a platinum-iridium alloy. This meter bar was taken as the basic unit of length, and any reference to the earth was omitted. This meter bar was the standard of length until it was redefined at the 11th General Conference on Weights and Measures in Paris on October 14, 1960. The meter is now defined as 1, 650, 763. 73 wavelengths of the orange-red line of the spectrum in vacuum of krypton 86 corresponding to the unperturbed transition between the $2P_{10}$ and $5d_5$ levels.

The new definition of the meter gives scientists in any laboratory the capabilities of their own fundamental length unit. There is now no need to periodically return meter bars to France to be compared with the original.

The basic unit of length in the United States, the foot, is still defined in terms of the meter. The U. S. Coast and Geodetic Survey defines the foot as exactly 1200/3937 (0. 3048006 ··) meters, whereas the National Bureau of Standards defines the foot as exactly 0. 3048 meters. The latter definition for the foot is used throughout this report.

3.1.2 Volume and Mass

When the metric system was first conceived, the unit of length, the meter, was to be the only material standard. The unit of mass, the gram, was originally defined as the mass of one cubic centimeter of pure water at its maximum density under a pressure of one standard atmosphere. This definition was ambiguous because the isotopic constituents of the water were unspecified. Since it was difficult to accurately reproduce this mass of water for the measurement of mass (evaporation would also present a problem), it was decided to reproduce this mass a thousand fold as a cylinder of platinum-iridium called the kilogram.

As more accurate measuring techniques were developed, it was found that this mass differed from the original definition. However, this cylinder had become accepted as the standard of mass. Instead of changing this standard, it was decided to change the volume of water in the original definition. This volume was designated a milliliter; the volume of one liter of water under the specified conditions would therefore contain a mass of one kilogram. It has been found from experiment that

$$1 \text{ liter} = (1000.028 \pm 0.004)\ \text{cm}^3$$

Other units of volume are defined in terms of the liter or the cube of length.

The unit of mass in this country, the pound mass, is defined as being 0.45359237 kilogram. The slug is that mass which will be accelerated at a rate of one foot per second when acted upon by a force of one pound.

3.1.3 Time

The fundamental unit of time, the second, is unique in that it is the only universally recognized basic unit. The second was redefined by the International Committee on Weights and Measures in 1956 as 1/31, 556, 925.9747 of the tropical year 1900. The tropical year, which is the interval between two consecutive returns of the sun to the vernal equinox, was selected because accurate tables were already available based on the year 1900. However, if time is based on any astronomical observation the unit can only be determined over a long period of time and then only in retrospect.

One reason for defining the second in terms of the year instead of the day is that the rotation of the earth about its axis is known to fluctuate about one part in 10^8. These variations are measured by molecular oscillators. The frequency of these oscillators is known to within a few parts in 10^{10}. The fact that the second was defined in terms of the epoch 1900 implies that the members of the International Conference were aware of variations even in the length of the year.

At present these molecular oscillators or "atomic clocks" are used to maintain time between astronomical observations. These clocks are adjusted to keep pace with nonuniform astronomical time. The standard time of the U. S. is broadcast by the National Bureau of Standards over their short wave stations. The alining process used by the National Bureau of Standards between the molecular oscillators and mean solar time is discussed below by McNish.

"The frequencies broadcast by the Bureau's stations WWV and WWVH are now monitored and kept as constant as possible by reference to the cesium resonance. The intervals between the seconds pulses are maintained in the same way. Therefore, the seconds pulses gradually get out of step with mean solar time. When the difference becomes great enough the pulses are shifted by exactly 20 milliseconds to bring them back in. Thus we are already using two kinds of time, atomic time--that's for the scientists--and mean solar time--that's for the birds. . . . " (Ref. 2, p. 642)

It has been proposed that time be redefined in terms of these accurate molecular oscillators (similar to the redefinition of the meter). In addition to being a stable and accurate means of defining time, these oscillators would provide a continuous and immediate standard.

3.1.4 Volume Flow Rate or Pumping Speed

The performance of various vacuum pumps is usually given by a volume flow per unit time as a function of pressure. This volume flow rate or pumping speed is at the pressure of the gas being pumped. The equation for pumping speed is therefore:

$$\dot{V} = dV/dt$$

3.1.5 Thruput

The mass of gas flowing or being pumped per unit time is given by:

$$\dot{m} = (\text{volume flow rate})\ (\text{density of gas})$$

$$= \dot{V}\rho$$

The perfect gas relation is,

$$\rho = \frac{p}{RT}$$

therefore,

$$\dot{m} = \frac{\dot{V}p}{RT}$$

The product $\dot{V}p$ is sometimes used by pump manufacturers to indicate the performance of vacuum pumping equipment. This product is usually called thruput. The mass flow capacity of a pump is therefore given by:

$$\dot{m} = \frac{\text{thruput}}{RT}$$

where:

R = gas constant of gas being pumped

T = absolute temperature of gas being pumped

3.1.6 Leak Rate

The leakage into a vacuum chamber through a fitting or connector is measured or specified by a pressure rise per unit time multiplied by the system volume. Thus the leak rate through an electrical connector installed on a vacuum chamber may be given as 1 μ of Hg - ft^3/hr. This means that if installed on a system of one cubic foot, the pressure would rise at the rate of one μ of Hg per hour. The units and conversions for leak rate are the same as those of thruput. The mass flow through a leak is of the same form as that for the mass flow handled by a pump. The equation for leak mass flow is:

$$\dot{m} = \frac{\text{leak rate}}{RT}$$

3.2 THERMAL

Temperature is introduced as a physical quantity early in the study of thermodynamics and kinetic theory. Temperature is defined in thermodynamics as that property that causes the transfer of energy by either conduction or radiation. The kinetic-theory concept is that absolute temperature is proportional to the average translational kinetic energy of the molecules of a substance under equilibrium conditions. Both these definitions can be reduced to the same approach when we note that an energy transfer would be a function of an energy differential.

Although temperature could be defined in terms of energy, i. e., mechanical units, it has always been defined independently. Therefore, dimensional constants will appear in equations involving temperature.

3.2.1 Temperature

The International Temperature Scale of 1948 is determined by six defined, reproducible points. Two of these points are designated as fundamental. These are the ice point (0°C) and the steam point (100°C) of water. Other points are the boiling points of oxygen and sulfur at -182. 970°C and 444. 600°C, respectively, and the freezing points of silver and gold at 960.8°C and 1063.0°C, respectively. These defining points have the same values as those used prior to 1948 with the exception of the silver point. The silver point was changed from 960.5°C to 960.8°C by the International Committee of Weights and Measures meeting in 1948.

The thermodynamic temperature scale of 1954 is an absolute temperature scale; therefore, only one point need be specified. The triple point of water was chosen for this defining point. The temperature agreed upon for the triple point was 273.16°K. A reason for using the triple point instead of the ice point is that it is easier to reproduce in the laboratory because no ambient condition need be specified.

As improved temperature measurement techniques become available, the discrepancies between the international and thermodynamic scales will become more apparent. It will then become necessary to redefine the fixed points on the international scale, as was done with the silver point in 1948, or allow a difference in the size of the Kelvin degree and the Celsius degree (formerly centigrade). The best information to date indicates that

$$[\theta]_{^\circ C} = (0.999964 \pm 0.000036)\,[\theta]_{^\circ K}$$

Elsewhere in this report it is assumed that the size of the Celsius degree is identical to the Kelvin degree.

The International Temperature Scale is still used for practical measurements. This scale was revised at the 11th General Conference on Weights and Measures in Paris, October 1960. The only change was the ice point which has been replaced by the triple point of water (0.01°C). The name of the scale was changed to the International Practical Temperature Scale.

Other commonly used temperature scales are the Fahrenheit and the Rankine scales. The Rankine scale, like the Kelvin, is an absolute scale. The size of the Rankine degree is defined as 5/9 that of the Kelvin degree. Therefore, the triple point of water is 491.688°R. The Fahrenheit scale is defined in terms of the ice point and the boiling point of water, 32°F and 212°F, respectively. While the zero on the Fahenheit scale has no physical significance, it was chosen by Gabriel Daniel Fahenheit (1686-1736) possibly in an attempt to represent most temperatures known to him as positive numbers. He chose the coldest day in Danzig in the year 1709, needless to say, a rather difficult point to reproduce.

3.2.2 Gas Constant and Molecular Weight

One of the most important constants relating temperature and energy is the gas constant. Because energy is an extensive property, that is, proportional to the mass of the system, and temperature is an intensive property (independent of mass), the gas constant for a given gas will be proportional to the mass involved. Working on a molecular scale we use the gas constant per molecule. This molecular gas constant, called Boltzmann's constant, k, when multiplied by one-half the absolute temperature gives the energy that is contained in each energy mode or degree of freedom of a gas molecule.

The gas constant per unit mass, R, is that constant that is included in the perfect gas equation relating pressure, density, and temperature. Because this equation is more applicable to dilute gases, the equation for the gas constant can be written as,

$$R = \left(\frac{p}{\rho T}\right)_{\lim\ p \to 0}$$

This constant for a specific gas can be related to the universal gas constant, R_o, by the equation

$$R = \frac{R_o}{\text{mol. wt}}$$

Although molecular weight is not a thermal quantity, it is discussed in this section because of its relation with the gas constant. Molecular weight (molecular mass is a more descriptive term) is a measure of the mass of a molecule using an atomic unit as the unit of mass. In the past, two slightly different atomic mass units have been used. The "chemical scale" used 1/16 the mass of the average oxygen atom of natural oxygen, consisting of a mixture of three isotopes, as this atomic unit of mass. The "physical scale" used 1/16 the mass of the oxygen 16 isotope, the most abundant oxygen isotope, as the unit of mass. However, the International Union of Pure and Applied Physics and the International Union of Pure and Applied Chemistry have agreed upon a new unit of mass for atomic and molecular weights. This new unit of mass is 1/12 the mass of the carbon 12 atom. The average molecular weight of oxygen is now 31.9988 instead of the previous 32.0000 on the chemical scale.

A mole of substance is an amount such that the measure of its mass is the same as the measure of its molecular weight.

$$1 \text{ mole} = \{\text{mol. wt}\}_x \ [\text{Unit Mass}]_x$$

Because the mole is a function of the unit mass it is usually preceeded by the unit used, e. g., gm mole, lb_m mole. One lb_m mole of O_2 would therefore be a mass of 32 lb_m of oxygen. Because the measure of mass of the mole is the same as that of molecular weight, the number of molecules per mole, N, is a constant. The number of molecules per mole is called Avogadro's number.

