Nomenclature and symbols

APR	axial power rating
BJT	bipolar junction transistor
CoP	coefficient of performance
CTE	coefficient of thermal expansion
CVD	chemical vapour deposition
DCB	direct copper bonding
EBL	electron beam lithography
EGS	electronic grade polysilicon
GTO	gate turn-off (thyristor)
IGBT	insulated gate bipolar transistor
LPCVD	low pressure CVD
MBE	molecular beam epitaxy
MFD	magneto-fluid-dynamic
MMF	magnetomotive force
MOSFET	metal oxide semiconductor field effect transistor
mtbf	mean time between failures
mttf	mean time to failure
NTD	neutron transmutation doping
PC	permeance coefficient ($B_d / \mu_o H_d$)
PCM	phase change material
PECVD	plasma enhanced CVD
POH	power on hours
PSG	phospho-silicate glass
PVD	physical vapour deposition
PVT	physical vapour transport
RIE	reactive ion etching
s/b	second breakdown
ScD	skeleton cemented diamond
SCR	silicon controlled rectifier
SOA	safe operating area
TEC	thermoelectric cooler
TIM	thermal interface material

α	gate threshold temperature dependence coefficient
α	temperature coefficient of on-state resistance
α	thermal coefficient of linear expansion, K^{-1}
α	current transfer ratio
α_o	current transfer ratio in mid current region
α_s	characteristic life (hours)
β	base-to-collector current amplification factor
β_f	forward current gain
β_Q	GTO turn-off gain
β_r	reverse current gain
$ß_s$	shape parameter
γ	surface tension, N/m
γ_i	injection efficiency
Γ	gamma function
δ	on-state duty cycle factor
δT, ΔT	temperature difference between regions of heat transfer, $T_2 - T_1$, K
ΔP	system static pressure loss [1Pascal = 1N/m²,]
ΔP_{cmax}	maximum capillary pressure difference between the evaporator and condenser
ΔP_g	hydrostatic pressure drop
ΔP_{liquid}, $\Delta P_{vavpour}$	viscous pressure drops in liquid and vapour phases
P_v	velocity pressure, $½\rho v^2$
ΔT	thermal shock temperature
ΔT	desired air temperature differential (enclosure inlet to discharge ambient air), K
ΔT_{sa}	average temperature difference between heat sink and ambient air

ε	surface property, termed emissivity, $0 \le \varepsilon \le 1$
ε_a	apparent emissivity of a channel
ε_o	free space permittivity, 8.854x10^{-12} F/m
ε_r	relative dielectric constant
ε_s	dielectric permittivity $\varepsilon_s = \varepsilon_r \varepsilon_o$
η_f	fin efficiency
η_v	volumetric heat transfer efficiency
θ	contact angle, rad,
θ_f	volume figure, dimensionless
λ	thermal conductivity, W/cm.K
λ	latent heat, J/kg
λ	wavelength
λ_{eff}	effective thermal conductivity for a heat pipe
μ_n, μ_p	hole/electron mobility, cm^2/V-s
μ_o μ_m μ_{rc}	permeability of vacuum/air, magnet, recoil
v	absolute fluid kinematic viscosity, Ns/m^2, Pa
ξ	electric potential, V/m
ξ_b	breakdown field, V/m
ρ	resistivity, Ω.cm
ρ_m	density of the heatsink material, kg/m^3
ρ_ℓ	density of working fluid (e.g. air, liquid) medium, (= 1/v specific volume), kg/m^3
σ	conductivity, Ω^{-1}.cm^{-1}
σ	Stefen-Boltzmann constant, 5.667×10^{-8} W/m^{2}K^4
σ	surface tension, N/m
σ_p	symmetrical standard deviation, cm
τ	period of the switching interval (both on and off), s
τ	thermal time constant, s
τ_h, τ_e	minority carrier hole/electron lifetime, s
φ	kT/q, thermal voltage, built in potential, V
Φ	zero external bias, built-in, junction potential or scl potential, V
Φ_b	Schottky barrier height
Φ_f	pressure figure, dimensionless parameter
ω	rotational (angular) velocity at the perimeter
A	total surface area (of die/outside/heatsink fins and base between fins) involved in the heat transfer, cooling, m^2
A_e, A_c	effective evaporator and condenser surface areas
A_g, A_m	cross-sectional area of air gap, magnet
A_x	cross sectional area (fin), m^2
b	thickness of the heat sink, mm
b_t	base transport factor
B	magnetic flux density (induction)
B_d	flux density in magnet at operating point on demagnetization curve
B_g	flux density in air gap
$(BH)_{max}$	maximum energy product
B_i	intrinsic flux density (induction) in a magnet
B_r	residual induction in magnet
B_{sat}	saturation flux density
cd	critical line width
c_p	specific heat capacity of the cooling fluid at constant pressure, $W/m\Delta T$, J/kg.K
C	linear rate constant
C_a	capacitance per unit area of the gate oxide, ε / t_{ox}

C_{ds} non-linear voltage-dependent drain to the source capacitance
C_{gd} non-linear voltage-dependent gate to the drain capacitance
C_{gs} non-linear voltage-dependent gate to the source capacitance
C_f correction factor for position and surface emissivity of heat-sink orientation
C_{in} gate input capacitance, approximately $C_{gd} + C_{gs}$, or C_{iss}
C_{iss} input capacitance
$C_j(v)$ voltage dependant scl capacitance, F
C_{jo} zero bias junction capacitance, F
C_{ob} output capacitance, essentially C_{ds}
C_{oss} common source output capacitance
C_r basic dynamic load capacity, kg
C_R correction factor
C_{rss} reverse transfer capacitance
C'_{sf} fluid surface combination constant
$C_t(v)$ voltage dependant transit capacitance, F

d diameter, m
d_1 n^- drift region width
di_F/dt forward current rate of change, A/s
di_{rr}/dt reverse recovery current rate of change, A/s
dm/dt mass evaporation rate
dv/dt anode impressed dv/dt
D diffusion or diffusivity coefficient, $\mu kT/q = \lambda / \gamma c_p$, m^2/s
D_o outer diameter of the fan impeller, m
D_H diameter (hydraulic/bore), mm
D_n, D_p hole/electron carrier diffusivity
DN_L speed limit, rpm-mm

E emf, circuit applied reverse voltage
E_a activation or threshold energy, eV
E_g band gap, eV
E_o diode model on-state voltage source, V

f friction factor (loss coefficient)
f_s switching frequency, Hz
F(t) cumulative distribution function, a function of age t
$\mathfrak{I}_m$ magnetomotive force

g gap
g_f gravitational acceleration, m/s^2
g_{fs} amplification factor, forward *transconductance n-channel,*
g_d output conductance
G volumetric fluid flow rate, m^3/s

h convection/conduction thermal heat transfer coefficient (of surface material) W/m^{2}K
h_r radiation heat transfer coefficient, W/m^{2}K
H capillary or lifting height, height of the fin, length (of heat sink base), m
HP impeller input power to rotate
H(t) hazard rate, failure rate or hazard function
H magnetic field strength, magnetizing force, demagnetizing force
H_c coercive force
H_{ci} intrinsic coercive force
H_d demagnetizing force at operating point of magnet on demagnetization curve
H_g magnetizing force in air gap

i_R leakage current, A
i_F forward current, A
i_{rr} reverse recovery current
I current, A
I_b base current
I_b reverse voltage breakdown diode current, A
I_{bf} forward base current
I_{br} reverse base current
I_c collector current

I_{ceo} collector current when $I_b = 0$ for $V_{(BR)ceo}$
I_{cer} collector current when R_{be} = R, for $V_{(BR)cer}$
I_{ces} collector current when $V_{be} = 0$ for $V_{(BR)ces}$
I_{cex} collector current when V_{eb} = X, for $V_{(BR)cex}$
I_d drain current n-channel
I_{dp} drain current p-channel
I_{DQ} positive - negative temperature coefficient boundary
I_{te} TE current drawn
I_e emitter current, A
I_{GQ} reverse gate current, A
I_G, I_g SCR/triac gate current
I_F diode (maximum) forward current, A
I_{FMG} peak forward gate current, A
I_g gate current, A
I_{GT}, V_{GT} minimum trigger values
I_G, V_G dc gate signal
I_{GQ} GTO minimum negative gate current at anode current I_{GTQ}
I_H holding current, $I_{Latch} > I_H$
I_K I_A SCR cathode/anode/gate current, A
I_L load current, A
I_{Latch} anode latching current, $I_{Latch} > I_H$
I_m maximum current level, A
I_{nom} nominal current, A
I_o reverse (saturation) leakage current, A
I_{RG} negative gate current, A
I_{RM} peak reverse recovery current, A
I_T GTO on-state current , A
I_{tail} storage current level, A
I_{RRM}, I_{DRM} reverse leakage and forward blocking current, A
I_{TSM} peak one cycle surge on-state current, A
I_{rms} rms current, A
I^2t thermal energy crated rating, A^{2}s

