Symbols & Formulae

SI UNITS AND SYMBOLS

SI Base Units

Quantity	Unit Symbol	Unit Name
Length	m	meter
Mass	kg	kilogram
Time	s	second
Electric current	A	Ampere
Temperature	K	Kelvin
Luminous intensity	cd	candela

Decimal Multiples and Sub-multiples

Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deca	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f
10^{-18}	atto	a

DERIVED UNITS
Geometrical

Symbol	Quantity	Symbol	Unit Name
l,s	length, distance	m	meter
A	area	m^2	square meter
V	volume	m^3	cubic meter
α, β, γ, etc.	plane angle	rad	radian
		°	degree
α, β, γ, etc.	solid angle		steradian

Time-related

Symbol	Quantity	Unit Symbol	Unit name
t	time	s	second
τ	time constant	s	second
u,v	velocity	ms^{-1}	meter per second
a	acceleration	ms^{-2}	meter per second per second
ω	angular velocity	rad s^{-1}	radian per second
α	angular acceleration	rad s^{-2}	radian per second per second
f	frequency	Hz	Hertz
n	rotational frequency	s^{-1}	(revolution) per second

Mechanical

Symbol	Quantity	Unit Symbol	Unit name
m	mass	kg	kilogram
F	force	N	Newton
G (W)	weight	N	Newton
J	moment of inertia	kgm^2	kilogram meter squared
M (T)	torque	kgm	kilogram meter
W (E)	work (energy)	J	Joule
P	power	W	Watt
p	pressure	Pa	Pascal
E	modulus of elasticity	Pa	Pascal
σ	stress	Pa	Pascal
ρ	density	kgm^{-3}	kilogram per cubic meter
δx	rate of flow	m^3s^{-1}	cubic meter per second
k, k_1, etc.	any constant factor		

Protective Enclosures

IP AND NEMA

Protective Enclosures - Non-hazardous Areas IP Protection

IP Protection is a European system of classification which is widely accepted internationally, and indicates the degree of protection against the ingress of solid objects, dust, liquids and personal contact.

The first numeral indicates the degree of protection against the ingress of solid objects (including parts of the body) and dust. The second numeral indicates the degree of protection against the ingress of water.

IP Enclosure - First Numeral

1st Numeral	Degree of Protection	
	Short Description	Definition
0	Non-protected	No special protection
1	Protected against solid objects greater than 50mm	A large surface of the body, such as a hand (but no protection against deliberate access). Solid objects exceeding 50mm in diameter.
2	Protected against solid objects greater than 12mm	Fingers or similar objects not exceeding 80mm in length. Solid objects exceeding 12mm in diameter.
3	Protected against solid objects greater than 2.5mm	Tools, wires, etc. of diameter or thickness greater than 2.5mm. Solid objects exceeding 2.5mm in diameter.
4	Protected against solid objects greater than 1.0mm	Wires, or strips of thickness greater than 1.0mm. Solid objects exceeding 1.0mm in diameter.
5	Dust-protected	Ingress of dust is not totally prevented but does not enter in sufficient quantity to interfere with satisfactory operation of the equipment.
6	Dust-tight	No ingress of dust.

IP Enclosure - Second Numeral

2nd Numeral	Degree of Protection	
	Short Description	Definition
0	Non-protected	No special protection
1	Protected against dripping water	Dripping water (vertically falling drops) shall have no harmful effect.
2	Protected against dripping water when tilted up to 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at any angle up to 15° from its normal position.
3	Protected against spraying water	Water falling as a spray at an angle up to 60° from the vertical shall have no harmful effect.
4	Protected against splashing water	Water sprayed against the enclosure from any direction shall have no harmful effect.
5	Protected against water jets	Water projected by a nozzle against the enclosure from any direction shall have no harmful effect.
6	Projected against heavy seas	Water from heavy seas or water projected in powerful jets shall not enter the enclosure in harmful quantities.
7	Protected against the effects of immersion	Ingress of water in a harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time.

NEMA and UL Standards

The North American Electrical Manufacturers Association (NEMA) and Underwriters Laboratories Inc. (UL) enclosure standards designate by means of a type number the environmental conditions for which an enclosure is suitable. A particular enclosure may have more than one type number.

The table below summarizes the type designations of NEMA 250; the designators specified by UL50 and UL508 are substantially the same, with differences of detail only in the description; for further information, reference should be made to the standard specification.

NEMA Standards 250 1.109. 1979

Type Designation	Intended Use and Description
1	Enclosure intended for indoor use primarily to provide a degree of protection against contact with the enclosed equipment.
2	Enclosure intended for indoor use primarily to provide a degree of protection against limited amounts of falling water and dirt.
3	Enclosure intended for outdoor use primarily to provide a degree of protection against windblown dust, rain, sleet and external ice formation.
3R	Enclosure intended for outdoor use primarily to provide a degree of protection against falling rain, sleet and external ice formation.
4	Enclosure intended for indoor or outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water and hose-directed water.
4X	Enclosure intended for indoor or outdoor use primarily to provide a degree of protection against corrosion, windblown dust and rain, splashing water and hose-directed water.
12	Enclosure intended for indoor use primarily to provide a degree of protection against dust, falling dirt and dripping non-corrosive liquid.
13	Enclosure intended for outdoor use primarily to provide a degree of protection against dust, spraying water, oil and non-corrosive liquid.