The ratio of the mole to the unit mass is identical to the ratio of universal gas constant to the gas constant per unit mass. Hence,

$$\frac{\text{mole}}{\text{unit mass}} = \frac{R}{R_o} = \text{mol. wt}$$

Therefore, the universal gas constant is the gas constant per mole.

Because the number of molecules per mole is constant, the relation between the gas constant per molecule and the universal gas constant is given by

$$R_o = Nk$$

3.3 ELECTRICAL

At least ten different systems of electrical and magnetic units are in use at the present time. These different systems can be subdivided into three different approaches--electromagnetic units (emu), electrostatic units (esu), and Gaussian or mixed units. These major headings are broken down further by rationalization and by the choice of mechanical units to be used.

The electrostatic units start with Coulomb's law of force between charges, and using permittivity as a basic dimension, a system of units is derived. Contrasting this approach is the electromagnetic system of units which have as a basis the fictitious equation between unit poles or the physical equation of force between current carrying elements. Permeability of vacuous space is used as a fundamental unit in the electromagnetic units system.

When problems are encountered to which magnetic and electrostatic equations apply, both the electrostatic and electromagnetic systems suffer from certain inconveniences. In an attempt to overcome these inconveniences the Gaussian or mixed system has increased in popularity. In this system, both the permittivity and permeability of empty space are assumed to be unity. The velocity of electromagnetic-wave propagation, c, now appears in certain equations. The Gaussian system is ideally suited to the theoretician. However, the esu, the emu, and the Gaussian systems all use electromagnetic units that are of magnitudes not suited to physical measurement. All three of these systems use centimeter-gram-second mechanical units.

The practical units have evolved from attempts to use units for physical measurements that are the same order of magnitude as the quantities being measured. By a lucky coincidence, if the meter-kilogram-second mechanical units are substituted for the cgs and the ampere is used as the unit of current, then most other electromagnetic units will coincide with the practical system. The volt, ohm, henry, and farad are thus units in the mksa system. This resulting system is usually called simply the mks system, although it is more rigorously called the practical rationalized mksa or the Giorgi system.

Each of the systems so far discussed can be subdivided into a rationalized or unrationalized system, differing by a factor of 4π in the equation or units. Rationalization gives simpler formulas when dealing with problems in rectangular coordinates, whereas phenomena of spherical symmetry are more aptly expressed by unrationalized units.

Although the Giorgi system is widely used in the field of engineering, it fails to meet the requirements of engineers who use the ft-lb_f systems. The electrical conversion tables in this report permit the conversion of commonly used electromagnetic quantities into a ft-lb_f-sec-amp* engineering system.

A brief comparison of some basic electromagnetic units used in these various systems is outlined in the table on the following page. Also included are values of permeability and permittivity of empty space in each system.

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*The absolute ampere. It is defined as that current which, when contained in two straight parallel conductors of infinite length and of negligible cross-section, at a distance of one meter apart in vacuo, would produce between the conductors a force of 2×10^{-7} newtons per meter of length.

UNITS IN VARIOUS ELECTROMAGNETIC SYSTEMS

Quantity	Defining Equation	esu (unrationalized)	emu (unrationalized	Gaussian (unrationalized)	mksa (rationalized)	Engineering (unrationalized)
Current	Basic	statampere	abampere	statampere	ampere	amp
Charge	$Q = It$	statcoulomb	abcoulomb	statcoulomb	coulomb	amp sec
Potential	$E = P/I$	statvolt	abvolt	statvolt	volt	ft lb_f/amp sec
Capacitance	$C = Q/E$	statfarad	abfarad	statfarad	farad	amp^2 sec^2/ft lb_f
Inductance	$E = -L\ dI/dt$	stathenry	abhenry	abhenry	henry	ft lb_f/amp^2
Resistance	$R = P/I^2$	statohm	abohm	statohm	ohm	ft lb_f/amp^2 sec
Resistivity	$\rho = RA/\ell$	statohm cm	abohm cm	statohm cm	ohm meter	ft^2 lb_f/amp^2/sec
Surface Current	$j = I/A$	statamp/cm^2	abamp/cm^2	statamp/cm^2	ampere/$meter^2$	amp/ft^2
Power	$P = \frac{f\ell}{t}$	erg/sec	erg/sec	erg/sec	watts	ft lb_f/sec
Permeability,	μ_{std}	1.112646×10^{-21} sec^2/cm^2	unity	unity	1.25664×10^{-6} henry/meter	2.24809×10^{-8} lb_f / amp^2
Permittivity,	ϵ_{std}	unity	1.112646×10^{-21} sec^2/cm^2	unity	8.85419×10^{-12} farad/meter	4.59805×10^{-11} $\frac{amp^2\ sec^2}{ft^2\ lb_f}$

3.3.1 International and Absolute Electrical Units

In 1893 the International Electrical Congress met at Chicago to define concrete units of current and resistance in an attempt to achieve unification of electrical standards. These concrete units were supposedly the redefined practical ampere and ohm. These international units were defined as:

1. The international ohm is the resistance offered to an unvarying electric current by a column of mercury at the temperature of melting ice, 14.4521 grams in mass, of a constant cross-sectional area and of a length of 106.3 centimeters.
2. The international ampere is the unvarying electric current which, when passed through a solution of nitrate of silver in water, under specified conditions, deposits silver at the rate of 0.00111800 of a gram per second.

As more accurate electrical measuring instruments were developed, discrepancies between these International units and the practical absolute units were discovered. The absolute system replaced the International system by international agreement in 1948. The relation between the international and the absolute electrical units is given in the following table:

3.3.2 Relationship between International and Absolute Units

International amp = 0.999835 absolute amp
International coulomb = 0.999835 absolute coulomb
International farad = 0.999505 absolute farad
International henry = 1.000495 absolute henry
International joules = 1.000165 absolute joules
International ohms = 1.000495 absolute ohms
International volt = 1.000330 absolute volt
International watt = 1.000165 absolute watt

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APPENDIX: CONVERSION TABLES

EXPLANATORY NOTES

The reader may convert from the measure of quantities in the units listed on the left to those across the top of the page by multiplying by the given factor. The small number to the upper right of each factor is the power of ten by which the factor is to be multiplied. For example, 8.68977^{-2} is equivalent to 0.0868977. Underscores indicate exact values.

Slight numerical differences will be noticed between the values herein and those in most currently existing texts because of the redefinition of the foot in 1960.

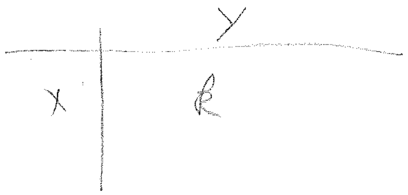

TABLE 1

Length (ℓ, d)

	Å	cm	ft	in.	km	m	μ	mils	miles (US)	mm	miles (Nautical)	rods	yd
Angstrom Units	$\underline{1.00000}$	$\underline{1.00000}^{-8}$	3.28084^{-10}	3.93701^{-9}	$\underline{1.00000}^{-13}$	$\underline{1.00000}^{-10}$	$\underline{1.00000}^{-4}$	3.93701^{-6}	6.21371^{-14}	$\underline{1.00000}^{-7}$	5.39957^{-14}	1.98839^{-11}	1.09361^{-10}
Centimeters	$\underline{1.00000}^{8}$	$\underline{1.00000}$	3.28084^{-2}	3.93701^{-1}	$\underline{1.00000}^{-5}$	$\underline{1.00000}^{-2}$	$\underline{1.00000}^{4}$	3.93701^{2}	6.21371^{-6}	$\underline{1.00000}^{1}$	5.39957^{-6}	1.98839^{-3}	1.09361^{-2}
Feet	$\underline{3.04800}^{9}$	$\underline{3.04800}^{1}$	$\underline{1.00000}$	$\underline{1.20000}^{1}$	$\underline{3.04800}^{-4}$	$\underline{3.04800}^{-1}$	$\underline{3.04800}^{5}$	$\underline{1.20000}^{4}$	1.89394^{-4}	$\underline{3.04800}^{2}$	1.64579^{-4}	6.06061^{-2}	3.33333^{-1}
Inches	$\underline{2.54000}^{8}$	$\underline{2.54000}$	8.33333^{-2}	$\underline{1.00000}$	$\underline{2.54000}^{-5}$	$\underline{2.54000}^{-2}$	$\underline{2.54000}^{4}$	$\underline{1.00000}^{3}$	1.57828^{-5}	$\underline{2.54000}^{1}$	1.37149^{-5}	5.05050^{-3}	2.77778^{-2}
Kilometers	$\underline{1.00000}^{13}$	$\underline{1.00000}^{5}$	3.28084^{3}	3.93701^{4}	$\underline{1.00000}$	$\underline{1.00000}^{3}$	$\underline{1.00000}^{9}$	3.93701^{7}	6.21371^{-1}	$\underline{1.00000}^{6}$	5.39957^{-1}	1.98839^{2}	1.09361^{3}
Meters	$\underline{1.00000}^{10}$	$\underline{1.00000}^{2}$	3.28084	3.93701^{1}	$\underline{1.00000}^{-3}$	$\underline{1.00000}$	$\underline{1.00000}^{6}$	3.93701^{4}	6.21371^{-4}	$\underline{1.00000}^{3}$	5.39957^{-4}	1.98839^{-1}	1.09361
Microns	$\underline{1.00000}^{4}$	$\underline{1.00000}^{-4}$	3.28084^{-6}	3.93701^{-5}	$\underline{1.00000}^{-9}$	$\underline{1.00000}^{-6}$	$\underline{1.00000}$	3.93701^{-2}	6.21371^{-10}	$\underline{1.00000}^{-3}$	5.39957^{-10}	1.98839^{-7}	1.09361^{-6}
Mils	$\underline{2.54000}^{5}$	$\underline{2.54000}^{-3}$	8.33333^{-5}	$\underline{1.00000}^{-3}$	$\underline{2.54000}^{-8}$	$\underline{2.54000}^{-5}$	$\underline{2.54000}^{1}$	$\underline{1.00000}$	1.57828^{-8}	$\underline{2.54000}^{-2}$	1.37149^{-8}	5.05050^{-6}	2.77778^{-5}
Miles (US)	1.60934^{13}	1.60934^{5}	$\underline{5.28000}^{3}$	$\underline{6.33600}^{4}$	1.60934	1.60934^{3}	1.60934^{9}	$\underline{6.33600}^{7}$	$\underline{1.00000}$	1.60934^{6}	8.68977^{-1}	$\underline{3.20000}^{2}$	$\underline{1.76000}^{3}$
Millimeters	$\underline{1.00000}^{7}$	$\underline{1.00000}^{-1}$	3.28084^{-3}	3.93701^{-2}	$\underline{1.00000}^{-6}$	$\underline{1.00000}^{-3}$	$\underline{1.00000}^{3}$	3.93701^{1}	6.21371^{-7}	$\underline{1.00000}$	5.39957^{-7}	1.98839^{-4}	1.09361^{-3}
Miles(Nautical)	$\underline{1.85200}^{13}$	$\underline{1.85200}^{5}$	6.07612^{3}	7.29134^{4}	$\underline{1.85200}$	$\underline{1.85200}^{3}$	$\underline{1.85200}^{9}$	7.29134^{7}	1.15078	$\underline{1.85200}^{6}$	$\underline{1.00000}$	3.68250^{2}	2.02537^{3}
Rods	$\underline{5.02920}^{10}$	$\underline{5.02920}^{2}$	$\underline{1.65000}^{1}$	$\underline{1.98000}^{2}$	$\underline{5.02920}^{-3}$	$\underline{5.02920}$	$\underline{5.02920}^{6}$	$\underline{1.98000}^{5}$	$\underline{3.12500}^{-3}$	$\underline{5.02920}^{3}$	2.71555^{-3}	$\underline{1.00000}$	$\underline{5.50000}$
Yards	$\underline{9.14400}^{9}$	$\underline{9.14400}^{1}$	$\underline{3.00000}$	$\underline{3.60000}^{1}$	$\underline{9.14400}^{-4}$	$\underline{9.14400}^{-1}$	$\underline{9.14400}^{5}$	$\underline{3.60000}^{4}$	5.68182^{-4}	$\underline{9.14400}^{2}$	4.93737^{-4}	1.81818^{-1}	$\underline{1.00000}$