J flux – heat, impurities
J_R reverse recovery W.s/pulse,
J1, J1, J1 SCR junctions

k constant
k Boltzmann's constant, 1.38 x 10^{-23}, J/K
k_{exp} load factor specific to the system, determined experimentally
k_ℓ leakage coefficient
k_r loss or reluctance factor

k_D characteristics dimension of the geometry
k_T grease temperature factor
K heat transfer coefficient constant units
K thermal resistance pu area, cm^2/W
K_q, K_m, K_p, K_{HP} constants for geometrically and dynamic operation
K_w wire current constant

ℓ vertical height in the direction of the airflow
ℓ thickness of insulation, m
ℓ distance (thickness)
ℓ length
ℓ_g, ℓ_m length of air gap, magnet
ℓ_m line resolution
L heat of vaporization per unit mass
L length (of cold plate), m
L characteristic passage length of the microchannel
L fin depth
L circuit inductance, H
L, W, t length/width/thickness, m
L_c effective channel length
L_{eff} effective length, $½(L_{evaporator} + L_{condenser}) + L_{adiabatic}$
L_p minority carrier diffusion length

L_t	service life, hours
L_w	sound pressure level, dB
L_2 L_{10}	life for 98%, 90% survival, second and tenth percentiles
m	breakdown multiplication exponent
m	mass (weight) of object, kg (density x volume)
m_f	mass flow rate of air/fluid through enclosure/heatsink, (equal to $\rho\, v_f\, s\, L$), kg/s
M	voltage dependant avalanche multiplication effect
M_ℓ	merit number (liquid transport factor), W/m^2
n	exponent
n_i	intrinsic carrier concentration, 1.4x10^{10} /cc
n_f	number of fins
n_q	airflow quality constant
$\overline{n}$	index of refraction
N_D, N_A	donor/acceptor concentration, cm^{-3}
N	speed (fan impeller), rps/rpm
N	number of cycles
NA	numerical aperture
N_B	background doping, cm^{-3}
N_c	concentration of the lighter doped region /cc
N_{nom}	nominal speed
Nu	Nusselt number, non-dimensional heat transfer coefficient, $h\delta/k$, ARe^mPr^n
p, n	electron/hole concentration, cm^{-3}
p_o, n_o	hole/electron equilibrium carrier concentrations, cm^{-3}
P	mean heat added (or being removed - dissipated) from the object, W, watts
P	heat transport rate
P	equivalent dynamic bearing load, kg
P	pressure
P	permeance (inverse of reluctance)
P_{cold}	amount of heat absorbed at the cold surface of TEC, W
P_c	conduction power loss
P_c	permeance coefficient
P_d	heat load (lost/gained), electrical power dissipated, rate of radiated heat transfer, W
P_D	amount/conducted heat dissipated (in enclosure, transferred to cooling system), W
P_{Dtotal}	total power to be dissipated
$\hat{P}_d$	maximum allowable power dissipation, W
P_{ref}	reference pressure
P_{max}	maximum power
P_{hot}	minimum total heat to be rejected by the heat exchanger on the hot side
P_G	drive input device power loss
P_{GM}, P_G	peak and mean gate power
P_ℓ	off-state leakage power loss
P_L	*load* electrical power dissipation, W
P_{RQ}	storage and fall time power loss
P_s	switching transition power loss
P_{tec}	TEC input dc power
P_{to}	initial heat pumping capacity when ΔT is zero
P_{tt}	heat pumping capacity at desired ΔT and heat-pumping capacity is decreased
P_T	power transported by the heat pipe
$P_\square$	fin perimeter, m
PWL	sound power level
q	electron charge, 1.602x10^{-19} C
Q	pool boiling heat transfer rate
Q_{flow}	heat flow
Q_o	zero bias scl charge, C
Q_R	reverse recovery charge, $Q_1 + Q_2$, C
Q_T	total gate charge
Q_Σ	total recovery charge, C
r	radius, m
r_c	effective capillary radius

$r(t_p)$	normalising factor
R	resistance, Ω
R_{be}	models the lateral p-body resistance
$R_{ds(on)}$	on-resistance n/p-channel
R_d	deposition rate
Re	Reynolds number, ratio of inertia forces to viscous forces in the fluid, $V\delta/v$
R_g	gate resistance
$R_{g\,int}$	internal gate resistance
$R_{g\,ext}$	external gate resistance
R_i	resistance modelling linear leakage current, Ω
R_L	load resistance, Ω
R_o	diode model series resistance, Ω
R_s	sheet resistance, Ω/square
R_t	thermal resistance of one channel
R_θ	thermal resistivity/resistivity
$R_{\theta\,j\text{-}c}$	virtual junction to case thermal resistance, K/W
$R_{\theta\,j\text{-}a}$	total thermal resistance from the virtual junction to the open air (ambient), K/W
$R_{\theta\,c\text{-}s}$	case-to-heat-sink thermal resistance, K/W
$R_{\theta\,s\text{-}a}$	heat-sinking thermal resistance
$\Re_m$	magnet reluctance
s	fin spacing
S	initial dose per unit area at the surface, cm^{-2}
S_f, S_{fm}, S_{fs}	selectivity (mask, substrate)
S_G	grease half-life subtraction factor
S_N	speed half-life subtraction factor
S_P	load half-life subtraction factor
SPL	sound pressure level, decibels, dB(A)
S_r	snap-off and soft recovery diode properties
$S_{½}$	half-life subtraction factor
$S_{\%s}$	fraction of solids
t	fin/plate thickness
t	time (required to cool down (or heat up) object), s
t_d	delay time
$t_{d\,off}$	turn-off delay time
$t_{d\,on}$	turn-on delay
t_{fi}	current fall time
t_{fr}	forward recovery characteristics of time
t_{fv}	voltage fall time
t_p	power pulse width
t_o	time to zero current, s
t_{off}	turn-off time, $t_s + t_{fi}$
t_{on}	turn-on time, $t_d + t_{ri}$
t_{ox}	oxide thickness, m
t_{ri}	current rise time
t_{rr}	reverse recovery time, s
t_{rv}	voltage rise, time
t_s	storage or saturation time
t_t	minority carrier lifetime
t_{tail}	current fall time
T	cycle or integration period
T	absolute temperature, K
T_a	ambient temperature
T_A	is the ambient temperature
T_{brg}	bearing temperature, K
T_c	case temperature, K
T_f	final temperature, °C
T_{hot}, T_{cold}, (or T_h and T_c)	
T_{in}, T_{out}	fluid (air, water, etc.) inlet and outlet temperatures, K
$T_{i/s}$	inside temperature, °C
T_j	junction temperature, K
$\hat{T}_j$	maximum allowable junction temperature, K
T_{max}	maximum operating temperature or desired cold plate surface temperature, K