Comparison of NEMA Type Numbers to IEC Classification Designations

Not to be used to convert IEC Classifications Designations to NEMA Numbers

NEMA Enclosure Type Number	IEC Enclosure Classification Designation
1	IP10
2	IP11
3	IP54
3R	IP14
3S	IP54
4 and 4X	IP56
5	IP52
6 and 6P	IP 67
12 and 12K	IP 52
13	IP54

Note:This comparison is based on tests specified in IEC Publication 529; 1976.

Electrical Formulae

Electrical Quantities

Quantity	Symbol	Unit Name	Unit Symbol
Electromotive force	E, e*	Volt	V
Potential difference	V, v*	Volt	V
Current	I, i*	Ampere	A
Magnetic flux	Φ	Weber	Weber
Frequency	f	Hertz	Hz
Flux linkage	λ	Weber-turns	-
Resistance	R	Ohm	Ω
Inductance	L	Henry	H
Capacitance	C	Farad	F
Impedance	Z	Ohm	Ω
Reactance	X	Ohm	Ω
Power,dc,or active	P	Watt	W
Power, reactive	Q	Volt-ampere reactive	VAr, var
Power, total or apparent	S	Volt-ampere	VA
Power factor angle	φ	-	°, deg.
Angular velocity	ω	Radians per second	$rads^{-1}$
Rotational velocity	n	Revolutions per second	s^{-1} ,rev s^{-1}
		Revolutions per minute	min^{-1}, rpm
Efficiency	η	-	
Number of pairs of poles	p	-	

** Capital and small letters designate rms and instantaneous value respectively.*

AC Single-Phase

All quantities r.m.s. values:

V = I Z

Total or apparent power in VA = $V_l = I^2Z = V^2/Z$

Active power in watts, W = $V_l \cos\varphi$

Reactive power in VAr = $V_l \sin\varphi$

AC Three-Phase

(Assuming Balanced Symmetrical Waveform)

All quantities r.m.s values:

V_l = Line-to-line voltage

V_p = Phase voltage (line-to-neutral)

I_l = line current (wye)

I_p = Phase current (delta)

In a WYE connected circuit, $V_p = V_l/\sqrt{3}$, $V_l = \sqrt{3}V_p$, $I_l = I_p$

In a DELTA connected circuit: $I_p = I_l/\sqrt{3}$, $I_l = \sqrt{3}\, I_p$ $V_l = V_p$

Total of apparent power in VA = $\sqrt{3}\, V_l I_l$

Active power in watts,W = $\sqrt{3}\, V_l I_l \cos\varphi$

Reactive power in VAr = $\sqrt{3}\, V_l I_l \sin\varphi$

Power factor (pf) = cos φ

= Active power / Apparent power

= W / VAr

Three-Phase Induction Motors

All quantities rms values:

kW_{mech} = horsepower x 0.746

$kW_{elec} = \sqrt{3}\, V_l\, I_l \cos\varphi$ at rated speed and load

where V_l = supply voltage I_l = rated full load current

cos φ = rated full load power factor

Efficiency, $\eta = (kW_{mech}/ kW_{elec})$ x 100 per cent

Phase current $I_p = I_l$ for wye connection

$I_p = I_l/\sqrt{3}$ for delta connection

Loads (phase values)

Resistance R, measured in Ohms (no energy storage)

Inductive reactance, $X_L = \omega L = 2\pi fL$ Ohms (stores energy)

Where f = frequency (Hz), L = Inductance (H)

Capacitative reactance, $X_C = 1/(\omega C) = 1/(2\pi f C)$

Where f = frequency (Hz), C = Capacitance (F)

Impedance

Impedance is the algebraic sum of the separate load values thus:

$$Z = \sqrt{(R^2 + X_L^2)} \text{ or } \sqrt{(R^2 + X_C^2)}$$

If R, X_L and X_C are present in series in the same circuit then X_L and X_C may be summated, treating X_C as negative, thus

$$Z = \sqrt{(R^2 + (X_L - X_C)^2)}$$

Electrical Formulae

Ohms Law

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}} \quad \text{or} \quad \text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$$

$$\text{or} \quad \text{Volts} = \text{Amperes} \times \text{Ohms}$$

Power in DC Circuits

$$\text{Horsepower} = \frac{\text{Volts} \times \text{Amperes}}{746}$$

$$\text{Watts} = \text{Volts} \times \text{Amperes}$$

$$\text{Kilowatts} = \frac{\text{Volts} \times \text{Amperes}}{1{,}000}$$

$$\text{Kilowatts-Hours} = \frac{\text{Volts} \times \text{Amperes} \times \text{Hours}}{1{,}000}$$

Power in AC Circuits

Kilovolt-Amperes (KVA):

$$\text{kVA}(1\varnothing) = \frac{\text{Volts} \times \text{Amperes}}{1{,}000}$$

$$\text{kVA}(3\varnothing) = \frac{\text{Volts} \times \text{Amperes} \times 1.73}{1{,}000}$$