1. LENGTH

TABLE 2

Area (A)

	Acre	in. (Circular)	Mil (Circular)	cm^{2}	ft^{2}	$in.^{2}$	m^{2}	mm^{2}	Rod^{2}	$Yard^{2}$
Acre	1.00000	7.98657^{6}	7.98657^{12}	4.04686^{7}	4.35600^{4}	6.27264^{6}	4.04686^{3}	4.04686^{9}	1.60000^{2}	4.84000^{3}
Circular inch	1.25211^{-7}	1.00000	1.00000^{6}	5.06707	5.45415^{-3}	7.85398^{-1}	5.06707^{-4}	5.06707^{2}	2.00336^{-5}	6.06017^{-4}
Circular mil	1.25211^{-13}	1.00000^{-6}	1.00000	5.06707^{-6}	5.45415^{-9}	7.85398^{-7}	5.06707^{-10}	5.06707^{-4}	2.00336^{-11}	6.06017^{-10}
$Centimeter^{2}$	2.47105^{-8}	1.97353^{-1}	1.97353^{5}	1.00000	1.07639^{-3}	1.55000^{-1}	1.00000^{-4}	1.00000^{2}	3.95368^{-6}	1.19598^{-4}
$Feet^{2}$	2.29568^{-5}	1.83347^{2}	1.83347^{8}	9.29030^{2}	1.00000	1.44000^{2}	9.29030^{-2}	9.29030^{4}	3.67310^{-3}	1.11111^{-1}
$Inch^{2}$	1.59423^{-7}	1.27324	1.27324^{6}	6.45160	6.94444^{-3}	1.00000	6.45160^{-4}	6.45160^{2}	2.55076^{-5}	7.71605^{-4}
$Meter^{2}$	2.47105^{-4}	1.97353^{3}	1.97353^{9}	1.00000^{4}	1.07639^{1}	1.55000^{3}	1.00000	1.00000^{6}	3.95368^{-2}	1.19598
$Millimeter^{2}$	2.47105^{-10}	1.97353^{-3}	1.97353^{3}	1.00000^{-2}	1.07639^{-5}	1.55000^{-3}	1.00000^{-6}	1.00000	3.95368^{-8}	1.19598^{-6}
Rod^{2}	6.25000^{-3}	4.99161^{4}	4.99161^{10}	2.52928^{5}	2.72250^{2}	3.92040^{4}	2.52928^{1}	2.52928^{7}	1.00000	3.02500^{1}
$Yard^{2}$	2.06611^{-4}	1.65012^{3}	1.65012^{9}	8.36127^{3}	9.00000	1.29600^{3}	8.36127^{-1}	8.36127^{5}	3.30578^{-2}	1.00000

2. AREA

TABLE 3

Volume (V)

	Centimeter^3	Feet^3	Gallon	Inch^3	Liter	Meter^3	Yard^3
Centimeter^3	$\underline{1.00000}$	3.53146^{-5}	2.64171^{-4}	6.10236^{-2}	9.99972^{-4}	$\underline{1.00000}^{-6}$	1.30794^{-6}
Feet^3	2.83168^{4}	$\underline{1.00000}$	7.48052	$\underline{1.72800^{3}}$	2.83161^{1}	2.83168^{-2}	3.70370^{-2}
Gallon (U.S.)	3.78543^{3}	1.33680^{-1}	$\underline{1.00000}$	$\underline{2.31000^{2}}$	3.78533	3.78543^{-3}	4.95113^{-3}
Inch^3	1.63871^{1}	5.78704^{-4}	4.32900^{-3}	$\underline{1.00000}$	1.63866^{-2}	1.63871^{-5}	2.14335^{-5}
Liter	1.00003^{3}	3.53156^{-2}	2.64178^{-1}	6.10253^{1}	$\underline{1.00000}$	1.00003^{-3}	1.30798^{-3}
Meter^3	$\underline{1.00000^{6}}$	3.53146^{1}	2.64171^{2}	6.10236^{4}	9.99972^{2}	$\underline{1.00000}$	1.30794
Yard^3 (U.S.)	7.64554^{5}	$\underline{2.70000^{1}}$	2.01974^{2}	$\underline{4.66560^{4}}$	7.64538^{2}	7.64554^{-1}	$\underline{1.00000}$

3. VOLUME

TABLE 4

Mass (m)

	Grain	Gram_m	Kilogram_m	Ounce (avdp)	Pound_{mass}	Slug	Ton (short)
Grain	$\underline{1.00000}$	6.47988^{-2}	6.47988^{-5}	2.28571^{-3}	1.42857^{-4}	4.44012^{-6}	7.14285^{-8}
Gram_{mass}	1.54323^{1}	$\underline{1.00000}$	$\underline{1.00000}^{-3}$	3.52739^{-2}	2.20462^{-3}	6.85216^{-5}	1.10231^{-6}
Kilogram_{mass}	1.54323^{4}	$\underline{1.00000}^{3}$	$\underline{1.00000}$	3.52739^{1}	2.20462	6.85216^{-2}	1.10231^{-3}
Ounce (avdp)	$\underline{4.37500}^{2}$	2.83495^{1}	2.83495^{-2}	$\underline{1.00000}$	6.25000^{-2}	1.94256^{-3}	3.12500^{-5}
Pound_{mass}	$\underline{7.00000}^{3}$	4.53592^{2}	4.53592^{-1}	$\underline{1.60000}^{1}$	$\underline{1.00000}$	3.10809^{-2}	$\underline{5.00000}^{-4}$
Slug	2.25218^{5}	1.45939^{4}	1.45939^{1}	5.14785^{2}	3.21740^{1}	$\underline{1.00000}$	1.60870^{-2}
Ton (short)	$\underline{1.40000}^{7}$	9.07184^{5}	9.07184^{2}	$\underline{3.20000}^{4}$	$\underline{2.00000}^{3}$	6.21618^{1}	$\underline{1.00000}$

4. MASS

TABLE 5

Time (t, τ)

	Day	Hour	Microsecond	Millisecond	Minute	Second
Day	$\underline{1.00000}$	$\underline{2.40000}^{1}$	$\underline{8.64000}^{10}$	$\underline{8.64000}^{7}$	$\underline{1.44000}^{3}$	$\underline{8.64000}^{4}$
Hour	4.16666^{-2}	$\underline{1.00000}$	$\underline{3.60000}^{9}$	$\underline{3.60000}^{6}$	$\underline{6.00000}^{1}$	$\underline{3.60000}^{3}$
Microsecond	1.15741^{-11}	2.77778^{-10}	$\underline{1.00000}$	$\underline{1.00000}^{-3}$	1.66667^{-8}	$\underline{1.00000}^{-6}$
Millisecond	1.15741^{-8}	2.77778^{-7}	$\underline{1.00000}^{3}$	$\underline{1.00000}$	1.66667^{-5}	$\underline{1.00000}^{-3}$
Minute	6.94444^{-4}	1.66667^{-2}	$\underline{6.00000}^{7}$	$\underline{6.00000}^{4}$	$\underline{1.00000}$	$\underline{6.00000}^{1}$
Second	1.15741^{-5}	2.77778^{-4}	$\underline{1.00000}^{6}$	$\underline{1.00000}^{3}$	1.66666^{-2}	$\underline{1.00000}$

5. TIME

TABLE 6

Angle (*a*)

	Degree	Minute	Quadrant (right angle)	Radians	Revolutions	Seconds
Degree	$\underline{1.00000}$	$\underline{6.00000^{1}}$	1.11111^{-2}	1.74533^{-2}	2.77778^{-3}	$\underline{3.60000^{3}}$
Minute	1.66667^{-2}	$\underline{1.00000}$	1.85185^{-4}	2.90889^{-4}	4.62963^{-5}	$\underline{6.00000^{1}}$
Quadrants (right angle)	$\underline{9.00000^{1}}$	$\underline{5.40000^{3}}$	$\underline{1.00000}$	1.57080	$\underline{2.50000^{-1}}$	$\underline{3.24000^{5}}$
Radians	5.72958^{1}	3.43775^{3}	6.36620^{-1}	$\underline{1.00000}$	1.59155^{-1}	2.06265^{5}
Revolutions	$\underline{3.60000^{2}}$	$\underline{2.16000^{4}}$	$\underline{4.00000}$	6.28320	$\underline{1.00000}$	$\underline{1.29600^{6}}$
Seconds	2.77777^{-4}	1.66667^{-2}	3.08642^{-6}	4.84815^{-6}	7.71605^{-7}	$\underline{1.00000}$