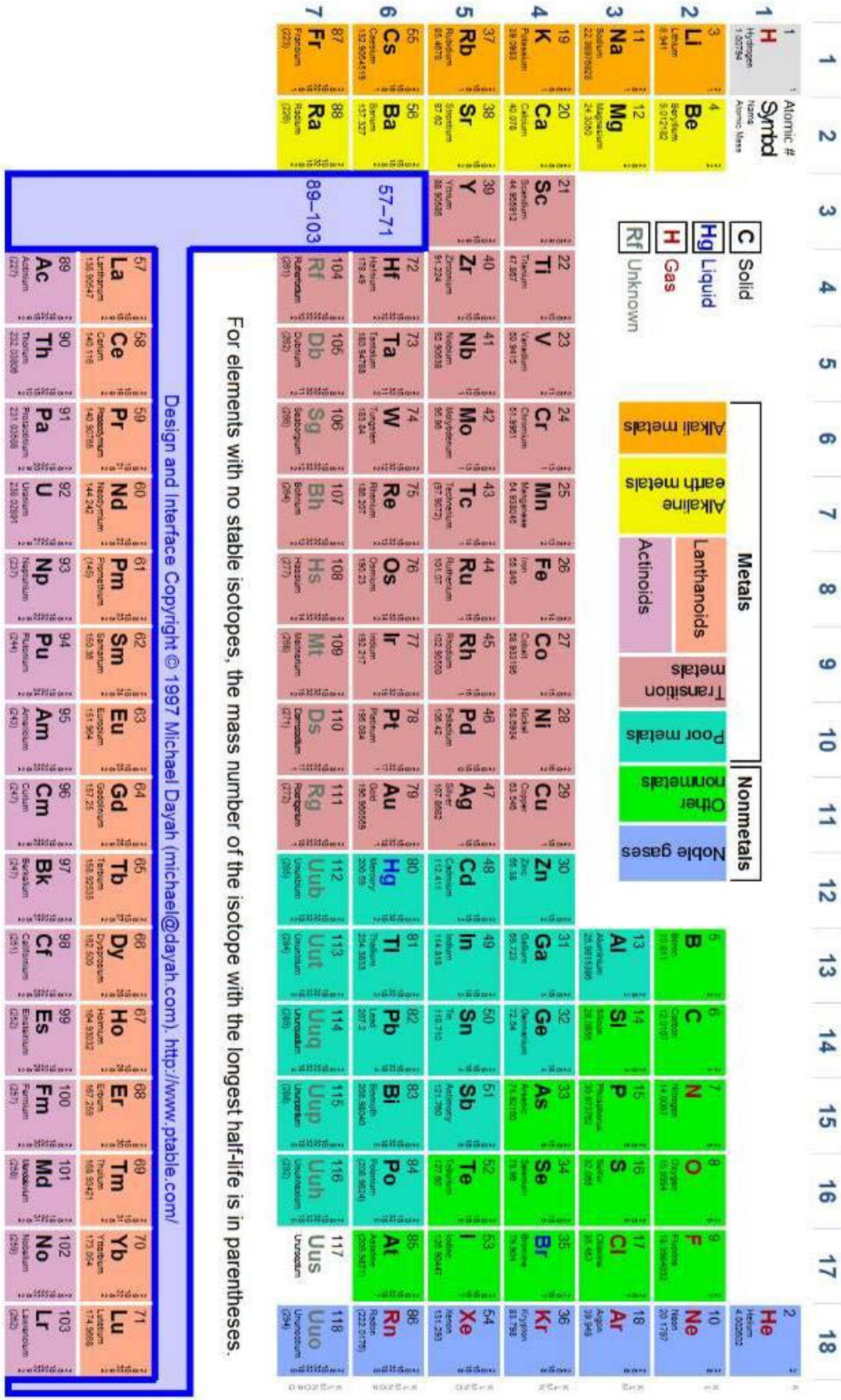
T_{mean} arithmetic mean of T_1 and T_2, specifically ½($T_1 + T_2$)
T_{melt} melting temperature
T_o initial/starting temperature, °C
$T_{o/s}$ outside temperature, °C
T_s heated surface temperature
T_{sat} liquid saturation temperature (boiling point)
T_{wall} heated surface temperature

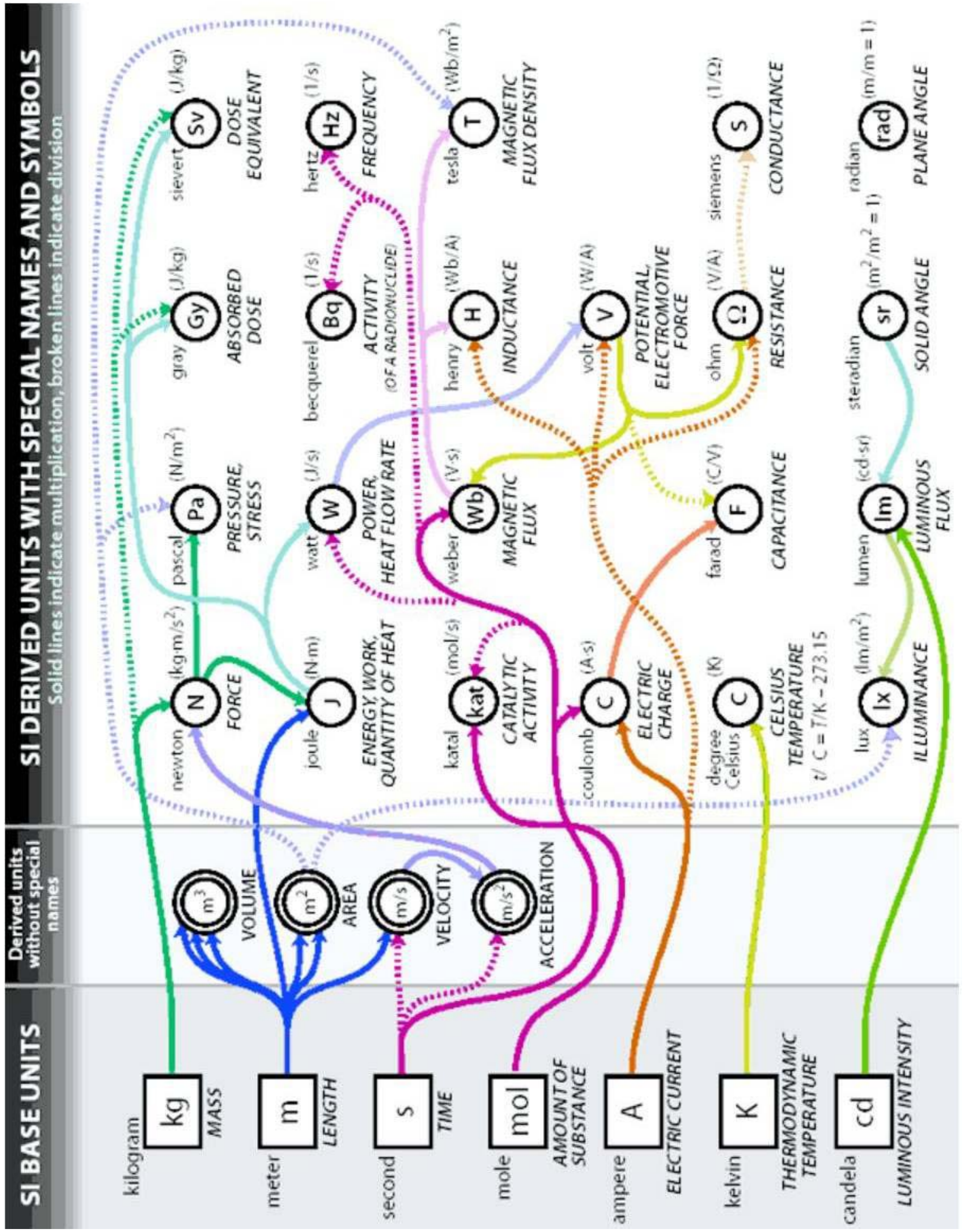
v cooling fluid flow rate, fluid velocity (volumetric flow rate), m^3/s
v velocity of the vertical airflow
v_{ce} collector to emitter voltage
v_{DR} reverse voltage
v_{sat} saturation velocity of electrons in silicon, 9.0x10^6 cm/s
V, v voltage, V
$V_A(t)$ anode turn-off voltage
V_b avalanche voltage, V
$V_{be(sat)}$ base to emitter saturation voltage
V_{BF} forward anode-cathode breakover voltage
V_{BR} reverse breakdown breakover voltage
$V_{(BR)cbo}$ $V_{(BR)ceo}$ maximum collector-base voltage with the emitter open circuit, base open
$V_{(BR)cex}$ maximum collector-emitter voltage with specific base V-R conditions
$V_{(BR)DSS}$ drain breakdown voltage, V
V_{cbo} collector to base avalanche breakdown voltage
V_{ceo} collector to emitter first breakdown
V_{ceo}, V_{cbo} BJT voltage characteristics
V_{cer}, V_{ces}, V_{cev} BJT voltage characteristics dependent on the external base circuit conditions
$V_{ce(sat)}$ collector emitter saturation voltage
V_{DRM} forward off-state
V_{ds} drain to source voltage
V_{dd} supply voltage
V_{te} TE voltage applied
V_F diode forward voltage, V
V_f velocity between the fins
V_{fp} peak forward voltage
V_g, V_m volume of air gap, magnet
V_{GC} gate junction voltage
V_{gg} gate source voltage maximum
V_{GFM}, V_{GRM} peak forward and reverse gate to cathode voltage
V_{gs} gate voltage
V_{Ls} stray inductance
V_{PT} punch-through voltage, V
V_{RM} diode recovery minimise voltage overshoot, V
V_{RRM} reverse direction
V_s maximum voltage level
V_t tip speed of impeller
V_{Th} gate threshold voltage
V_Z Zener breakdown voltage

w width
W energy, J
W_c width of region/channel, μm
W_{hs} width of heat sink base
W_i intrinsic *i*-layer thickness
W_{n2} *n*-base width
W_o zero bias scl width, m
W_{ref} acoustic reference power
W_{scl} scl width

x_j metallurgical/impurity junction depth, m
x_n, x_p scl penetration into n/p sides, m
X_p penetration depth peak, m