Kilowatts (Kw)

$$\text{kW}(1\varnothing) = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor}}{1{,}000}$$

$$\text{kW}(3\varnothing) = \frac{\text{Volts} \times \text{Amperes} \times \text{Power Factor} \times 1.73}{1{,}000}$$

$$\text{Power Factor} = \frac{\text{Kilowatts}}{\text{Kilovolts} \times \text{Amperes}}$$

Other Useful Formulae

Three-Phase (3Ø) Circuits

$$\text{HP} = \frac{E \times I \times \sqrt{3} \times \text{Eff} \times \text{PF}}{746}$$

$$\text{Motor Amps} = \frac{\text{HP} \times 746}{E \times \sqrt{3} \times \text{Eff} \times \text{PF}}$$

$$\text{Motor Amps} = \frac{\text{kVA} \times 1000}{\sqrt{3} \times E}$$

$$\text{Motor Amps} = \frac{\text{kW} \times 1000}{\sqrt{3} \times E \times \text{PF}}$$

$$\text{Power Factor} = \frac{\text{kW} \times 1000}{E \times I \times \sqrt{3}}$$

$$\text{Kilowatt Hours} = \frac{E \times I \times \text{Hours} \times \sqrt{3} \times \text{PF}}{1000}$$

$$\text{Power (Watts)} = E \times I \times \sqrt{3} \times \text{PF}$$

Mechanical Variables

Material Densities		
Materials	**lb/in³**	**gm/cm³**
Aluminum	0.096	2.66
Brass	0.299	8.3
Bronze	0.295	8.17
Copper	0.322	8.91
Hard Wood	0.029	0.8
Soft Wood	0.018	0.48
Plastic	0.04	1.11
Glass	0.079-0.090	2.2-2.5
Titanium	0.163	4.51
Paper	0.025-0.043	0.7-1.2
Polyvinyl chloride	0.047-0.050	1.3-1.4
Rubber	0.033-0.036	0.92-0.99
Silicone Rubber, without filler	0.043	1.2
Cast Iron, gray	0.274	7.6
Steel	0.28	7.75

Friction Coefficients	Ffr=μWL
Materials	**μ**
Steel on Steel (greased)	~0.15
Plastic on Steel	~0.15-0.25
Copper on Steel	~0.30
Brass on Steel	~0.35
Aluminum on Steel	~0.45
Steel on Steel	~0.58
Mechanism	μ
Ball Bushings	<0.001
Linear Bearings	<0.001
Dove-tail Slides	~0.2++
Gibb Ways	~0.5++

Mechanism Efficiencies	
Acme screw with brass nut	~0.35-0.65
Acme screw with plastic nut	~0.50-0.85
Ballscrew	~0.85-0.95
Chain and Sprocket	~0.95-0.98
Preloaded Ballscrew	~0.75-0.85
Spur or Bevel gears	~0.90
Timing Belts	~0.96-0.98
Worm Gears	~0.45-0.85
Helical Gear (1 reduction)	~0.92

Mechanical Formulae

Term	Description	Unit
d	Diameter	m
F	Force	N
g	Acceleration due to gravity	ms^{-2}
J	Total inertia	kgm^2
J_L	Load inertia	kgm^2
J_M	Motor inertia	kgm^2
m	Mass	kg
M	Motor torque	Nm
M_a	Accelerating torque	Nm
M_L	Load torque	Nm
n	Rotational frequency	rpm*
$n1$	- input	rpm*
$n2$	- output	rpm*
Δn	Change of rotational frequency	rpm*
p	Pitch	m
P	Motor power	kW
P_a	Accelerating power	kW
P_L	Load power absorbed	kW
r	Radius	m
s	Distance	m
t	Acceleration time	s
Δt	Acceleration period	s
v	Linear velocity	m/min*
Δv	Change of linear velocity	m/min*
V	Traction capacity	M^3s^{-1}
W	Energy	J (Joule)
η	Efficiency	-
μ	Coefficient of friction	-

Note: For practical convenience, some of the units in the formulae following are not S1 units; for example, rotational frequency is commonly measured in revolutions per minute, although the S1 unit is revolutions per second. In these Servo Formulae, the terms used are as tabulated above.Those which are in non-S1 units are marked *.

Linear Motion

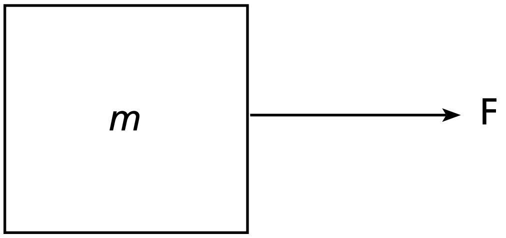

Fig. A

Consider a body mass m acted upon by a single force F, Fig A. The body accelerates in the direction in which the force is acting, at a rate given by:

$$A = F/m$$

After a time t has elapsed, the body has achieved a velocity v, where:

$$v = u + at$$

(u is the initial velocity, before the force F was applied. If the body was initially at rest, u is zero)