6. ANGLE

TABLE 7

Velocity (v)

	cm/sec	ft/min	ft/sec	Kilometer/hr	Knot	Meter/min	Meter/sec	Mile/hr
Centimeter/second	$\underline{1.00000}$	1.96850	3.28084^{-2}	$\underline{3.60000}^{-2}$	1.94384^{-2}	$\underline{6.00000}^{-1}$	$\underline{1.00000}^{-2}$	2.23694^{-2}
Feet/minute	$\underline{5.08000}^{-1}$	$\underline{1.00000}$	1.66667^{-2}	$\underline{1.82880}^{-2}$	9.87473^{-3}	$\underline{3.04800}^{-1}$	$\underline{5.08000}^{-3}$	1.13636^{-2}
Feet/second	$\underline{3.04800}^{1}$	$\underline{6.00000}^{1}$	$\underline{1.00000}$	$\underline{1.09728}$	5.92484^{-1}	$\underline{1.82880}^{1}$	$\underline{3.04800}^{-1}$	6.81818^{-1}
Kilometer/hour	2.77778^{1}	5.46807^{1}	9.11344^{-1}	$\underline{1.00000}$	5.39957^{-1}	1.66667^{1}	2.77778^{-1}	6.21371^{-1}
Knot*	5.14444^{1}	1.01268^{2}	1.68781	$\underline{1.85200}$	$\underline{1.00000}$	3.08667^{1}	5.14444^{-1}	1.15078
Meter/minute	1.66667	3.28084	5.46807^{-2}	$\underline{6.00000}^{-2}$	3.23974^{-2}	$\underline{1.00000}$	1.66667^{-2}	3.72823^{-2}
Meter/second	$\underline{1.00000}^{2}$	1.96850^{2}	3.28084	$\underline{3.60000}$	1.94384	$\underline{6.00000}^{1}$	$\underline{1.00000}$	2.23694
Mile/hour	4.47040^{1}	8.80000^{1}	1.46667	1.60934	8.68976^{-1}	2.68224^{1}	$\underline{4.47040}^{-1}$	$\underline{1.00000}$

*One knot = one nautical mile per hour

7. VELOCITY

TABLE 8

Acceleration (a)

	Centimeter/Second^2	Feet/Second^2	Gravity, Standard	Kilometer/(Hour/Second)	Meter/Second^2	Mile/(Hour/Second)
Centimeter/Second^2	1.00000	3.28084^{-2}	1.01972^{-3}	3.60000^{-2}	1.00000^{-2}	2.23694^{-2}
Feet/Second^2	3.04800^{1}	1.00000	3.10809^{-2}	1.09728	3.04800^{-1}	6.81818^{-1}
Gravity, Standard	9.80665^{2}	3.21740^{1}	1.00000	3.53039^{1}	9.80655	2.19369^{1}
Kilometer/(Hour/Second)	2.77778^{1}	9.11344^{-1}	2.83255^{-2}	1.00000	2.77778^{-1}	6.21371^{-1}
Meter/Second^2	1.00000^{2}	3.28084	1.01972^{-1}	3.60000	1.00000	2.23694
Mile/(Hour/Second)	4.47040^{1}	1.46667	4.55853^{-2}	1.60934	4.47040^{-1}	1.00000

8. ACCELERATION

TABLE 9

Force (f)

	Dyne	Gram force	Kilogram force	Newton	Poundal	Pound force
Dyne	$\underline{1.00000}$	1.01972^{-3}	1.01972^{-6}	$\underline{1.00000}^{-5}$	7.23301^{-5}	2.24809^{-6}
Gram force	$\underline{9.80665}^{2}$	$\underline{1.00000}$	$\underline{1.00000}^{-3}$	$\underline{9.80665}^{-3}$	7.09316^{-2}	2.20462^{-3}
Kilogram force	$\underline{9.80665}^{5}$	$\underline{1.00000}^{3}$	$\underline{1.00000}$	9.80665	7.09316^{1}	2.20462
Newton	$\underline{1.00000}^{5}$	1.01972^{2}	1.01972^{-1}	$\underline{1.00000}$	7.23301	2.24809^{-1}
Poundal	1.38255^{4}	1.40981^{1}	1.40981^{-2}	1.38255^{-1}	$\underline{1.00000}$	3.10809^{-2}
Pound force	4.44822^{5}	4.53594^{2}	4.53594^{-1}	4.44822	3.21740^{1}	$\underline{1.00000}$

9. FORCE

TABLE 10

Density (ρ)

	gm_m/cm^3	kg_m/m^3	lb_m/ft^3	lb_m/gal	$lb_m/in.^3$	$Slug/ft^3$	Specific gravity H_2O at 4°C = 1
$Gram_{mass}/Centimeter^3$	1.00000	1.00000^{3}	6.24280^{1}	8.34540	3.61273^{-2}	1.94032	1.00003
$Kilogram_{mass}/Meter^3$	1.00000^{-3}	1.00000	6.24280^{-2}	8.34540^{-3}	3.61273^{-5}	1.94032^{-3}	1.00003^{-3}
$Pound_{mass}/Feet^3$	1.60185^{-2}	1.60185^{1}	1.00000	1.33681^{-1}	5.78704^{-4}	3.10809^{-2}	1.60189^{-2}
$Pound_{mass}/Gallon$	1.19826^{-1}	1.19826^{2}	7.48052	1.00000	4.32900^{-3}	2.32502^{-1}	1.19830^{-1}
$Pound_{mass}/Inch^3$	2.76799^{1}	2.76799^{4}	1.72800^{3}	2.31000^{2}	1.00000	5.37079^{1}	2.76807^{1}
$Slug/Feet^3$	5.15379^{-1}	5.15379^{2}	3.21740^{1}	4.30104	1.86192^{-2}	1.00000	5.15393^{-1}
Specific Gravity* H_2O at 4°C = 1	9.99972^{-1}	9.99972^{2}	6.24262	8.34517	3.61263^{-2}	1.94027	1.00000

*Density of H_2O at maximum density (i.e., 3.98°C) = one gram per milliliter

10. DENSITY

TABLE 11

Density of Gases at $p = 1$ atm and $T = 0°C$ (ρ_{std})

	Amagats	Kg/m^3	lb_m/ft^3	slug/ft^3	Specific Density (air at 0^oC & 1 atm = 1)
Air	1	1.29304	8.07219^{-2}	2.50891^{-3}	1
Argon	1	1.78377	1.11357^{-1}	3.46108^{-3}	1.37952
Carbon Dioxide	1	1.97700	1.23420^{-1}	3.83601^{-3}	1.52895
Hydrogen	1	8.98854^{-2}	5.61136^{-3}	1.74406^{-4}	6.95146^{-2}
Nitrogen	1	1.25046	7.80637^{-2}	2.42629^{-3}	9.67069^{-1}
Oxygen	1	1.42900	8.92096^{-2}	2.77272^{-3}	1.10515

ρ/ρ_{std} = density measured in amagats

11. ρ_{std}

TABLE 12

Pressure (p)

	Standard Atmosphere	Bar**	Dynes/cm^{2} (Barye)	Feet Water at 60°F*	Gm$_{f}$/cm^{2}	Inches Hg at 32°F*	Inches Water at 60°F*	Kg$_{f}$/cm^{2}	Lb$_{f}$/ft^{2}	Lb$_{f}$/in.^{2}	Micron Hg at 32°F*	mm Hg at 32°F*
Standard Atmosphere	$\underline{1.00000}$	$\underline{1.01325}$	$\underline{1.01325}^{6}$	3.39320^{1}	1.03323^{3}	2.99213^{1}	4.07184^{2}	1.03323	2.11622^{3}	1.46959^{1}	$\underline{7.60000}^{5}$	$\underline{7.60000}^{2}$
Bar**	9.86923^{-1}	$\underline{1.00000}$	$\underline{1.00000}^{6}$	3.34882^{1}	1.01972^{3}	2.95300^{1}	4.01859^{2}	1.01972	2.08854^{3}	1.45038^{1}	7.50062^{5}	7.50062^{2}
Dynes/Centimeter^{2} (Barye)	9.86923^{-7}	$\underline{1.00000}^{-6}$	$\underline{1.00000}$	3.34882^{-5}	1.01972^{-3}	2.95300^{-5}	4.01859^{-4}	1.01972^{-6}	2.08854^{-3}	1.45038^{-5}	7.50062^{-1}	7.50062^{-4}
Feet Water (at 60°F)*	2.94707^{-2}	2.98612^{-2}	2.98612^{4}	$\underline{1.00000}$	3.04500^{1}	8.81801^{-1}	$\underline{1.20000}^{1}$	3.04500^{-2}	6.23664^{1}	4.33100^{-1}	2.23977^{4}	2.23977^{1}
Gram$_{force}$/Centimeter^{2}	9.67841^{-4}	$\underline{9.80665}^{-4}$	$\underline{9.80665}^{2}$	3.28408^{-2}	$\underline{1.00000}$	2.89590^{-2}	3.94089^{-1}	$\underline{1.00000}^{-3}$	2.04816	1.42233^{-2}	7.35559^{2}	7.35559^{-1}
Inches Mercury at 32°F*	3.34211^{-2}	3.38639^{-2}	3.38639^{4}	1.13404	3.45315^{1}	$\underline{1.00000}$	1.36085^{1}	3.45315^{-2}	7.07262^{1}	4.91154^{-1}	$\underline{2.54000}^{4}$	$\underline{2.54000}^{1}$
Inches Water at 60°F*	2.45589^{-3}	2.48843^{-3}	2.48843^{3}	8.33333^{-2}	2.53750	7.34834^{-2}	$\underline{1.00000}$	2.53750^{-3}	5.19720	3.60917^{-2}	1.86648^{3}	1.86648
Kilogram$_{force}$/Centimeter^{2}	9.67841^{-1}	$\underline{9.80665}^{-1}$	$\underline{9.80665}^{5}$	3.28408^{1}	$\underline{1.00000}^{3}$	2.89590^{1}	3.94089^{2}	$\underline{1.00000}$	2.04816^{3}	1.42233^{1}	7.35559^{5}	7.35559^{2}
Pound$_{force}$/Feet^{2}	4.72541^{-4}	4.78803^{-4}	4.78803^{2}	1.60343^{-2}	4.88243^{-1}	1.41390^{-2}	1.92411^{-1}	4.88243^{-4}	$\underline{1.00000}$	6.94444^{-3}	3.59131^{2}	3.59131^{-1}
Pound$_{force}$/Inch^{2}	6.80460^{-2}	6.89476^{-2}	6.89476^{4}	2.30894	7.03070^{1}	2.03602	2.77072^{1}	7.03070^{-2}	$\underline{1.44000}^{2}$	$\underline{1.00000}$	5.17149^{4}	5.17149^{1}
Microns Mercury at 32°F*	1.31579^{-6}	1.33322^{-6}	1.33322	4.46474^{-5}	1.35951^{-3}	3.93701^{-5}	5.35768^{-4}	1.35951^{-6}	2.78450^{-3}	1.93368^{-5}	$\underline{1.00000}$	$\underline{1.00000}^{-3}$
Millimeters Mercury at 32°F*	1.31579^{-3}	1.33322^{-3}	1.33322^{3}	4.46474^{-2}	1.35951	3.93701^{-2}	5.35768^{-1}	1.35951^{-3}	2.78450	1.93368^{-2}	$\underline{1.00000}^{3}$	$\underline{1.00000}$