Z altitude, above sea level, m
$Z_{\theta\, j\text{-}c}$ thermal impedance, K/W





Emissivities of surfaces
(*a*) Metals

Material	Temperature, K	Emissivity, ε	Material	Temperature, K	Emissivity, ε
Aluminum			Magnesium, polished	300–500	0.07–0.13
Polished	300–900	0.04–0.06	Mercury	300–400	0.09–0.12
Commercial sheet	400	0.09	Molybdenum		
Heavily oxidized	400–800	0.20–0.33	Polished	300–2000	0.05–0.21
Anodized	300	0.8	Oxidized	600–800	0.80–0.82
Bismuth, bright	350	0.34	Nickel		
Brass			Polished	500–1200	0.07–0.17
Highly polished	500–650	0.03–0.04	Oxidized	450–1000	0.37–0.57
Polished	350	0.09	Platinum, polished	500–1500	0.06–0.18
Dull plate	300–600	0.22	Silver, polished	300–1000	0.02–0.07
Oxidized	450–800	0.6	Stainless steel		
Chromium, polished	300–1400	0.08–0.40	Polished	300–1000	0.17–0.30
Copper			Lightly oxidized	600–1000	0.30–0.40
Highly polished	300	0.02	Highly oxidized	600–1000	0.70–0.80
Polished	300–500	0.04–0.05	Steel		
Commercial sheet	300	0.15	Polished sheet	300–500	0.08–0.14
Oxidized	600–1000	0.5–0.8	Commercial sheet	500–1200	0.20–0.32
Black oxidized	300	0.78	Heavily oxidized	300	0.81
Gold			Tin, polished	300	0.05
Highly polished	300–1000	0.03–0.06	Tungsten		
Bright foil	300	0.07	Polished	300–2500	0.03–0.29
Iron			Filament	3500	0.39
Highly polished	300–500	0.05–0.07	Zinc		
Case iron	300	0.44	Polished	300–800	0.02–0.05
Wrought iron	300–500	0.28	Oxidized	300	0.25
Rusted	300	0.61			
Oxidized	500–900	0.64–0.78			
Lead					
Polished	300–500	0.06–0.08			
Unoxidized, rough	300	0.43			
Oxidized	300	0.63			

Boiling- and freezing-point properties

	Boiling Data at 1 atm		*Freezing Data*		*Liquid Properties*		
Substance	Normal Boiling Point, °C	Latent Heat of Vaporization, h_{fg} kJ/kg	Freezing Point, °C	Latent Heat of Fusion, h_{if} kJ/kg	Temp., °C	Density, ρ kg/m³	Specific Heat, C_p kJ/kg · °C
Ammonia	−33.3	1357	−77.7	322.4	−33.3	682	4.43
					−20	665	4.51
					0	639	4.62
					25	603	4.78
Argon	−185.9	161.6	−189.3	28	−185.6	1394	1.14
Benzene	80.2	394	5.5	126	20	879	1.72
Brine (20% sodium chloride by mass)	103.9	—	−17.4	—	20	1150	3.11
n-Butane	−0.5	385.2	−138.5	80.3	−0.5	601	2.31
Carbon dioxide	−78.4*	230.5 (at 0°C)	−56.6		0	298	0.59
Ethanol	78.2	838.3	−114.2	109	25	783	2.46
Ethyl alcohol	78.6	855	−156	108	20	789	2.84
Ethylene glycol	198.1	800.1	−10.8	181.1	20	1109	2.84
Glycerine	179.9	974	18.9	200.6	20	1261	2.32
Helium	−268.9	22.8	—	—	−268.9	146.2	22.8
Hydrogen	−252.8	445.7	−259.2	59.5	−252.8	70.7	10.0
Isobutane	−11.7	367.1	−160	105.7	−11.7	593.8	2.28
Kerosene	204–293	251	−24.9	—	20	820	2.00
Mercury	356.7	294.7	−38.9	11.4	25	13560	0.139
Methane	−161.5	510.4	−182.2	58.4	−161.5	423	3.49
					−100	301	5.78
Methanol	64.5	1100	−97.7	99.2	25	787	2.55
Nitrogen	−195.8	198.6	−210	25.3	−195.8	809	2.06
					−160	596	2.97
Octane	124.8	306.3	−57.5	180.7	20	703	2.10
Oil (light)					25	910	1.80
Oxygen	−183	212.7	−218.8	13.7	−183	1141	1.71
Petroleum	—	230–384			20	640	2.0
Propane	−42.1	427.8	−187.7	80.0	−42.1	581	2.25
					0	529	2.51
					50	449	3.12
Refrigerant-134a	−26.1	216.8	−96.6	—	−50	1443	1.23
					−26.1	1374	1.27
					0	1295	1.34
					25	1207	1.43
Water	100	2257	0.0	333.7	0	1000	4.22
					25	997	4.18
					50	988	4.18
					75	975	4.19
					100	958	4.22

Properties of solid nonmetals

		Properties at 300 K				*Properties at Various Temperatures* (K), k(W/m · K)/C_p(J/kg · K)					
Composition	Melting Point, K	ρ kg/m³	C_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m²/s	100	200	400	600	800	1000
Aluminum oxide,	2323	3970	765	46	15.1	450	82	32.4	18.9	13.0	10.5
sapphire						—	—	940	1110	1180	1225
Aluminum oxide,	2323	3970	765	36.0	11.9	133	55	26.4	15.8	10.4	7.85
polycrystalline						—	—	940	1110	1180	1225
Beryllium oxide	2725	3000	1030	272	88.0			196	111	70	47
								1350	1690	1865	1975
Boron	2573	2500	1105	27.6	9.99	190	52.5	18.7	11.3	8.1	6.3
						—	—	1490	1880	2135	2350
Boron fiber epoxy (30% vol.) composite	590	2080									
k, ∥ to fibers				2.29		2.10	2.23	2.28			
k, ⊥ to fibers				0.59		0.37	0.49	0.60			
C_p			1122			364	757	1431			
Carbon											
Amorphous	1500	1950	—	1.60	—	0.67	1.18	1.89	21.9	2.37	2.53
						—	—	—	—	—	—
Diamond, type IIa	—	3500	509	2300		10,000	4000	1540			
insulator						21	194	853			
Graphite, pyrolytic	2273	2210									
k, ∥ to layers				1950		4970	3230	1390	892	667	534
k, ⊥ to layers				5.70		16.8	9.23	4.09	2.68	2.01	1.60
C_p			709			136	411	992	1406	1650	1793
Graphite fiber epoxy (25% vol.) composite	450	1400									
k, heat flow ∥ to fibers				11.1		5.7	8.7	13.0			
k, heat flow ⊥ to fibers				0.87		0.46	0.68	1.1			
C_p			935			337	642	1216			
Pyroceram,	1623	2600	808	3.98	1.89	5.25	4.78	3.64	3.28	3.08	2.96
Corning 9606						—	—	908	1038	1122	1197
Silicon carbide	3100	3160	675	490	230			—	—	—	87
								880	1050	1135	1195
Silicon dioxide, crystalline (quartz)	1883	2650									
k, ∥ to c-axis				10.4		39	16.4	7.6	5.0	4.2	
k, ⊥ to c-axis				6.21		20.8	9.5	4.70	3.4	3.1	
C_p			745			—	—	885	1075	1250	
Silicon dioxide,	1883	2220	745	1.38	0.834	0.69	1.14	1.51	1.75	2.17	2.87
polycrystalline (fused silica)						—	—	905	1040	1105	1155
Silicon nitride	2173	2400	691	16.0	9.65	—	—	13.9	11.3	9.88	8.76
						—	578	778	937	1063	1155
Sulfur	392	2070	708	0.206	0.141	0.165	0.185				
						403	606				
Thorium dioxide	3573	9110	235	13	6.1			10.2	6.6	4.7	3.68
								255	274	285	295
Titanium dioxide,	2133	4157	710	8.4	2.8			7.01	5.02	3.94	3.46
polycrystalline								805	880	910	930

Properties of solid metals

Composition	Melting Point, K	Properties at 300 K: ρ kg/m³	C_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m²/s	Properties at Various Temperatures (K), k(W/m · K)/C_p(J/kg · K): 100	200	400	600	800	1000
Aluminum:											
Pure	933	2702	903	237	97.1	302	237	240	231	218	
						482	798	949	1033	1146	
Alloy 2024-T6 (4.5% Cu, 1.5% Mg,	775	2770	875	177	73.0	65	163	186	186		
0.6% Mn)						473	787	925	1042		
Alloy 195, Cast (4.5% Cu)		2790	883	168	68.2			174	185		
Beryllium	1550	1850	1825	200	59.2	990	301	161	126	106	90.8
						203	1114	2191	2604	2823	3018
Bismuth	545	9780	122	7.86	6.59	16.5	9.69	7.04			
						112	120	127			
Boron	2573	2500	1107	27.0	9.76	190	55.5	16.8	10.6	9.60	9.85
						128	600	1463	1892	2160	2338
Cadmium	594	8650	231	96.8	48.4	203	99.3	94.7			
						198	222	242			
Chromium	2118	7160	449	93.7	29.1	159	111	90.9	80.7	71.3	65.4
						192	384	484	542	581	616
Cobalt	1769	8862	421	99.2	26.6	167	122	85.4	67.4	58.2	52.1
						236	379	450	503	550	628
Copper:											
Pure	1358	8933	385	401	117	482	413	393	379	366	352
						252	356	397	417	433	451
Commercial bronze	1293	8800	420	52	14		42	52	59		
(90% Cu, 10% Al)							785	160	545		
Phosphor gear bronze	1104	8780	355	54	17		41	65	74		
(89% Cu, 11% Sn)							—	—	—		
Cartridge brass	1188	8530	380	110	33.9	75	95	137	149		
(70% Cu, 30% Zn)							360	395	425		
Constantan	1493	8920	384	23	6.71	17	19				
(55% Cu, 45% Ni)						237	362				
Germanium	1211	5360	322	59.9	34.7	232	96.8	43.2	27.3	19.8	17.4
						190	290	337	348	357	375
Gold	1336	19,300	129	317	127	327	323	311	298	284	270
						109	124	131	135	140	145
Iridium	2720	22,500	130	147	50.3	172	153	144	138	132	126
						90	122	133	138	144	153
Iron:											
Pure	1810	7870	447	80.2	23.1	134	94.0	69.5	54.7	43.3	32.8
						216	384	490	574	680	975
Armco (99.75% pure)		7870	447	72.7	20.7	95.6	80.6	65.7	53.1	42.2	32.3
						215	384	490	574	680	975
Carbon steels:											
Plain carbon (Mn ≤ 1%,		7854	434	60.5	17.7			56.7	48.0	39.2	30.0
Si ≤ 0.1%)								487	559	685	1169