The distance, s, travelled by the body during time t is

$$s = ut + at^2/2$$

Distance and velocity are related by the following equation, derived from the two previous ones:

$$v^2 - u^2 = 2as$$

The work done by the force in accelerating the body is the product of force and distance:

$$W = Fs$$

The kinetic energy of the body, ie the energy which it possesses by virtue of its motion, is the product of its mass and the square of its velocity:

$$E_k = mv^2/2$$

Furthermore, since energy is conserved, the work done by the force is equal to the change in the body's kinetic energy (neglecting losses):

$$W = m(v^2 - u^2)/2$$

Power is the rate at which work is done, therefore it is the product of force and velocity:

$$P = Fv$$

Rotational or Angular Motion

$M=Fr$

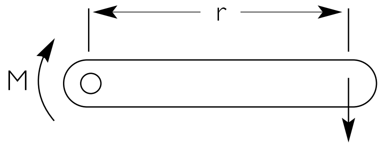

Fig A.11
The concept of torque

A force acting perpendicular to a pivoted lever, Fig A.11, causes a turning effect or torque at the fulcrum. The torque is the product of the force and the radius at which it is applied.

$$M = Fr$$

If a torque is applied to a body which is free to rotate, as in Fig A.12, an acceleration results in a way which is analogous to the example of linear motion above. Indeed a similarity will be noticed between the equations of motion.

Any body which is capable of rotating possesses a property known as Moment of Inertia which tends to resist acceleration in the same way as does the mass of a body in linear motion. The moment of inertia is related not only to the mass of the body, but also to the distribution of that mass with respect to radius.

The moment of inertia of a solid cylinder of radius r is given by:

$$J = mr^2/2$$

By comparison, the moment of inertia of a hollow cylinder, of inner and outer radii respectively, is as follows:

$$J = m(r_o^2 - r_i^2)/2$$

It can be seen that, for a given outer radius, the moment of inertia of a hollow cylinder is greater than that of a solid cylinder of the same mass. In Fig A.12, a body having a moment of inertia J is acted upon by a torque M. Its angular acceleration is:

$$\alpha = M/J$$

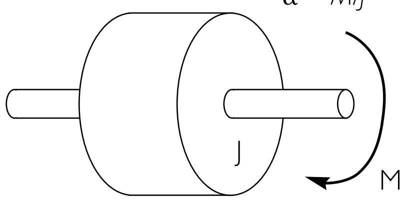

Fig A.12
The Action of torque on a body

After a time t has elapsed, the angular velocity, ω (rate of change of angle) is given by:

$$\omega = \omega_o + \alpha t$$

(wo is the initial angular velocity, before the torque M was applied. If the body was initially at rest, ω_o is zero)

The angle, g, through which the body rotates in time t is:

$$\gamma = \omega_o t + \alpha t^2/2$$

Angle and angular velocity are related by the following equation:

$$\omega^2 - \omega_o^2 = 2\alpha\gamma$$

The work done in accelerating the body is the product of torque and angle of rotation:

$$W = M\gamma$$

The kinetic energy of the body is the product of its moment of inertia and the square of its angular velocity:

$$E_k = J\omega^2/2$$

Since energy is conserved, the work done is equal to the change in kinetic energy (neglecting losses):

$$W = J(\omega^2 - \omega_o^2)/2$$

Power is the product of torque and angular velocity, i.e. the rate at which work is being done:

$$P = M\omega$$

Relationship between linear and angular motion

Consider a body of mass *m* moving in a circle of radius *r* with an angular velocity ω, Fig A.13.

When the body has rotated through an angle γ, it has covered a distance s along circumference of the circle, where:

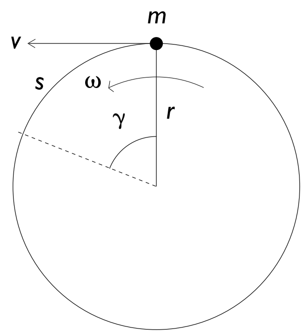

Fig A.13
Relationship between linear and angular motion

Similarly, the tangential velocity or peripheral speed v, being the quotient of distance and time, is given by:

$$v = s/t = \gamma r/t$$

Angular velocity w is the quotient of angle and time;

$$w = \gamma/t$$

Therefore

$$v = wr$$

Similarly, for acceleration:

$$a = v/t = wr/t$$

$$\alpha = w$$

Therefore

$$a = \alpha r$$

The moment of inertia is given by

$$J = mr^2$$

Motor Application Formulae

Calculating Horsepower

Once the machine torque requirement is determined, horsepower can be calculated using the formula:

$$HP = \frac{T \times N}{5{,}250}$$

where,

HP = Horsepower
T = Torque (ft-lb)
N = Base speed of motor (rpm)

If the calculated horsepower falls between standard available motor ratings, select the higher available horsepower rating. It is good practice to allow some margin when selecting the motor horsepower.

For many applications, it is possible to calculate the horsepower required without actually measuring the torque required. The following useful formulae will help:

Conveyors

$$HP\ (\text{Vertical}) = \frac{\text{Weight (lb)} \times \text{Velocity (FPM)}}{33{,}000}$$

$$HP\ (\text{Horizontal}) = \frac{\text{Weight (lb)} \times \text{Velocity (FPM)} \times \text{Coefficient of Friction}}{33{,}000}$$

Web Transport Systems and Surface Winders

$$HP = \frac{\text{Tension (lb)} \times \text{Velocity (FPM)}}{33{,}000}$$

Note: The tension value used in this calculation is the actual web tension for surface winder applications. For sectional drives, it is the tension differential: downstream tension – upstream tension.