*For g = 980.665 centimeters per second^{2}

**Some writers erroneously use the term bar for barye.

12. PRESSURE

TABLE 13

Energy, Work (e)

	Btu	I.T. Calorie	electron volt	erg (dyne-cm)	ft-lb$_f$	gm$_f$cm	hp hr (Mech)	ab. joule	kilocalorie	kg$_f$ m	kw hr	watt hr	ft poundal
Btu	1.00000	2.51996^{2}	6.58577^{21}	1.05504^{10}	7.78158^{2}	1.07584^{7}	3.93009^{-4}	1.05504^{3}	2.51996^{-1}	1.07584^{2}	2.93067^{-4}	2.93067^{-1}	2.50365^{4}
I.T.Calorie	3.96832^{-3}	1.00000	2.61344^{19}	4.18674^{7}	3.08798	4.26928^{4}	1.55958^{-6}	4.18674	1.00000^{-3}	4.26928^{-1}	1.16298^{-6}	1.16298^{-3}	9.93528^{1}
electron volt	1.51842^{-22}	3.82637^{-20}	1.00000	1.60200^{-12}	1.18157^{-19}	1.63358^{-15}	5.96755^{-26}	1.60200^{-19}	3.82637^{-23}	1.63358^{-20}	4.45000^{-26}	4.45000^{-23}	3.80160^{-18}
erg (dyne-cm)	9.47831^{-11}	2.38849^{-8}	6.24220^{11}	1.00000	7.37562^{-8}	1.01972^{-3}	3.72506^{-14}	1.00000^{-7}	2.38849^{-11}	1.01972^{-8}	2.77778^{-14}	2.77778^{-11}	2.37304^{-6}
ft-lb$_f$	1.28509^{-3}	3.23836^{-1}	8.46328^{18}	1.35582^{7}	1.00000	1.38255^{4}	5.05050^{-7}	1.35582	3.23836^{-4}	1.38255^{-1}	3.76616^{-7}	3.76616^{-4}	3.21740^{1}
gram$_f$ cm	9.29505^{-8}	2.34231^{-5}	6.12150^{14}	9.80665^{2}	7.23301^{-5}	1.00000	3.65304^{-11}	9.80665^{-5}	2.34231^{-8}	1.00000^{-5}	2.72407^{-11}	2.72407^{-8}	2.32715^{-3}
hp hr (Mech)	2.54447^{3}	6.41196^{5}	1.67573^{25}	2.68452^{13}	1.98000^{6}	2.73745^{10}	1.00000	2.68452^{6}	6.41196^{2}	2.73745^{5}	7.45700^{-1}	7.45700^{2}	6.37046^{7}
ab. joule (Watt sec)	9.47831^{-4}	2.38849^{-1}	6.24220^{18}	1.00000^{7}	7.37562^{-1}	1.01972^{4}	3.72506^{-7}	1.00000	2.38849^{-4}	1.01972^{-1}	2.77778^{-7}	2.77778^{-4}	2.37304^{1}
kilocalorie	3.96832	1.00000^{3}	2.61344^{22}	4.18674^{10}	3.08798^{3}	4.26928^{7}	1.55958^{-3}	4.18674^{3}	1.00000	4.26928^{2}	1.16298^{-3}	1.16298	9.93528^{4}
kg$_f$ m	9.29505^{-3}	2.34231	6.12150^{19}	9.80665^{7}	7.23301	1.00000^{5}	3.65304^{-6}	9.80665	2.34231^{-3}	1.00000	2.72407^{-6}	2.72407^{-3}	2.32715^{2}
kw hr	3.41219^{3}	8.59858^{5}	2.24719^{25}	3.60000^{13}	2.65522^{6}	3.67098^{10}	1.34102	3.60000^{6}	8.59858^{2}	3.67098^{5}	1.00000	1.00000^{3}	8.54293^{7}
watt hr	3.41219	8.59858^{2}	2.24719^{22}	3.60000^{10}	2.65522^{3}	3.67098^{7}	1.34102^{-3}	3.60000^{3}	8.59858^{-1}	3.67098^{2}	1.00000^{-3}	1.00000	8.54293^{4}
ft poundal	3.99417^{-5}	1.00651^{-2}	2.63047^{17}	4.21401^{5}	3.10810^{-2}	4.29710^{2}	1.56974^{-8}	4.21401^{-2}	1.00651^{-5}	4.29710^{-3}	1.17056^{-8}	1.17056^{-5}	1.00000

Definitions: $\frac{1\ \text{Btu}}{{}^{\circ}\text{F lb}_m} = \frac{1\ \text{I.T. Cal}}{{}^{\circ}\text{C gm}}$

1 I.T.Cal = 1/860 int. watt hr

1 int. watt = 1.000165 ab. watt

1 Btu$_{\text{mean}}$ = 1055.8 absolute joules

1 Btu$_{39}$°F = 1060 absolute joules

1 Btu$_{60}$°F = 1054.6 absolute joules

I.T. Btu = 1055.04 absolute joules

I.T. Cal$_{15}$°C = 4.1854 absolute joules

I.T. Calorie = 4.18674 absolute joules

1 Cal$_{\text{mean}}$ = 4.190 absolute joules

1 Cal$_{20}$°C = 4.181 absolute joules

1 Thermochemical Calorie = 4.1840 absolute joules

1 International Joule = 1.000165 absolute joules

1 I.T. Calorie = 1/860 international watt hour

Kilocalorie or large calorie = 1000 calories

TABLE 14

Power (P)

	Btu/hr	Btu/min	Btu/sec	I.T.Cal/hr	I.T.Cal/min	I.T.Cal/sec	erg/sec	ft-lb$_f$/min	ft-lb$_f$/sec	hp (Elec)	hp (Mech)	hp (Metric)	kg$_f$m/sec	kw	w
Btu/hr	$\underline{1.00000}$	1.66667^{-2}	2.77778^{-4}	2.51996^{2}	4.19993	6.99988^{-2}	2.93067^{6}	1.29693^{1}	2.16155^{-1}	3.92851^{-4}	3.93009^{-4}	3.98460^{-4}	2.98845^{-2}	2.93067^{-4}	2.93067^{-1}
Btu/min	$\underline{6.00000}^{1}$	$\underline{1.00000}$	1.66667^{-2}	1.51197^{4}	2.51996^{2}	4.19993	1.75840^{8}	7.78158^{2}	1.29693^{1}	2.35711^{-2}	2.35805^{-2}	2.39076^{-2}	1.79307	1.75840^{-2}	1.75840^{1}
Btu/sec	$\underline{3.60000}^{3}$	$\underline{6.0000}^{1}$	$\underline{1.00000}$	9.07183^{5}	1.51197^{4}	2.51996^{2}	1.05504^{10}	4.66894^{4}	7.78158^{2}	1.41426	1.41483	1.43446	1.07584^{2}	1.05504	1.05504^{3}
I.T.Cal/hr	3.96832^{-3}	6.61387^{-5}	1.10231^{-6}	$\underline{1.00000}$	1.66667^{-2}	2.77778^{-4}	1.16298^{4}	5.14663^{-2}	8.57772^{-4}	1.55896^{-6}	1.55958^{-6}	1.58122^{-6}	1.18591^{-4}	1.16298^{-6}	1.16298^{-3}
I.T.Cal/min	2.38099^{-1}	3.96832^{-3}	6.61387^{-5}	$\underline{6.00000}^{1}$	$\underline{1.00000}$	1.66667^{-2}	6.97790^{5}	3.08798	5.14663^{-2}	9.35376^{-5}	9.35751^{-5}	9.48730^{-5}	7.11547^{-3}	6.97790^{-5}	6.97790^{-2}
I.T.Cal/sec	1.42859^{1}	2.38100^{-1}	3.96832^{-3}	$\underline{3.60000}^{3}$	$\underline{6.00000}^{1}$	$\underline{1.00000}$	4.18674^{7}	1.85279^{2}	3.08798	5.61225^{-3}	5.61451^{-3}	5.69238^{-3}	4.26928^{-1}	4.18674^{-3}	4.18674
erg/sec	3.41219^{-7}	5.68699^{-9}	9.47831^{-11}	8.59858^{-5}	1.43310^{-6}	2.38849^{-8}	$\underline{1.00000}$	4.42537^{-6}	7.37562^{-8}	1.34048^{-10}	1.34102^{-10}	1.35962^{-10}	1.01972^{-8}	$\underline{1.00000}^{-10}$	$\underline{1.00000}^{-7}$
ft-lb$_f$/min	7.71052^{-2}	1.28509^{-3}	2.14181^{-5}	1.94302^{1}	3.23836^{-1}	5.39727^{-3}	2.25970^{5}	$\underline{1.00000}$	1.66667^{-2}	3.02909^{-5}	3.03030^{-5}	3.07233^{-5}	2.30425^{-3}	2.25970^{-5}	2.25970^{-2}
ft-lb$_f$/sec	4.62631	7.71052^{-2}	1.28509^{-3}	1.16581^{3}	1.94302^{1}	3.23836^{-1}	1.35582^{7}	$\underline{6.00000}^{1}$	$\underline{1.00000}$	1.81745^{-3}	1.81818^{-3}	1.84340^{-3}	1.38255^{-1}	1.35582^{-3}	1.35582
hp (Elec)	2.54549^{3}	4.24249^{1}	7.07081^{-1}	6.41453^{5}	1.06909^{4}	1.78182^{2}	$\underline{7.46000}^{9}$	3.30132^{4}	5.50221^{2}	$\underline{1.00000}$	1.00040	1.01427	7.60707^{1}	$\underline{7.46000}^{-1}$	$\underline{7.46000}^{2}$
hp (Mech)	2.54447^{3}	4.24079^{1}	7.06798^{-1}	6.41196^{5}	1.06866^{4}	1.78110^{2}	7.45701^{9}	$\underline{3.30000}^{4}$	$\underline{5.50000}^{2}$	9.99599^{-1}	$\underline{1.00000}$	1.01387	7.60402^{1}	7.45701^{-1}	7.45701^{2}
hp (Metric)	2.50966^{3}	4.18277^{1}	6.97129^{-1}	6.32424^{5}	1.05404^{4}	1.75673^{2}	7.35500^{9}	3.25486^{4}	5.42476^{2}	9.85924^{-1}	9.86320^{-1}	$\underline{1.00000}$	$\underline{7.50000}^{1}$	7.35500^{-1}	7.35500^{2}
kg$_f$m/sec	3.34622^{1}	5.57703^{-1}	9.29505^{-3}	8.43233^{3}	1.40539^{2}	2.34231	$\underline{9.80665}^{7}$	4.33981^{2}	7.23301	1.31456^{-2}	1.31509^{-2}	1.33333^{-2}	$\underline{1.00000}$	$\underline{9.80665}^{-3}$	$\underline{9.80665}$
kilowatt	3.41219^{3}	5.68699^{1}	9.47831^{-1}	8.59858^{5}	1.43310^{4}	2.38849^{2}	$\underline{1.00000}^{10}$	4.42537^{4}	7.37562^{2}	1.34048	1.34102	1.35962	1.01972^{2}	$\underline{1.00000}$	$\underline{1.00000}^{3}$
watt	3.41219	5.68699^{-2}	9.47831^{-4}	8.59858^{2}	1.43310^{1}	2.38849^{-1}	$\underline{1.00000}^{7}$	4.42537^{1}	7.37562^{-1}	1.34048^{-3}	1.34102^{-3}	1.35962^{-3}	1.01972^{-1}	$\underline{1.00000}^{-3}$	$\underline{1.00000}$