Properties of solid metals *(Continued)*

Composition	Melting Point, K	Properties at 300 K: ρ kg/m³	C_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m²/s	Properties at Various Temperatures (K), k(W/m · K)/C_p(J/kg · K): 100	200	400	600	800	1000
AISI 1010		7832	434	63.9	18.8			58.7	48.8	39.2	31.3
								487	559	685	1168
Carbon–silicon (Mn ≤ 1%,		7817	446	51.9	14.9			49.8	44.0	37.4	29.3
0.1% < Si ≤ 0.6%)								501	582	699	971
Carbon–manganese–silicon		8131	434	41.0	11.6			42.2	39.7	35.0	27.6
(1% < Mn ≤ 1.65%								487	559	685	1090
0.1% < Si ≤ 0.6%)											
Chromium (low) steels:											
$\frac{1}{2}$ Cr–$\frac{1}{4}$ Mo–Si (0.18% C, 0.65% Cr, 0.23% Mo,		7822	444	37.7	10.9			38.2	36.7	33.3	26.9
0.6% Si)								492	575	688	969
1Cr–$\frac{1}{2}$ Mo (0.16% C, 1% Cr, 0.54% Mo,		7858	442	42.3	12.2			42.0	39.1	34.5	27.4
0.39% Si)								492	575	688	969
1Cr–V (0.2% C, 1.02% Cr,		7836	443	48.9	14.1			46.8	42.1	36.3	28.2
0.15% V)								492	575	688	969
Stainless steels:											
AISI 302		8055	480	15.1	3.91			17.3	20.0	22.8	25.4
								512	559	585	606
AISI 304	1670	7900	477	14.9	3.95	9.2	12.6	16.6	19.8	22.6	25.4
						272	402	515	557	582	611
AISI 316		8238	468	13.4	3.48			15.2	18.3	21.3	24.2
								504	550	576	602
AISI 347		7978	480	14.2	3.71			15.8	18.9	21.9	24.7
								513	559	585	606
Lead	601	11,340	129	35.3	24.1	39.7	36.7	34.0	31.4		
						118	125	132	142		
Magnesium	923	1740	1024	156	87.6	169	159	153	149	146	
						649	934	1074	1170	1267	
Molybdenum	2894	10,240	251	138	53.7	179	143	134	126	118	112
						141	224	261	275	285	295
Nickel:											
Pure	1728	8900	444	90.7	23.0	164	107	80.2	65.6	67.6	71.8
						232	383	485	592	530	562
Nichrome	1672	8400	420	12	3.4			14	16	21	
(80% Ni, 20% Cr)								480	525	545	
Inconel X-750 (73% Ni, 15% Cr,	1665	8510	439	11.7	3.1	8.7	10.3	13.5	17.0	20.5	24.0
6.7% Fe)						—	372	473	510	546	626
Niobium	2741	8570	265	53.7	23.6	55.2	52.6	55.2	58.2	61.3	64.4
						188	249	274	283	292	301
Palladium	1827	12,020	244	71.8	24.5	76.5	71.6	73.6	79.7	86.9	94.2
						168	227	251	261	271	281
Platinum:											
Pure	2045	21,450	133	71.6	25.1	77.5	72.6	71.8	73.2	75.6	78.7
						100	125	136	141	146	152
Alloy 60Pt–40Rh	1800	16,630	162	47	17.4			52	59	65	69
(60% Pt, 40% Rh)								—	—	—	—

Properties of solid metals *(Concluded)*

Composition	Melting Point, K	Properties at 300 K: ρ kg/m^3	C_p J/kg · K	k W/m · K	$\alpha \times 10^6$ m^2/s	Properties at Various Temperatures (K), k(W/m · K)/C_p(J/kg · K): 100	200	400	600	800	1000
Rhenium	3453	21,100	136	47.9	16.7	58.9	51.0	46.1	44.2	44.1	44.6
						97	127	139	145	151	156
Rhodium	2236	12,450	243	150	49.6	186	154	146	136	127	121
						147	220	253	274	293	311
Silicon	1685	2330	712	148	89.2	884	264	98.9	61.9	42.4	31
						259	556	790	867	913	946
Silver	1235	10,500	235	429	174	444	430	425	412	396	379
						187	225	239	250	262	277
Tantalum	3269	16,600	140	57.5	24.7	59.2	57.5	57.8	58.6	59.4	60.2
						110	133	144	146	149	152
Thorium	2023	11,700	118	54.0	39.1	59.8	54.6	54.5	55.8	56.9	56.9
						99	112	124	134	145	156
Tin	505	7310	227	66.6	40.1	85.2	73.3	62.2			
						188	215	243			
Titanium	1953	4500	522	21.9	9.32	30.5	24.5	20.4	19.4	19.7	20.7
						300	465	551	591	633	675
Tungsten	3660	19,300	132	174	68.3	208	186	159	137	125	118
						87	122	137	142	146	148
Uranium	1406	19,070	116	27.6	12.5	21.7	25.1	29.6	34.0	38.8	43.9
						94	108	125	146	176	180
Vanadium	2192	6100	489	30.7	10.3	35.8	31.3	31.3	33.3	35.7	38.2
						258	430	515	540	563	597
Zinc	693	7140	389	116	41.8	117	118	111	103		
						297	367	402	436		
Zirconium	2125	6570	278	22.7	12.4	33.2	25.2	21.6	20.7	21.6	23.7
						205	264	300	332	342	362

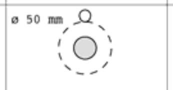
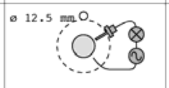
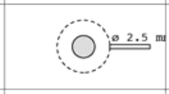
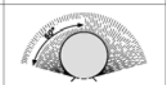
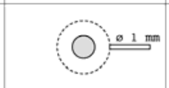
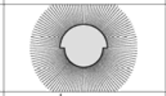
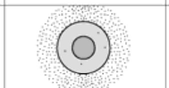
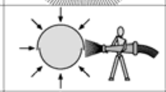
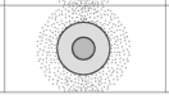
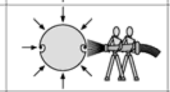
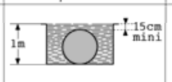
Boiling- and freezing-point properties

Substance	Boiling Data at 1 atm: Normal Boiling Point, °C	Latent Heat of Vaporization, h_{fg} kJ/kg	Freezing Data: Freezing Point, °C	Latent Heat of Fusion, h_{if} kJ/kg	Liquid Properties: Temp., °C	Density, ρ kg/m^3	Specific Heat, C_p kJ/kg · °C
Ammonia	−33.3	1357	−77.7	322.4	−33.3	682	4.43
					−20	665	4.51
					0	639	4.62
					25	603	4.78
Argon	−185.9	161.6	−189.3	28	−185.6	1394	1.14
Benzene	80.2	394	5.5	126	20	879	1.72
Brine (20% sodium chloride by mass)	103.9	—	−17.4	—	20	1150	3.11
n-Butane	−0.5	385.2	−138.5	80.3	−0.5	601	2.31
Carbon dioxide	−78.4*	230.5 (at 0°C)	−56.6		0	298	0.59
Ethanol	78.2	838.3	−114.2	109	25	783	2.46
Ethyl alcohol	78.6	855	−156	108	20	789	2.84
Ethylene glycol	198.1	800.1	−10.8	181.1	20	1109	2.84
Glycerine	179.9	974	18.9	200.6	20	1261	2.32
Helium	−268.9	22.8	—	—	−268.9	146.2	22.8
Hydrogen	−252.8	445.7	−259.2	59.5	−252.8	70.7	10.0
Isobutane	−11.7	367.1	−160	105.7	−11.7	593.8	2.28
Kerosene	204–293	251	−24.9	—	20	820	2.00
Mercury	356.7	294.7	−38.9	11.4	25	13560	0.139
Methane	−161.5	510.4	−182.2	58.4	−161.5	423	3.49
					−100	301	5.78
Methanol	64.5	1100	−97.7	99.2	25	787	2.55
Nitrogen	−195.8	198.6	−210	25.3	−195.8	809	2.06
					−160	596	2.97
Octane	124.8	306.3	−57.5	180.7	20	703	2.10
Oil (light)					25	910	1.80
Oxygen	−183	212.7	−218.8	13.7	−183	1141	1.71
Petroleum	—	230–384			20	640	2.0
Propane	−42.1	427.8	−187.7	80.0	−42.1	581	2.25
					0	529	2.51
					50	449	3.12
Refrigerant-134a	−26.1	216.8	−96.6	—	−50	1443	1.23
					−26.1	1374	1.27
					0	1295	1.34
					25	1207	1.43
Water	100	2257	0.0	333.7	0	1000	4.22
					25	997	4.18
					50	988	4.18
					75	975	4.19
					100	958	4.22

Degrees of protection

IP codes according to IEC 60529 standard

Degrees of protection are identified by IP followed by two numbers followed by an optional letter, as defined in the table to follow.