Center Winders (Control to Base Speed Only)

$$HP = \frac{\text{Tension (lb)} \times \text{Line Speed (FPM)} \times \text{Buildup}}{33{,}000 \times \text{Taper}}$$

Center Winders (Field Control)

If Taper x Field Range $\geq$ Buildup, then,

$$HP = \frac{\text{Tension (lb)} \times \text{Line Speed (FPM)}}{33{,}000}$$

If Taper x Field Range $\leq$ Buildup, then,

$$HP = \frac{\text{Tension (lb)} \times \text{Line Speed (FPM)} \times \text{Buildup}}{33{,}000 \times \text{Taper} \times \text{Field Range}}$$

NOTE: The preceding formulae for calculating horsepower do not include any allowance for machine function windage or other factors. These factors must be considered when selecting a drive for a machine application.

Fans and Blowers

$$HP = \frac{\text{CFM} \times \text{Pressure (lb/ft}^2)}{33{,}000 \times \text{Efficiency of Fan}}$$

Effect of Speed on HP:

$HP = K_1\ (RPM)^3$ — Horsepower varies as the 3rd power of power of speed.

$T = K_2\ (RPM)^2$ — Torque varies as the 2nd power of speed

$Flow = K_3\ (RPM)$ — Flow varies directly as the speed

$$HP = \frac{\text{CFM} \times \text{Pressure (lb/in}^2)}{229 \times \text{Efficiency of Fan}}$$

$$HP = \frac{\text{CFM} \times \text{Inches of Water Gauge}}{6356 \times \text{Efficiency of Fan}}$$

Pumps

$$HP = \frac{\text{GPM} \times \text{Head (ft)} \times \text{Specific Gravity}}{3960 \times \%\ \text{Efficiency of Pump}}$$

Specific Gravity of Water = 1.0
1 ft^3 per sec. = 448 GPM
1 PSI = A head of 2.309 ft for water weighing 62.36 lb/ft^3 at 62°F

Constant Displacement Pumps

Effect of Speed on HP:

$HP = K\ (RPM)$ — Horsepower and capacity vary directly as the speed.

Displacement pumps under constant head require approximately constant torque at all speeds.

Centrifugal Pumps

Effect of Speed on HP:

$HP = K_1\ (RPM)^3$ — Horsepower varies as the 3rd power of speed.

$T = K_2\ (RPM)^2$ — Torque varies as the 2nd power of speed.

$Flow = K_3\ (RPM)$ — Flow varies directly as the speed.

Efficiency:

500 to 1,000 gal/min	= 70% to 75%
1,000 to 1,500 gal/min	= 75% to 80%
Larger than 1,500 gal/min	= 80% to 85%

Displacement pumps may vary between 50% and 80% efficiency, depending on size of pumps.

Mechanical Conversion Table

Length

	mm	cm	m	inch	foot	yard	km	Mile
mm	1	10^{-1}	10^{-3}	3.937×10^{-2}	3.280×10^{-3}	1.093×10^{-3}	10^{-6}	6.213×10^{-7}
cm	10	1	10^{-2}	3.937×10^{-1}	3.280×10^{-2}	1.093×10^{-2}	10^{-5}	6.213×10^{-6}
m	1000	100	1	39.370	3.28084	1.09361	10^{-3}	6.213×10^{-4}
Inch	25.4	2.54	2.54×10^{-2}	1	8.333×10^{-2}	2.777×10^{-2}	2.54×10^{-5}	1.578×10^{-5}
foot	304.8	30.48	3.048×10^{-1}	12	1	3.333×10^{-1}	3.048×10^{-4}	1.893×10^{-4}
yard	914.4	91.44	9.144×10^{-1}	36	3	1	9.144×10^{-4}	5.681×10^{-4}
km	10^{6}	10^{5}	1000	39370.1	3280.84	1093.61	1	6.213×10^{-1}
mile	1.609×10^{6}	160934	1609.34	63360	5280	1760	1.609	1

Mass

	g	kg	oz	lb	US ton
g	1	10^{-3}	3.5274×10^{-2}	2.204×10^{-3}	$1. 102 \times 10^{-6}$
kg	1000	1	35.274	2.20462	1.102×10^{-3}
oz	28.2495	2.835×10^{-2}	1	6.25×10^{-2}	3.125×10^{-5}
lb	453.592	4.536×10^{-1}	16	1	5×10^{-4}
US ton	907185	907.185	32	2000	1

Energy

	J	Wh	kp m	k cal	BTU
J	1	2778×10^{-4}	1.019×10^{-1}	2.388×10^{-4}	9.478×10^{-4}
Wh	3600	1	367.098	8.598×10^{-1}	3.412
kp m	9.807	2.724×10^{-3}	1	2.342×10^{-3}	9.295×10^{-3}
k cal	4186.8	1.163	426.935	1	3.968
BTU	1055.06	$2.93\ 1 \times 10^{-1}$	107.586	2.519×10^{-1}	1