14. POWER

TABLE 15

Viscosity (μ)

	Centipoise	gm$_f$ sec/cm^2	kg$_m$/m sec	lb$_m$/ft hr	lb$_m$/ft sec	lb$_f$ sec/in.^{2}	Poises	Slug/ft sec
Centipoise	1.00000	1.01972^{-5}	1.00000^{-3}	2.41909	6.71969^{-4}	1.45038^{-7}	1.00000^{-2}	2.08854^{-5}
gm$_f$ sec/cm^2	9.80665^{4}	1.00000	9.80665^{1}	2.37232^{5}	6.58976^{1}	1.42233^{-2}	9.80665^{2}	2.04816
kg$_m$/m sec	1.00000^{3}	1.01972^{-2}	1.00000	2.41909^{3}	6.71969^{-1}	1.45038^{-4}	1.00000^{1}	2.08854^{-2}
lb$_m$/ft hr	4.13379^{-1}	4.21529^{-6}	4.13379^{-4}	1.00000	2.77778^{-4}	5.99556^{-8}	4.13379^{-3}	8.63360^{-6}
lb$_m$/ft sec	1.48816^{3}	1.51750^{-2}	1.48816	3.60000^{3}	1.00000	2.15840^{-4}	1.48816^{1}	3.10809^{-2}
lb$_f$ sec/in.^{2}	6.89476^{6}	7.03070^{1}	6.89476^{3}	1.66790^{7}	4.63306^{3}	1.00000	6.89476^{4}	1.44000^{2}
Poises	1.00000^{2}	1.01972^{-3}	1.00000^{-1}	2.41909^{2}	6.71969^{-2}	1.45038^{-5}	1.00000	2.08854^{-3}
Slug/ft sec	4.78803^{4}	4.88243^{-1}	4.78803^{1}	1.15826^{5}	3.21740^{1}	6.94444^{-3}	4.78803^{2}	1.00000

15. VISCOSITY

TABLE 16

Specific Energy or Energy per Unit Mass (h)

	Btu/lb$_{m}$	Btu/slug	Cal/gm	Ft lb$_{f}$/lb$_{m}$	Ft lb$_{f}$/slug	Abs. ~~Ab~~ Joule/gm
Btu/lb$_{m}$	1.00000	3.21740^{1}	5.55556^{-1}	7.78158^{2}	2.50365^{4}	2.32596
Btu/slug	3.10809^{-2}	1.00000	1.72672^{-2}	2.41859^{1}	7.78158^{2}	7.22932^{-2}
Cal/gm	1.80000	5.79133^{1}	1.00000	1.40068^{3}	4.50657^{4}	4.18674
Ft lb$_{f}$/lb$_{m}$	1.28509^{-3}	4.13464^{-2}	7.13937^{-4}	1.00000	3.21740^{1}	2.98907^{-3}
Ft lb$_{f}$/slug	3.99417^{-5}	1.28509^{-3}	2.21898^{-5}	3.10809^{-2}	1.00000	9.29030^{-5}
Abs. ~~Ab~~ Joule/gm	4.29929^{-1}	1.38326^{1}	2.38849^{-1}	3.34551^{2}	1.07639^{4}	1.00000

16. SPECIFIC ENERGY

TABLE 17

Mass Flow Rate ($\dot{m}$)

	Gm$_m$/sec	Kg$_m$/sec	Lb$_m$/hr	Lb$_m$/min	Lb$_m$/sec	Slug/sec
Gm$_m$/sec	$\underline{1.00000}$	$\underline{1.00000^{-3}}$	7.93664	1.32277^{-1}	2.20462^{-3}	6.85218^{-5}
Kg$_m$/sec	$\underline{1.00000^{3}}$	$\underline{1.00000}$	7.93664^{3}	1.32277^{2}	2.20462	6.85218^{-2}
Lb$_m$/hr	1.25998^{-1}	1.25998^{-4}	$\underline{1.00000}$	1.66667^{-2}	2.77778^{-4}	8.63360^{-6}
Lb$_m$/min	7.55987	7.55987^{-3}	$\underline{6.00000^{1}}$	$\underline{1.00000}$	1.66667^{-2}	5.18016^{-4}
Lb$_m$/sec	4.53592^{2}	4.53592^{-1}	$\underline{3.60000^{3}}$	$\underline{6.00000^{1}}$	$\underline{1.00000}$	3.10809^{-2}
Slug/sec	1.45939^{4}	1.45939^{1}	1.15826^{5}	1.93044^{3}	3.21740^{1}	$\underline{1.00000}$

17. MASS FLOW RATE

TABLE 18

Pumping Speed or Volume Flow ($\dot{V}$)

	Cm^3/sec	Ft^3/min	Ft^3/sec	Gal/min	Liter/min	Liter/sec	M^3/hr	M^3/min
Cm^3/sec	1.00000	2.11888^{-3}	3.53147^{-5}	1.58503^{-2}	5.99983^{-2}	9.99972^{-4}	3.60000^{-3}	6.00000^{-5}
Ft^3/min	4.71947^{2}	1.00000	1.66667^{-2}	7.48052	2.83160^{1}	4.71934^{-1}	1.69901	2.83168^{-2}
Ft^3/sec	2.83168^{4}	6.00000^{1}	1.00000	4.48831^{2}	1.69896^{3}	2.83160^{1}	1.01941^{2}	1.69901
Gal/min	6.30902^{1}	1.33680^{-1}	2.22801^{-3}	1.00000	3.78530	6.30884^{-2}	2.27125^{-1}	3.78541^{-3}
Liter/min	1.66671^{1}	3.53156^{-2}	5.88594^{-4}	2.64179^{-1}	1.00000	1.66667^{-2}	6.00017^{-2}	$1.00003^{\cancel{-4}}$ -3
Liter/sec	1.00003^{3}	2.11894	3.53156^{-2}	1.58508^{1}	6.00000^{1}	1.00000	3.60010	6.00017^{-2}
M^3/hr	2.77778^{2}	5.88578^{-1}	9.80963^{-3}	4.40287	1.66662^{1}	2.77770^{-1}	1.00000	1.66667^{-2}
M^3/min	1.66667^{4}	3.53147^{1}	5.88578^{-1}	2.64172^{2}	9.99972^{2}	1.66662^{1}	6.00000^{1}	1.00000

18. PUMPING SPEED

TABLE 19

Throughput

	Atm ft^{3}/sec	Atm cm^{3}/sec	Ft lb$_{f}$/sec	Mm ft^{3}/min	Micron ft^{3}/min	Micron liter/sec	Psi ft^{3}/sec
Atm ft^{3}/sec	1.00000	2.83168^{4}	~~1.02055^{1}~~ 2.11622^{3}	4.56001^{4}	4.56001^{7}	2.15201^{7}	1.46960^{1}
Atm cm^{3}/sec	3.53147^{-5}	1.00000	~~3.60405^{-6}~~ -2 7.47337	1.61035	1.61035^{3}	7.59973^{2}	5.18983^{-4}
Ft lb$_{f}$/sec	~~9.79862~~ -4 4.72541	~~2.77465^{5}~~ 1 1.33808	1.00000	~~4.46818^{5}~~ 2.15478 ^{1}	~~4.46818^{8}~~ 2.15478 ^{4}	~~2.10866^{8}~~ 1.01691 ^{4}	~~1.44000^{2}~~ 6.94444
Mm ft^{3}/min	2.19298^{-5}	6.20983^{-1}	~~2.23806^{-6}~~ -2 4.64084	1.00000	1.00000^{3}	4.71930^{2}	3.22280^{-4}
Micron ft^{3}/min	2.19298^{-8}	6.20983^{-4}	~~2.23806^{-9}~~ -5 4.64084	1.00000^{-3}	1.00000	4.71930^{-1}	3.22280^{-7}
Micron Liter/sec	4.64683^{-8}	1.31584^{-3}	~~4.74233^{-9}~~ -5 9.83370	2.11896^{-3}	2.11896	1.00000	6.82896^{-7}
Psi ft^{3}/sec	6.80460^{-2}	1.92684^{3}	~~6.94444^{-3}~~ 1.44000 ^{2}	3.10290^{3}	3.10290^{6}	1.46435^{6}	1.00000

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19. THRUPUT

TABLE 20

Temperature* (T, θ)

To convert from the units below to those on the right, perform the indicated operations in order.	°C	°F	°K	°R
°C	x 1	x 9/5 + 32	+ 273.15	x 9/5 + 491.67
°F	- 32 x 5/9	x 1	x 5/9 + 255.372	+ 459.67
°K	- 273.15	x 9/5 - 459.67	x 1	x 9/5
°R	x 5/9 - 273.15	- 459.67	x 5/9	x 1

*Based on the thermodynamic temperature scale as defined by the Tenth General Conference on Weights and Measure meeting at Paris in October 1954.