FIRST NUMBER PROTECTION AGAINST SOLID BODY PENETRATION			SECOND NUMBER PROTECTION AGAINST LIQUID PENETRATION			ADDITIONAL LETTER[2]	DEGREE OF PROTECTION
IP	Tests		IP	Tests			BRIEF DESCRIPTION
0		No protection	0		No protection		
1		Protected against solid bodies greater than 50 mm	1		Protected against water drops falling vertically (condensation)	A	Protected against access with back of hand
2[1]		Protected against solid bodies greater than 12 mm	2		Protected against water drops falling up to 15° from the vertical	B	Protected against access with finger
3		Protected against solid bodies greater than 2.5 mm	3		Protected against water showers up to 60° from the vertical	C	Protected against access with tool
4		Protected against solid bodies greater than 1 mm	4		Protected against water splashes from any direction	D	Protected against access with wire
5		Protected against dust (excluding damaging deposits)	5		Protected against water jets from any hosed direction		
6		Total protection against dust	6		Protected against water splashes comparable to heavy seas		
The first two numbers are defined by NF EN 60 529, IEC 529 and DIN 40 050			7		Protected against total immersion		

IEC 947 and IEC 947-3 Standards

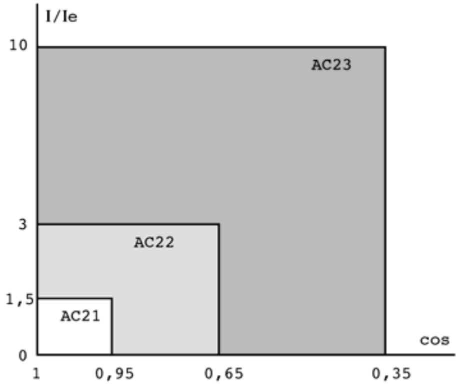
Selecting contactors according to IEC 947-3 standard

UTILIZATION	CATEGORY	USE	APPLICATION
AC AC20	DC DC20	No-load making and breaking	Disconnector (device without on-load making and breaking capacity)
AC21	DC21	Resistive loads including moderate overloads.	Switches at installation head or for resistive circuits (heating, lighting, except discharge lamps, etc.).
AC22	DC22	Inductive and resistive mixed loads including moderate overloads.	Switches in secondary circuits or reactive circuits (capacitor banks, discharge lamps, shunt motors, etc.).
AC23	DC23	Loads made of motors or other highly inductive loads.	Switches feeding one or several motors or inductive circuits (electric carriers, brake magnet, series motor, etc.).

Breaking and making capacities

Unlike circuit breakers, where these criteria indicate tripping or short-circuit making characteristics and perhaps requiring device replacement, switch making and breaking capacities correspond to utilization category maximum performance values.
In these uses, the switch must still maintain its characteristics, in particular its resistance to leakage current and temperature rise.

	MAKING		BREAKING		N° OF OPERATING CYCLES
	I/I_e	cos φ	I/I_e	cos φ	
AC 21	1.5	0.95	1.5	0.95	5
AC 22	3	0.65	3	0.65	5
AC 23 $I_e \leq 100$ A	10	0.45	8	0.45	5
$I_e > 100$ A	10	0.35	8	0.35	3
		L/R (ms)		L/R (ms)	
DC 21	1.5	1	1.5	1	5
DC 22	4	2.5	4	2.5	5
DC 23	4	15	4	15	5



Making and breaking capacities

Electrical and mechanical endurance

This standard establishes the minimum number of electrical (full load) and mechanical (no-load) operating cycles that must be performed by devices. These characteristics also specify the device's theoretical lifespan during which it must maintain its characteristics, particularly resistance to leakage current and temperature rise.
This performance is linked to the device's use and rating. According to anticipated use, two additional application categories are offered:

- category A: frequent operations (in close proximity to the load)
- category B: infrequent operations (at installation head or wiring system).

I_e (A)	≤ 100	≤ 315	≤ 630	≤ 2500	> 2500
N° CYCLES/HOUR	120	120	60	20	10
N° OF OPERATIONS IN CAT. A					
without current	8500	7000	4000	2500	1500
with current	1500	1000	1000	500	500
Total	10000	8000	5000	3000	2000
N° OF OPERATIONS IN CAT. B					
without current	1700	1400	800	500	300
with current	300	200	200	100	100
Total	2000	1600	1000	600	400

Definitions

Conventional thermal current (I_{th}):
Value of the current the disconnect switch can withstand with poles in closed position, in free air for an eight hour duty, without the temperature rise of its various parts exceeding the limits specified by the standards.

Rated insulation voltage (U_i):
Voltage value which designates the unit and to which dielectric tests, clearance and creepage distances are referred.

Rated impulse withstand voltage (U_{imp}):
Peak value of an impulse voltage of prescribed form and polarity which the equipment is capable of withstanding without failure under specified conditions of test and to which the values of the clearances are referred.

Rated operating current (I_e):
Current value determined by endurance tests (both mechanical and electrical) and by making and breaking capacity tests.

Short circuit characteristics

- short-time withstand current (I_{cw}): Allowable rms current for 1 second.
- short circuit making capacity (I_{cm}): peak current value which the device can withstand when closed on a short-circuit.
- conditional short circuit current: the rms current the switch can withstand when associated with a protection device limiting both the current and short circuit duration.
- dynamic withstand: peak current the device can withstand in a closed position.

The characteristic established by this standard is the short-time withstand current (I_{cw}) from which minimal dynamic withstand is deduced. This essential withstand value corresponds to what the switch can stand without welding.

Glossary of terms

Glossary of Wafer Processing terminology

Alloying:- The process of forming a low-resistance contact between the aluminium metal and silicon substrate on a metallised semiconductor wafer.
Amorphous Si, a-Si:- non-crystalline thin-film silicon; features no long-range crystallographic order; inferior electrical characteristics as compared to single-crystal and poly Si but cheaper and easier to manufacture; used primarily to fabricate solar cells.
Angstrom, Å:- unit of length commonly used in semiconductor industry, though not recognised as a standard international unit; 1 Å = 10^{-10} m = 10^{-4} micrometer = 0.1 nm.
Annealing:- The process of combining hydrogen with uncommitted atoms at or near the silicon-silicon dioxide interface on a metallised semiconductor wafer.
Ashing:- The process of removal (by volatilization) of organic materials (e.g. photoresist) from the wafer surface using strongly oxidizing ambient; e.g. oxygen plasma ashing.
Backlapping:- The process of mechanically thinning the backside of a finished semiconductor wafer.
Backside metallisation:- The process of depositing a metal layer on the backside of a finished wafer.
Bandgap, energy gap E_g:- forbidden energy levels separating the valence and conduction bands. Electrons are allowed to have energies at these levels.
Barrier metal:- thin layer of metal, e.g. TiN, sandwiched between other metal and semiconductor (or insulator) to prevent potentially harmful interactions between these two, e.g. spiking.
Boat:- 1. a device made of high purity temperature resistant materials such as fused silica, quartz, poly Si, or SiC. designed to hold many semiconductor wafers during thermal or other processes;
2. device designed to simultaneously contain source material during evaporation while at the same time heating the source to its melting point; made of highly conductive, temperature resistant material through which current is passed.
Chip:- The final integrated semiconductor circuit.
Conduction band:- the upper energy band in a semiconductor separated from the valence band by the energy gap; The conduction band is not completely filled with electrons.
Constant-source diffusion:- also know as unlimited-source diffusion or predeposition; concentration of diffusant (dopant) on the surface of the wafer remains constant during the diffusion process, i.e. while some dopant atoms diffuse into the substrate additional dopant atoms are continuously supplied to the surface of the wafer.
Crystal pulling:- The process of forming a crystal ingot; a seed crystal of silicon is attached to a rod and "pulled" out of a silicon melt to form an ingot.
Czochralski Crystal Growth, CZ:- process utilizing crystal pulling to obtain single-crystal solids; the most common method for obtaining large diameter semiconductor wafers (300mm Si wafers); desired conductivity type and doping level is accomplished by adding dopants to molten material. Wafers used in high-end Si microelectronics are almost uniquely CZ grown.
Czochralski method:- The crystal pulling method used to form crystal ingots.
Chemical vapour deposition:- The process of applying a thin film to a substrate using a controlled chemical reaction.
Deposition:- A general term used to describe the addition of material layers on a semiconductor wafer.
Die:- An individual device or chip cut from a semiconductor wafer.
Diffusion:- A doping process; a high-temperature furnace is used to diffuse an applied layer of dopant into the wafer surface.
Diffusion coefficient, D:- determines rate with which element moves in a given solid by diffusion; depends strongly on temperature; expressed in cm^2/s; varies between elements by orders of magnitude, e.g. in the case of diffusion in silicon diffusion coefficient for gold, Au, is in the range of 10^{-3} cm^2/s (fast diffusant) while for Sb is in the range of 10^{-17} cm^2/s.
Dopant:- element introduced intentionally into a semiconductor to establish either p-type or n-type conductivity; Common dopants in silicon are: Boron (p-type) and phosphorous, arsenic, and antimony (n-type).
Doping:- The process of introducing impurity elements (dopants) into a semiconductor wafer to form regions of differing electrical conductivity. The two most common doping processes are diffusion and ion implantation.
Drive in:- high temperature (>800°C) operation performed on semiconductor wafer in an inert ambient; causes motion of dopant atoms in semiconductor in the direction of concentration gradient (diffusion); used to drive dopant atoms deeper into semiconductor.