Area

	cm^2	m^2	are	hect.	km^2	$inch^2$	$foot^2$	$yard^2$	$mile^2$	acre
cm^2	1	10^{-4}	10^{-6}	10^{-8}	10^{-10}	1.55×10^{-1}	1.076×10^{-3}	1.196×10^{-4}	3.861×10^{-11}	2.471×10^{-8}
m^2	10000	1	10^{-2}	10^{-4}	10^{-6}	1550	10.7639	1.19599	3.861×10^{-7}	2.471×10^{-4}
are	10^6	100	1	10^{-2}	10^{-4}	155000	1076.39	119599	3.861×10^{-5}	2.471×10^{-2}
hectare	10^8	10000	100	1	10^{-2}	1.55×10^7	107639	11959.9	3.861×10^{-3}	2.47105
km^2	10^{10}	10^6	10000	100	1	1.55×10^9	1.076×10^7	1.196×10^6	3.861×10^{-1}	247.105
$inch^2$	6.4516	6.4516×10^{-4}	6.4516×10^{-6}	6.4516×10^{-8}	6.4516×10^{-10}	1	6.944×10^{-3}	7.716×10^{-4}	2.491×10^{-10}	1.594×10^{-7}
$foot^2$	929.03	9.2903×10^{-2}	9.2903×10^{-4}	9.2903×10^{-6}	9.2903×10^{-8}	144	1	1.1111×10^{-1}	3.587×10^{-8}	2.295×10^{-5}
$yard^2$	8.36127	8.36127×10^{-1}	8.36127×10^{-3}	8.36127×10^{-5}	8.36127×10^{-7}	1296	9	1	3.228×10^{-7}	2.066×10^{-4}
$mile^2$	2.589×10^{10}	2.589×10^6	25899.9	258.999	2.58999	4.014×10^9	2.787×10^7	2.0976×10^6	1	640
acre	4.046×10^7	4046.86	40.4686	4.04686×10^{-1}	4.04686×10^{-3}	6.272×106	43560	4840	1.5625×10^{-3}	1

Volume

	cm^3	dm^3 (=litre)	$inch^3$	$foot^3$	$yard^3$	US fl oz	Imp fl oz	US gal	Imp gal	Imp pint
cm^3	1	10^{-3}	6.102×10^{-2}	3.531×10^{-5}	1.308×10^{-6}	3.3814×10^{-2}	3.519×10^{-2}	2.641×10^{-4}	2.199×10^{-4}	1.759×10^{-3}
dm^3	1000	1	61.0237	3.531×10^{-2}	1.308×10^{-3}	33.814	35.1951	2.641×10^{-1}	2.199×10^{-1}	1.75975
$inch^3$	16.3871	1.638×10^{-2}	1	5.787×10^{-4}	2.143×10^{-5}	5.541×10^{-1}	5.767×10^{-1}	4.329×10^{-3}	3.604×10^{-3}	2.883×10^{-2}
$foot^3$	28316.8	28.3168	1728	1	3.7037×10^2	957.506	996.614	7.48052	6.22884	49.8307
$yard^3$	764555	764.555	46656	27	1	25852.7	26.908.6	201.974	168.179	1345.43
US fl oz	29.5735	2.957×10^{-2}	1.80469	1.044×10^{-3}	3.868×10^{-5}	1	1.04084	7.8125×10^{-3}	6.505×10^{-3}	5.204×10^{-2}
Imp fl oz	28.4131	2.841×10^{-2}	1.73387	1.003×10^{-3}	3.716×10^{-5}	9.6076×10^{-1}	1	7.506×10^{-3}	6.25×10^{-3}	5×10^{-2}
US gal	3785.41	3.78541	231	1.336×10^{-1}	4.951×10^{-3}	128	133.228	1	8.326×10^{-1}	6.66139
Imp gal	4546.09	4.54609	277.149	1.605×10^{-1}	5.946×10^{-3}	153.772	160	1.20095	1	8
Imp pint	568.261	5.682×10^{-1}	34.6774	2.0068×10^{-2}	7.432×10^{-4}	19.2152	20	1.501×10^{-1}	1.25×10^{-1}	1

Inertia

	kg cm^2	kp cm s^2	kg m^2	kp m s^2	oz in^2	oz in s^2	lb in^2	lb in s^2	lb ft^2	lb ft s^2
kg cm^2	1	1.019×10^{-3}	10^{-4}	1.019×10^{-5}	5.467	1.416×10^{-2}	3.417×10^{-1}	8.850×10^{-4}	2.373×10^{-3}	7.375×10^{-5}
kp cm s^2	980.665	1	9.806×10^{-12}	10^{-2}	5361.76	13.8874	335.11	8.679×10^{-1}	2.32715	7.233×10^{-2}
kg m^2	10^4	10.1927	1	1.019×10^{-1}	54674.8	141.612	3417.17	8.851	23.7304	7.375×10^{-1}
kp m s^2	98066.5	100	9.86065	1	536176	1388.74	33.511	86.796	232.715	7.23301
oz in^2	1.829×10^{-1}	1.865×10^{-4}	1.829×10^{-5}	1.865×10^{-6}	1	2.590×10^{-3}	6.25×10^{-2}	1.6188×10^{-4}	2.340×10^{-4}	7.349×10^{-5}
oz in s^2	70.6155	7.201×10^{-2}	7.061×10^{-3}	7.200×10^{-4}	386.089	1	24.1305	6.25×10^{-2}	1.675×10^{-1}	5.208×10^{-3}
lb in^2	2.926	2.984×10^{-3}	2.9264×10^{-4}	2.984×10^{-5}	16	4.144×10^{-2}	1	2.590×10^{-3}	6.944×10^{-3}	2.1548×10^{-4}
lb in s^2	1129.85	1.15212	1.29×10^{-1}	1.152×10^{-2}	6177.42	16	386.089	1	2.68117	8.333×10^{-2}
lb ft^2	421.401	4.297×10^{-1}	4.214×10^{-2}	4.2971×10^{-3}	2304	5.96754	144	3.729×10^{-1}	1	3.108×10^{-2}
lb ft s^2	13558.2	13.826	1.355	1.382×10^{-1}	74129	192	4633.06	12	32.174	1