Temperature of triple point of water = 273.16°K = 491.688°R = 32.018°F = 0.01°C

Temperature of ice point of water = 273.15°K = 491.67°R = 0°C = 32°F

20. TEMPERATURE

TABLE 21

Gas Constant

Tables of $\{R_o\}_x$ are given below for use in the perfect gas measure equations, $\{p\}_x = \{\rho\}_x\ \{R\}_x\ \{T\}_x$ when p, ρ, and T are measured in various units, identified by the subscript x. R_x is given by the equation $\{R\}_x = \dfrac{\{Ro\}_x}{\{\text{mol wt}\}_{chem}}$. R, for use in the physical equation $p = \rho RT$, is given by

$$R = \frac{\{R_o\}_x \quad [\text{unit pressure}]_x}{\{\text{mol wt}\}_{chem}\ [\text{unit density}]_x\ [\text{unit temp}]_x}$$

Values of $\{R_o\}_x$ for T Measured in ^oK

Pressure measured in	Density measured in gm/cm^3	kg/m^3	lb$_m$/ft^3	slugs/ft^3
atmospheres	8.20820^{1}	8.20820^{-2}	1.31483	4.23033^{1}
dynes/cm^2	8.31696^{7}	8.31696^{4}	1.33225^{6}	4.28639^{7}
kg$_f$/cm^2	8.48097^{1}	8.48097^{-2}	1.35852	4.37091^{1}
lb$_f$/ft^2	1.73703^{5}	1.73703^{2}	2.78246^{3}	8.95229^{4}
lb$_f$/in.^{2}	1.20627^{3}	1.20627	1.93226^{1}	6.21682^{2}
mm Hg	6.23821^{4}	6.23821^{1}	9.99263^{2}	3.21504^{4}

Values of $\{R_o\}_x$ for T Measured in ^oR

Pressure measured in	Density measured in gm/cm^3	kg/m^3	lb$_m$/ft^3	slugs/ft^3
atmospheres	4.56011^{1}	4.56011^{-2}	7.30461^{-1}	2.35018^{1}
dynes/cm^2	4.62053^{7}	4.62053^{4}	7.40139^{5}	2.38133^{7}
kg$_f$/cm^2	4.71165^{1}	4.71165^{-2}	7.54733^{-1}	2.42828^{1}
lb$_f$/ft^2	9.65017^{4}	9.65017^{1}	1.54581^{3}	4.97349^{4}
lb$_f$/in.^{2}	6.70150^{2}	6.70150^{-1}	1.07348^{1}	3.45379^{2}
mm Hg	3.46567^{4}	3.46567^{1}	5.55149^{2}	1.78613^{4}

Tables of $\{R_o\}_x$ for use in converting units of energy per unit mass such as enthalpy and internal energy are given below. For example, enthalpy is sometimes given as h/RT_{std}. R can be written as

$$R = \frac{\{R_o\}_x \quad [\text{unit energy}]_x}{\{\text{mol wt}\}_{chem}\ [\text{unit mass}]_x\ [\text{unit temp}]_x}$$

Values of $\{\text{mol wt}_{chem}$ for various gasses are given in Table 22. Suppose that a value of h/RT_{std} for air is given as 27 and that h is desired in Btu/lb$_m$. T_{std} is equal to 273.15 ^oK. Since the unit of energy is the Btu, the unit of mass the lb$_m$ and the unit of temperature the ^oK, Table 21 gives $\{R_o\}_x = 3.57571$. The molecular weight of air from Table 22 is 28.966. The gas constant is written as, $R = \dfrac{3.57571\ \text{Btu}}{28.966\ \text{lb}_m\ {}^oK}$. Therefore, $h = \dfrac{h}{RT_{std}}\ RT_{std} = 27\ \dfrac{3.57571\ \text{Btu}}{28.966\ \text{lb}_m\ {}^oK}\ 273.15^oK = 910.4\ \text{Btu/lb}_m$.

Values of $\{R_o\}_x$ for T Measured in ^oK

Mass measured in	Energy measured in Btu	calorie	ft lb$_f$	kcal
gram	7.88308^{-3}	1.98650	6.13427	1.98650^{-3}
kilogram	7.88308	1.98650^{3}	6.13427^{3}	1.98650
pound$_m$	3.57571	9.01065^{2}	2.78246^{3}	9.01065^{-1}
slug	1.15045^{2}	2.89909^{4}	8.95230^{4}	2.89909^{1}

Values of $R_o\}_x$ for T Measured in ^oR

Mass measured in	Energy measured in Btu	calorie	ft lb$_f$	kcal
gram	4.37949^{-3}	1.10361	3.40792	1.10361^{-3}
kilogram	4.37949	1.10361^{3}	3.40792^{3}	1.10361
pound$_m$	1.98651	5.00592^{2}	1.54581^{3}	5.00592^{-1}
slug	6.39140^{1}	1.61061^{4}	4.97350^{4}	1.61061^{1}

TABLE 22

Molecular Weight

Values of molecular weight, $\{\text{mol wt}\}_{\text{chem}}$, are given below. Molecular weight is based upon the older chemical scale instead of the newest carbon 12 scale, since most existing data is based upon the chemical scale. The relation between the chemical, physical and carbon 12 scales of molecular weights based on data from Ref. 7 is:

$$\{\text{mol wt}\}_{\text{chem}} = .999728\,\{\text{mol wt}\}_{\text{physical}}$$

$$= 1.0000493\,\{\text{mol wt}\}_{\text{carbon 12}}$$

Notice that the gas constant is independent of the unit of molecular weight, since a change in the measure of molecular weight will produce a corresponding change in the measure of the universal gas constant, thereby leaving the gas constant for a particular gas unchanged.

Value of $\{\text{mol wt}\}_{\text{chemical scale}}$ for various gasses

Air	28.966	Hydrogen	2.016
Argon	39.944	Nitrogen	28.016
Carbon Dioxide	44.011	Oxygen	32.000
Carbon Monoxide	28.011	Steam	18.016

TABLE 23

Current (I)

	Abamp ~~Ab. amp~~	Amp	Microamp	Milliamp	Statamp
abamp ~~Ab. amp~~	$\underline{1.00000}$	$\underline{1.00000}^{1}$	$\underline{1.00000}^{7}$	$\underline{1.00000}^{4}$	2.99793^{10}
Amp	$\underline{1.00000}^{-1}$	$\underline{1.00000}$	$\underline{1.00000}^{6}$	$\underline{1.00000}^{3}$	2.99793^{9}
Microamp	$\underline{1.00000}^{-7}$	$\underline{1.00000}^{-6}$	$\underline{1.00000}$	$\underline{1.00000}^{-3}$	2.99793^{3}
Milliamp	$\underline{1.00000}^{-4}$	$\underline{1.00000}^{-3}$	$\underline{1.00000}^{3}$	$\underline{1.00000}$	2.99793^{6}
Statamp	3.33563^{-11}	3.33563^{-10}	3.33563^{-4}	3.33563^{-7}	$\underline{1.00000}$

23. CURRENT

TABLE 24

Charge (q)

Abcoulombs

	Ab coulombs	Amp sec	Coulombs	Statcoulombs
Ab coulombs	1.00000	1.00000^{1}	1.00000^{1}	2.99793^{10}
Amp sec	1.00000^{-1}	1.00000	1.00000	2.99793^{9}
Coulombs	1.00000^{-1}	1.00000	1.00000	2.99793^{9}
Statcoulombs	3.33563^{-11}	3.33563^{-10}	3.33563^{-10}	1.00000

24. CHARGE

TABLE 25

Potential (E)

abvolt

	Ab/ volt	Ft lb_f/amp sec	Microvolt	Millivolt	Statvolt	Volts
Ab/ volt	$\underline{1.00000}$	7.37562^{-9}	$\underline{1.00000^{-2}}$	$\underline{1.00000^{-5}}$	3.33563^{-11}	$\underline{1.00000^{-8}}$
Ft lb_f/amp sec	1.35582^{8}	$\underline{1.00000}$	1.35582^{6}	1.35582^{3}	4.52252^{-3}	1.35582
Microvolt	$\underline{1.00000^{2}}$	7.37562^{-7}	$\underline{1.00000}$	$\underline{1.00000^{-3}}$	3.33563^{-9}	$\underline{1.00000^{-6}}$
Millivolt	$\underline{1.00000^{5}}$	7.37562^{-4}	$\underline{1.00000^{3}}$	$\underline{1.00000}$	3.33563^{-6}	$\underline{1.00000^{-3}}$
Statvolt	2.99793^{10}	2.21116^{2}	2.99793^{8}	2.99793^{5}	$\underline{1.00000}$	2.99793^{2}
Volts	$\underline{1.00000^{8}}$	7.37562^{-1}	$\underline{1.00000^{6}}$	$\underline{1.00000^{3}}$	3.33563^{-3}	$\underline{1.00000}$

25. POTENTIAL

TABLE 26

Capacitance (C)