Electron beam (e-beam) *evaporation*:- source material is evaporated as a result of highly localized heating by bombardment with high energy electrons; the electron beam is spatially confined and accelerated by electrostatic interactions. The direction and cross-section of the beam can be precisely controlled and rapidly altered to scan the target; evaporated material is very pure; bombardment of metal with electrons is accompanied by generation of low intensity X-rays which may create defects in the oxide present on the surface of the substrate; typically, an anneal is needed to eliminate those defects.
Epi Layer:- The term epitaxial comes from the Greek word meaning 'arranged upon.' In semiconductor technology, it refers to the single crystalline structure of the film. The structure comes about when silicon atoms are deposited on a bare silicon wafer in a CVD reactor. When the chemical reactants are controlled and the system parameters are set correctly, the depositing atoms arrive at the wafer surface with sufficient energy to move around on the surface and orient themselves to the crystal arrangement of the wafer atoms. Thus an epitaxial film deposited on a <111>-oriented wafer will take on a <111> orientation.
Epitaxial layer:- layer grown in the course of epitaxy.
Epitaxy:- process by which a thin *epitaxial* layer of single-crystal material is deposited on single-crystal substrate; epitaxial growth occurs in such way that the crystallographic structure of the substrate is reproduced in the growing material; also crystalline defects of the substrate are reproduced in the growing material. Although crystallographic structure of the substrate is reproduced, doping levels and the conductivity type of a epitaxial layer is controlled independently of the substrate; e.g. the epitaxial layer can be made more pure chemically than the substrate.
Etching:- The process of removing silicon dioxide layers, accomplished by "wet etching" with chemicals or by "dry etching" with ionized gases.
Evaporation:- common method used to deposit thin film materials; material to be deposited is heated in vacuum (10^{-6} - 10^{-7} Torr range) until it melts and starts evaporating; this vapour condenses on a cooler substrate inside the evaporation chamber forming smooth and uniform thin films; not suitable for high melting point materials; PVD method of thin film formation.
External, extrinsic gettering:- process in which gettering of contaminants and defects in a semiconductor wafer is accomplished by stressing its back surface (by inducing damage or depositing material featuring different than semiconductor thermal expansion coefficient) and then thermally treating the wafer; contaminants and/or defects are relocated toward back surface and away from the front surface where semiconductor devices can be formed.
Fick's law:- describe diffusion in solids; 1st and 2nd Fick's law; 1st Fick's law describes motion by diffusion of an element in the solid in the direction of the concentration gradient; 2nd Fick's law determines changes of concentration gradient in the course of diffusion (function of time and diffusion coefficient).
Filament evaporation:- thermal evaporation; source material is contacted to the filament (a refractory metal) and melted by high current flowing through the filament; alternatively, a "boat" which contains material to be evaporated may be made out of refractory metal;
Float-zone Crystal Growth, FZ:- method used to form single crystal semiconductor substrates (alternative to CZ); polycrystalline material is converted into single-crystal by locally melting the plane where a single crystal seed is contacting the polycrystalline material; used to make very pure, high resistance Si wafers; does not allow as large wafers (< 200mm) as CZ does; radial distribution of dopant in FZ wafer is not as uniform as in CZ wafer.
Gettering:- process which moves contaminants and/or defects in a semiconductor away from its top surface into its bulk and traps them there, creating a denuded zone.
HMDS:- Hexamethyldisilizane; improves adhesion of photoresist to the surface of a wafer; especially designed for adhesion of photoresist to SiO_2; deposited on wafer surface immediately prior to deposition of resist.
Hydrogenated a-Si:- amorphous silicon (a-Si) containing substantial quantities of hydrogen; hydrogen passivated Si dangling bonds and results in substantially improved electrical properties of A-Si
Ingot:- circular piece of single-crystal semiconductor material resulting from a crystal growth process; an ingot is ready to be shaped and sliced into wafers used to manufacture semiconductor devices.
Intrinsic gettering:- process in which gettering of contaminants and/or defects in a semiconductor is accomplished (without any physical interactions with the wafer) by a series of heat treatments.
Ion implantation:- A doping process; the dopant material is ionized and magnetically accelerated to strike the wafer surface, thereby embedding the dopant into the substrate.
Lapping:- The process of mechanically grinding the surface of a sliced wafer.
Lead frame:- The die attachment surface and lead attachment points that a die or chip is attached to prior to wire bonding and packaging.
limited-source diffusion:- also known as drive-in; concentration of diffusant (dopant) on the surface decreases during the diffusion process, i.e. while some dopant atoms diffuse into the substrate no new dopant atoms are supplied to the surface of the wafer.
Metallization:- formation of metal contacts and interconnects in the manufacturing of semiconductor devices.

Metal-semiconductor contact:- key component of any semiconductor device; depending on materials involved in the contact its properties can differ drastically; ohmic contact (linear, symmetric current-voltage characteristic)in the case when work function of metal matches work function of semiconductor (no potential barrier at the interface); rectifying contact(non-linear, highly asymmetric, diode-like current-voltage characteristic) in the case when work function of metal differs from the work function of semiconductor (potential barrier at the interface)- commonly referred to as a Schottky diode.

Minority carriers:- one of two carrier types (electrons of holes)whose equilibrium concentration is lower than that of the other type; holes in n-type semiconductors, electrons in p-type semiconductors.

N-type semiconductor:- semiconductor in which the concentration of electrons is much higher than the concentration of holes (p>>n); electrons are majority carriers and dominate conductivity.

Ohmic contact:- metal-semiconductor contact with very low resistance independent of applied voltage (may be represented by constant resistance); to form an 'ohmic' contact metal and semiconductor must be selected such that there is no potential barrier formed at the interface (or potential barrier is so thin that charge carriers can readily tunnel through it).

Oxidation:- The process of oxidizing the wafer surface to form a thin layer of silicon dioxide.

Passivation:- The process of applying a final passivating or protective layer of either silicon nitride or silicon dioxide to a wafer.

Photolithography:- The process of creating patterns on a silicon substrate. The main steps of the process include photoresist application, mask alignment, photoexposure, developing, and etching the portions of the substrate that are unprotected by the resist.

Photomask:- A mask that delineates the pattern applied to a substrate during photolithography.

Photoresist:- A photo-sensitive material used in photolithography to transfer pattern from the mask onto the wafer; a liquid deposited on the surface of the wafer as a thin film then solidified by low temperature anneal; in the areas in which photoresist can be reached by UV radiation photochemical reactions change its properties, specifically, solubility in the developer; two types of photoresist:- positive and negative.

Physical Vapour Deposition, PVD:- deposition of thin film occurs through physical transfer of material (e.g. thermal evaporation and sputtering)from the source to the substrate; chemical composition of deposited material is not altered in the process.

Polishing:- process applied to either reduce roughness of the wafer surface or to remove excess material from the surface; typically polishing is a mechanical-chemical process using a chemically reactive slurry.

Polycrystalline silicon:- An amorphous form of silicon with randomly oriented crystals, used to produce silicon ingots.