Torque

	N cm	Nm	kp cm	kp m	p cm	oz in	in lb	ft lb
N cm	1	10-2	1.019×10^{-1}	1.019×10^{-3}	101.972	1.41612	8.850×10^{-2}	7.375×10^{-3}
Nm	100	1	10.1972	1.019×10^{-1}	10197.2	141.612	8.851	7.375×10^{-1}
kp cm	9.80665	9.806×10^{-2}	1	10^{-2}	1000	13.8874	8.679×10^{-1}	7.233×10^{-2}
kp m	980.665	9.80665	100	1	10^5	1388.74	86.7962	7.233
p cm	9.806×10^{-3}	9.806×10^{-5}	10^{-3}	10^{-5}	1	1.388×10^{-2}	8.679×10^{-4}	7.233×10^{-5}
oz in	7.061×10^{-1}	7.061×10^{-3}	7.200×10^{-2}	7.200×10^{-4}	72.0078	1	6.25×10^{-2}	5.208×10^{-3}
in lb	11.2985	1.129×10^{-1}	1.15212	1.152×10^{-2}	1152.12	16	1	8.333×10^{-2}
ft lb	135.582	1.35582	13.8225	1.382×10^{-1}	13825.5	192	12	1

Force

	N	kp	p	oz	lbf
N	1	1.019×10^{-1}	101.972	3.59694	2.248×10^{-1}
kp	9.80665	1	1000	35.274	2.20462
p	9.806×10^{-3}	10^{-3}	1	3.5274×10^{-2}	2.204×10^{-3}
oz	2.780×10^{-1}	2.835×10^{-2}	28.3595	1	6.25×10^{-2}
lbf	4.44822	4.536×10^{-1}	453.592	16	1

Power

	kW	PS	hp	kp m s^{-1}	kcal s^{-1}
kW	1	1.35962	1.34102	101972	2.388×10^{-1}
PS	7.355×10^{-1}	1	9.8632×10^{-1}	75	1.756×10^{-1}
hp	7.457×10^{-1}	1.01387	1	76.0402	1.781×10^{-1}
kp ms^{-1}	9.806×10^{-3}	1.333×10^{-2}	$1.35\ 15 \times 10^{-2}$	1	2.342×10^{-3}
kcals^{-1}	4.1868	5.69246	5.61459	426.935	1

General Conversation Tables

Length

SI UNIT - meter (m)		
To convert from:	To:	Multiply by:
Mile	m	1609.344
Nautical Mile	m	1853
km	m	10^3
cm	m	10^{-2}
mm	m	10^{-3}
yd	m	0.914
ft	m	0.305
in	m	2.54×10^{-2}
mil	m	2.54×10^{-5}

Area

SI UNIT - square meter (m^2)		
To convert from:	To:	Multiply by:
Square Miles	m^2	2.59×10^6
Acre	m^2	4047
Hectare ha	m^2	10^4
Km^2 (sq. km)	m^2	10^6
cm^2	m^2	10^{-4}
mm^2	m^2	10^{-6}
yd^2	m^2	0.836
ft^2	m^2	9.29×10^{-2}
in^2	m^2	6.45×10^{-4}
mil^2	m^2	6.45×10^{-10}

Volume

SI UNIT - cubic meter (m^3)		
To convert from:	To:	Multiply by:
yd^3	m^3	0.765
ft^3	m^3	2.83×10^{-2}
in^3	m^3	1.64×10^{-4}
dm^3	m^3	10^{-3}
Litre	m^3	10^{-3}
Gallon (Imperial)	m^3	4.55×10^{-3}
Gallon (U.S.)	m^3	3.79×10^{-3}
Pint (Imperial)	m^3	5.68×10^{-4}
Pint (U.S.)	m^3	4.73×10^{-4}

Mass

SI UNIT - kilogram (kg)		
To convert from:	To:	Multiply by:
ton (Imperial)	kg	1016
ton (U.S.)	kg	907.2
tonne (metric)	kg	10^3
slug	kg	14.59
lb	kg	0.454
oz	kg	2.84×10^{-2}
g	kg	10^{-3}