Abfarad

	Ab farad	Amp^2 sec^2/ft lb$_f$	Farad	Microfarad	Millifarad	Statfarad
Ab farad	1.00000	1.35582^{9}	1.00000^{9}	1.00000^{15}	1.00000^{12}	8.98758^{20}
Amp^2 sec^2/ft lb$_f$	7.37562^{-10}	1.00000	7.37562^{-1}	7.37562^{5}	7.37562^{2}	6.62890^{11}
Farad	1.00000^{-9}	1.35582	1.00000	1.00000^{6}	1.00000^{3}	8.98758^{11}
Microfarad	1.00000^{-15}	1.35582^{-6}	1.00000^{-6}	1.00000	1.00000^{-3}	8.98758^{5}
Millifarad	1.00000^{-12}	1.35582^{-3}	1.00000^{-3}	1.00000^{3}	1.00000	8.98758^{8}
Statfarad	1.11265^{-21}	1.50855^{-12}	1.11265^{-12}	1.11265^{-6}	1.11265^{-9}	1.00000

26. CAPACITANCE

TABLE 27

Inductance (L)

Abhenry

	Ab henry	Ft lb_f/amp^2	Henry	Microhenry	Millihenry	Stathenry
Ab henry	$\underline{1.00000}$	7.37562^{-10}	$\underline{1.00000}^{-9}$	$\underline{1.00000}^{-3}$	$\underline{1.00000}^{-6}$	1.11265^{-21}
Ft lb_f/amp^2	1.35582^{9}	$\underline{1.00000}$	1.35582	1.35582^{6}	1.35582^{3}	1.50855^{-12}
Henry	$\underline{1.00000}^{9}$	7.37562^{-1}	$\underline{1.00000}$	$\underline{1.00000}^{6}$	$\underline{1.00000}^{3}$	1.11265^{-12}
Microhenry	$\underline{1.00000}^{3}$	7.37562^{-7}	$\underline{1.00000}^{-6}$	$\underline{1.00000}$	$\underline{1.00000}^{-3}$	1.11265^{-18}
Millihenry	$\underline{1.00000}^{6}$	7.37562^{-4}	$\underline{1.00000}^{-3}$	$\underline{1.00000}^{3}$	$\underline{1.00000}$	1.11265^{-15}
Stathenry	8.98758^{20}	6.62890^{11}	8.98758^{11}	8.98758^{17}	8.98758^{14}	$\underline{1.00000}$

27. INDUCTANCE

TABLE 28

Resistance (R)

Abohms

	Ab ohms	Ft lb_f/amp^2 sec	Microhms	Milliohms	Ohms	Statohms
Ab ohms	1.00000	7.37562^{-10}	1.00000^{-3}	1.00000^{-6}	1.00000^{-9}	1.11265^{-21}
Ft lb_f/amp^2 sec	1.35582^{9}	1.00000	1.35582^{6}	1.35582^{3}	1.35582	1.50855^{-12}
Microhms	1.00000^{3}	7.37562^{-7}	1.00000	1.00000^{-3}	1.00000^{-6}	1.11265^{-18}
Milliohms	1.00000^{6}	7.37562^{-4}	1.00000^{3}	1.00000	1.00000^{-3}	1.11265^{-15}
Ohms	1.00000^{9}	7.37562^{-1}	1.00000^{6}	1.00000^{3}	1.00000	1.11265^{-12}
Statohms	8.98758^{20}	6.62890^{11}	8.98758^{17}	8.98758^{14}	8.98758^{11}	1.00000

28. RESISTANCE

TABLE 29

Resistivity (ρ)

	Ft^{2} lb$_{f}$/amp^{2} sec	Microhm cm	Milliohm cm	Ohm cir mil/ft	Ohm cm	Ohm ft	Ohm in.	Ohm meter
Ft^{2} lb$_{f}$/amp^{2} sec	1.00000	4.13253^{7}	4.13253^{4}	2.48584^{8}	4.13253^{1}	1.35582	1.62698^{1}	4.13253^{-1}
Microhm cm	2.41982^{-8}	1.00000	1.00000^{-3}	6.01531	1.00000^{-6}	3.28084^{-8}	3.93701^{-7}	1.00000^{-8}
Milliohm cm	2.41982^{-5}	1.00000^{3}	1.00000	6.01531^{3}	1.00000^{-3}	3.28084^{-5}	3.93701^{-4}	1.00000^{-5}
Ohm cir mil/ft	4.02278^{-9}	1.66243^{-1}	1.66243^{-4}	1.00000	1.66243^{-7}	5.45415^{-9}	6.54498^{-8}	1.66243^{-9}
Ohm cm	2.41982^{-2}	1.00000^{6}	1.00000^{3}	6.01531^{6}	1.00000	3.28084^{-2}	3.93701^{-1}	1.00000^{-2}
Ohm ft	7.37562^{-1}	3.04800^{7}	3.04800^{4}	1.83347^{8}	3.04800^{1}	1.00000	1.20000^{1}	3.04800^{-1}
Ohm in.	6.14635^{-2}	2.54000^{6}	2.54000^{3}	1.52790^{7}	2.54000	8.33333^{-2}	1.00000	2.54000^{-2}
Ohm meter	2.41982	1.00000^{8}	1.00000^{5}	6.01531^{8}	1.00000^{2}	3.28084	3.93701^{1}	1.00000

29. RESISTIVITY

TABLE 30

Surface Current (j)

	Amp/cir mil	Amp/cm^2	Amp/ft^2	Amp/in.^{2}	Amp/m^2	Amp/mil^2	Amp/mm^2
Amp/cir mil	$\underline{1.00000}$	1.97353^{5}	1.83347^{8}	1.27324^{6}	1.97353^{9}	1.27324	1.97353^{3}
Amp/cm^2	5.06707^{-6}	$\underline{1.00000}$	9.29030^{2}	6.45160	$\underline{1.00000^{4}}$	6.45160^{-6}	1.00000^{-2}
Amp/ft^2	5.45415^{-9}	1.07639^{-3}	$\underline{1.00000}$	6.94444^{-3}	1.07639^{1}	6.94444^{-9}	1.07639^{-5}
Amp/in.^{2}	7.85398^{-7}	1.55000^{-1}	$\underline{1.44000^{2}}$	$\underline{1.00000}$	1.55000^{3}	$\underline{1.00000^{-6}}$	1.55000^{-3}
Amp/m^2	5.06707^{-10}	$\underline{1.00000^{-4}}$	9.29030^{-2}	6.45160^{-4}	$\underline{1.00000}$	6.43160^{-10}	$\underline{1.00000^{-6}}$
Amp/mil^2	7.85398^{-1}	1.55000^{5}	$\underline{1.44000^{8}}$	$\underline{1.00000^{6}}$	1.55000^{9}	$\underline{1.00000}$	1.55000^{3}
Amp/mm^2	5.06707^{-4}	$\underline{1.00000^{2}}$	9.29030^{4}	6.45160^{2}	$\underline{1.00000^{6}}$	6.45160^{-4}	$\underline{1.00000}$

30. SURFACE CURRENT

TABLE 31

Magnetic Flux (ϕ)

	Ft lb_f/amp	Kilolines	Maxwells	Webers
Ft lb_f/amp	$\underline{1.00000}$	1.35582^{5}	1.35582^{8}	1.35582
Kilolines	7.37562^{-6}	$\underline{1.00000}$	$\underline{1.00000}^{3}$	$\underline{1.00000}^{-5}$
Ab. Maxwells	7.37562^{-9}	$\underline{1.00000^{-3}}$	$\underline{1.00000}$	$\underline{1.00000}^{-8}$
Webers (volt sec)	7.37562^{-1}	$\underline{1.00000^{5}}$	$\underline{1.00000^{8}}$	$\underline{1.00000}$

31. MAGNETIC FLUX

TABLE 32

Electric Field Intensity (ξ)

	Lb_f/amp sec	Volt/cm	Volt/ft	Volt/in.	Volt/meter	Volt/mil
Lb_f/amp sec	1.00000	4.44823^{-2}	1.35582	1.12985^{-1}	4.44823	1.12985^{-4}
Volts/cm	2.24809^{1}	1.00000	3.04800^{1}	2.54000	1.00000^{2}	2.54000^{-3}
Volts/ft	7.37562^{-1}	3.28084^{-2}	1.00000	8.33333^{-2}	3.28084	8.33333^{-5}
Volts/in.	8.85075	3.93701^{-1}	1.20000^{1}	1.00000	3.93701^{1}	1.00000^{-3}
Volts/meter	2.24809^{-1}	1.00000^{-2}	3.04800^{-1}	2.54000^{-2}	1.00000	2.54000^{-5}
Volts/mil	8.85075^{3}	3.93701^{2}	1.20000^{4}	1.00000^{3}	3.93701^{4}	1.00000

32. ELECTRIC FIELD INTENSITY

TABLE 33

Magnetic Field Intensity (H)

	Amp/cm	Amp/ft	Amp/in.	Amp/meter	Oersted	Praoersted
Amp/cm	1.00000	3.04800^{1}	2.54000	1.00000^{2}	1.25664	1.25664^{3}
Amp/ft	3.28084^{-2}	1.00000	8.33333^{-2}	3.28084	4.12282^{-2}	4.12282^{1}
Amp/in.	3.93701^{-1}	1.20000^{1}	1.00000	3.93701^{1}	4.94738^{-1}	4.94738^{2}
Amp/meter	1.00000^{-2}	3.04800^{-1}	2.54000^{-2}	1.00000	1.25664^{-2}	1.25664^{1}
Oersted	7.95775^{-1}	2.42552^{1}	2.02127	7.95775^{1}	1.00000	1.00000^{3}
Praoersted	7.95775^{-4}	2.42552^{-2}	2.02127^{-3}	7.95775^{-2}	1.00000^{-3}	1.00000

33. MAGNETIC FIELD INTENSITY

TABLE 34

Magnetic Flux Density (B)

	Gauss	Lines/in.^{2}	Lb/amp ft	Webers/ft^2	Webers/meter^2
Gauss	1.00000	6.45161	6.85218^{-6}	9.29030^{-6}	1.00000^{-4}
Lines/in.^{2}	1.55000^{-1}	1.00000	1.06209^{-6}	1.44000^{-6}	1.55000^{-5}
Lb/amp ft	1.45939^{5}	9.41540^{5}	1.00000	1.35582	1.45939^{1}
Webers/ft^2	1.07639^{5}	6.94445^{5}	7.37562^{-1}	1.00000	1.07639^{1}
Webers/meter^2	1.00000^{4}	6.45161^{4}	6.85218^{-2}	9.29030^{-2}	1.00000

34. MAGNETIC FLUX DENSITY