Force and Weight

SI UNIT - Newton (N)		
To convert from:	To:	Multiply by:
tonf (ton wt)	N	9964
lbf (lb wt)	N	4.448
poundal	N	0.138
ozf (oz wt)	N	0.278
kp	N	9.807
p	N	9.81×10^{-2}
kgf (kg wt)	N	9.807
gf (g wt)	N	9.81×10^{-2}
dyn	N	10^{-5}

Pressure and Stress

SI UNIT - Pascal (Pa)		
To convert from:	To:	Multiply by:
at (technical atmosphere)	Pa	9.81×10^3
in WG	Pa	248.9
mm WG	Pa	10.34
in HG	Pa	3385
mm HG (torr)	Pa	131
kp cm^{-2}	Pa	9.81×10^3
Nm^{-2}	Pa	1
bar	Pa	10^5
lbf ft^{-2}	Pa	47.88
lbf in^{-2}	Pa	6895
kgf m^{-2}	Pa	9.807
kgf cm^{-2}	Pa	9.81×10^4

Velocity (Linear)

SI UNIT - meter per second (ms^{-1})		
To convert from:	**To:**	**Multiply by:**
mph (mile per hour)	ms^{-1}	0.447
ft min^{-1}	ms^{-1}	5.08×10^{-3}
fts^{-1}	ms^{-1}	0.305
km h^{-1}	ms^{-1}	0.278
m min^{-1}	ms^{-1}	1.67×10^{-2}
knot	ms^{-1}	0.515

Velocity (Angular)

SI UNIT - radians per second (rad s-1)		
To convert from:	**To:**	**Multiply by:**
rpm (revolutions per min)	$rads^{-1}$	0.1037 ($2\pi/60$)
rs^{-1} (revolutions per sec)	$rads^{-1}$	6.283 (2π)
$°s^{-1}$ (degrees per sec)	$rads^{-1}$	1.75×10^{-2} ($2\pi/360$)

Torque

SI UNIT - Newton meter (Nm)		
To convert from:	**To:**	**Multiply by:**
lbf ft	Nm	1.356
lbf in	Nm	0.113
ozf in	Nm	7.062×10^{-3}
kgf m	Nm	9.807
kp m	Nm	9.807

Energy

SI UNIT - Joule (J)		
To convert from:	**To:**	**Multiply by:**
Btu	J	1.055×10^{3}
therm (10^5 btu)	J	1.055×10^{8}
cal	J	4.187
ft lbf (ft lb wt)	J	1.356
ft poundal	J	0.042

Power

SI UNIT - kilowatt (kW)		
To convert from:	**To:**	**Multiply by:**
hp	kW	0.746
ps	kW	0.736
ch, CV	kW	0.736
Btu s^{-1}	kW	1.055
kcal s^{-1}	kW	4.187
ft lbf s^{-1}	kW	1.36×10^{-3}

Force

SI UNIT - Newton (N)		
To convert from:	To:	Multiply by:
lb(f)	N	4.448
N	lb(f)	0.225

Moment of Inertia

SI UNIT - Kilogram meter² (kgm^2)		
To convert from:	**To:**	**Multiply by:**
lb in s^2	kgm^2	0.113
oz in s^2	kgm^2	7.06155×10^{-2}
kg m^2	lb in s^2	8.85075
kg m^2	oz in s^2	141.612
kg cm^2	kgm^2	10^{-4}
kgf m^2 (GD^2)	kgm^2	0.25
lbf ft^2 (WK^2)	kgm^2	4.21×10^{-2}
kp m s^2	kgm^2	9.807
ft lbf s^2	kgm^2	1.356
lbf in^2	kgm^2	2.926×10^{-4}
ozf in^2	kgm^2	1.829×10^{-5}

Temperature

SI UNIT - Kelvin (K)		
To convert from:	**To:**	**Multiply by:**
°C	K	x 1
t°C	K	t+273.15
°F	K	x 0.5555
t°F	K	(t-32) x 0.5555

Flow

SI UNIT - cubic meter per second (m^3s^{-1})		
To convert from:	**To:**	**Multiply by:**
gallon per hour (Imp)	m^3s^{-1}	1.26×10^{-6}
gallon per hour (US)	m^3s^{-1}	1.05×10^{-6}
litre per hour	m^3s^{-1}	1.67×10^{-5}
litre per second	m^3s^{-1}	10^{-3}
cfm	m^3s^{-1}	4.72×10^{-4}
m^3h^{-1}	m^3s^{-1}	2.78×10^{-4}
m^3min^{-1}	m^3s^{-1}	1.67×10^{-2}

Torque

SI UNIT - Newton meter (Nm)		
To convert from:	**To:**	**Multiply by:**
lb ft	Nm	1.356
lb in	Nm	0.113
oz in	Nm	7.062×10^{-3}
Nm	lb ft	0.738
Nm	lb ft	8.857
Nm	oz in	141.6

Linear Acceleration

SI UNIT - meter per second² (ms^{-2})		
To convert from:	**To:**	**Multiply by:**
ins^{-2}	ms^{-2}	2.54×10^{-2}
fts^{-2}	ms^{-2}	0.305
ms^{-2}	ins^{-2}	39.37
ms^{-2}	fts^{-2}	3.281