Polycrystalline material, poly:- many (often) small single-crystal regions are randomly connected to form a solid; size of regions varies depending on the material and the method of its formation. Heavily doped poly Si is commonly used as a gate contact in silicon MOS and CMOS devices.

Predeposition:- semiconductor doping by diffusion; process of thermal oxidation of silicon in the ambient containing dopant atoms; heavily doped oxide formed is acting as a source of dopant during the diffusion.

P-type semiconductor:- semiconductor in which the concentration of holes is much higher than the concentration of electrons (n>>p); holes are majority carriers and dominate conductivity.

Quartz:- single-crystal SiO_2.

Quartzite:- Silica sand used as a raw material to produce metallurgical grade silicon.

Reactive ion etching RIE:-., RIE variation of plasma etching that uses physical sputtering and chemically reactive species in which during etching semiconductor wafer is placed on the RF powered electrode; wafer takes on potential which accelerates etching species extracted from plasma toward the etched surface; chemical etching reaction is preferentially taking place in the direction normal to the surface, i.e. etching is more anisotropic than in plasma etching but is less selective; leaves etched surface damaged; the most common etching mode in semiconductor manufacturing, also used to remove metal layers.

Rectifying contact:- metal-semiconductor contact displaying asymmetric current-voltage characteristics, i.e. allowing high current to flow across under the forward bias condition and blocking current off under the reverse bias; this behaviour is controlled by the bias voltage dependent changes of the potential barrier height in the contact region.

Seed crystal:- single crystal material used in crystal growing to set a pattern for the growth of material in which this pattern is reproduced.

Semiconductor:- solid-state material in which (unlike in metals and insulators) (1) large changes in electrical conductivity can be effected by adding very small amounts of impurity elements known as dopants, (2) electrical conductivity can be controlled by both negatively charged electrons and positively charged holes and (3) electrical conductivity is sensitive to temperature, illumination, and magnetic field.

Silicon:- A semi-metallic element used to create a wafer.

Silicon dioxide, SiO_2:- silica; native oxide of silicon; the most common insulator in semiconductor device technology; high quality films are obtained by thermal oxidation of silicon; thermal SiO_2 forms smooth, low-defect interface with Si; can be also readily deposited by CVD; Key parameters: energy gap E_g ~ 8eV; dielectric strength 5-15 x 10^6 V/cm; dielectric constant k = 3.9; density 2.3 g/cm^3; refractive index n =1.46; melting point ~ 1700°C; prone to contamination with alkali ions and sensitive to high energy radiation (i.e. X-rays); single crystal SiO_2 is known as quartz.

Silicon Nitride, Si_3N_4:- dielectric material with energy gap = 5 eV and density ~3.0 g/cm^3; excellent mask against oxidation of Si and KOH; properties depend on deposition method: dielectric strength ~10^7 V/cm, dielectric constant k ~6-7, bulk resistivity 10^{15}-10^{17} ohm-cm; deposited by CDV.

Silyation:- The process of introducing silicon atoms into the surface of an organic photoresist in order to harden the photoresist.

Single-crystal:- crystalline solid in which atoms are arranged following specific pattern throughout the entire piece of material; in general, single crystal material features superior electronic and photonic properties as compared to polycrystalline and amorphous materials, but is more difficult to fabricate; all high-end semiconductor electronic and photonic materials are fabricated using single-crystal substrates.

Slice orientation: - the angle between the surface of a slice and the growth plane of the crystal. The most common slice orientations are (100), (111) and (110).

Slicing:- term refers to the process of cutting of the single-crystal ingot into wafers; high precision diamond blades are used.

Slurry:- a liquid containing suspended abrasive component; used for lapping, polishing and grinding of solid surfaces; can be chemically active; key element of CMP processes.

Spiking:- uncontrolled penetration of semiconductor substrate by contact metal; problem with Al in contact with silicon; may short ultra-shallow p-n junction underneath the contact.

Sputtering, sputter deposition:- bombardment of a solid (target) by high energy chemically inert ions (e.g. Ar+); causes ejection of atoms from the target which are then re-deposited on the surface of a substrate purposely located in the vicinity of the target; common method of Physical Vapour Deposition of metals and oxides.

Sputtering target:- source material during sputter deposition processes; typically a disc inside the vacuum chamber which is exposed to bombarding ions, knocking source atoms loose and onto samples.

Sputter yield:- efficiency of the sputtering process (differs for different materials).

Surface damage:- process related disruption of the crystallographic order at the surface of single-crystal semiconductor substrates; typically caused by surface interactions with high energy ions during dry etching and ion implantation.

Staebler - Wronski effect:- degradation of electrical output of hydrogenated amorphous silicon solar cells as a result of prolonged illumination.

Stripping:- process of material removal from the wafer surface; typically implies that removal is not carried out for the pattering purpose, e.g. resist stripping in which case entire resist is removed following lithography and etching.

Target:- source material used during evaporation or deposition; In sputtering, typically in the form of high purity disc. In e-Beam evaporation, typically in the form of a crucible. In thermal evaporation, the source material is typically held in a boat which is heated resistively.

Thermal oxidation, thermal oxide:- growth of oxide on the substrate through oxidation of the surface at elevated temperature; thermal oxidation of silicon results in a very high quality oxide, SiO2; most other semiconductors do not form device quality thermal oxide, hence, "thermal oxidation" is almost synonymous with "thermal oxidation of silicon".

Valence band:- the lower energy band in a semiconductor that is completely filled with electrons at 0 K; electrons cannot conduct in valence band.

Volume defect:- voids and/or local regions featuring different phase (e.g. precipitates or amorphous phase) in crystalline materials.

Wafer:- thin (thickness depends on wafer diameter, but is typically less than 1 mm), circular slice of single-crystal semiconductor material cut from the ingot of single crystal semiconductor; used in manufacturing of semiconductor devices and integrated circuits; wafer diameter may range from 25 mm to 300 mm.

Wafer bonding:- process in which two semiconductor wafers are bonded to form a single substrate; commonly applied to form SOI substrates; bonding of wafers of different materials, e.g. GaAs on Si, or SiC on Si; is more difficult than bonding of similar materials.

Wafer fabrication:- process in which single crystal semiconductor ingot is fabricated and transformed by cutting, grinding, polishing, and cleaning into a circular wafer with desired diameter and physical properties.

Wafer flat:- flat area on the perimeter of the wafer; location and number of wafer flats contains information on crystal orientation of the wafer and the dopant type (n-type or p-type).

Work function difference:- defines characteristics of contact between two materials featuring different work function; for conductor-semiconductor contact w.f.d. determines height of potential barrier in the contact plane, and hence, determines whether contact is ohmic or rectifying.

Glossary of Fuselink terminology (Fuseology)

'A' Fuselink (formerly Back-Up Fuselink):- A current limiting fuselink capable of breaking under specified conditions all currents between the lowest current indicated on its operating time-current characteristic and its rated breaking capacity.

Ambient Temperature:- The temperature of the surrounding medium which comes in contact with the fuse. The medium is usually air. Fuse current carrying capacity tests are performed at 25°C and are affected by changes in ambient temperature. A fuse runs hotter as the normal operating current approaches or exceeds its current rating. At room temperature, 25°C, a fuse should last indefinitely if operated at no more than 75% of fuse ampere rating. The fuse ambient temperature may be significantly higher because it is enclosed or mounted near other heat producing components, such as resistors, transformers, etc.

Ampacity:- The current a conductor can carry continuously without exceeding its temperature rating. Ampacity is a function of cable size, insulation type and the conditions of use.

Ampere Rating:- Same as Current Rating or the current carrying capacity of a fuse. The continuous current carrying capability of a fuse under defined conditions. When a fuse is subjected to a current above its ampere rating, it will open the circuit after a predetermined period of time. Continuous load current should not exceed 75% of fuse ampere rating (at 25°C ambient) except fuses that may be specifically loaded to 100% of their ampere rating.

Ampere Squared Seconds, I^2t:- A measure of thermal (heat) energy associated with current flow during fuse clearing. I^2t is equal to I^2_{RMS} x t, where t is the duration of current flow in seconds. It can be expressed as melting I^2t, arcing I^2t or their sum as Clearing I^2t. Clearing I^2t is the total I^2t passed by a fuse as the fuse clears a fault, with t being equal to the time elapsed from the initiation of the fault to the instant the fault has been cleared. Melting I^2t is the minimum I^2t required to melt the fuse element. 'I' is the effective let-through RMS current, which is squared, and 't' is the time of opening, in seconds.

Arc Quenching Time:- As part of the Operating Time it is the time between the arc starting and the final current zero. Depending on the Melting Time the Arc Quenching Time is typically just a few ms up to a couple of 100 ms.

Arcing Time:- The arcing time is the interval of time between the instant of the initiation of the arc and the instant of final arc extinction. That is the time from when the fuselink has melted until the over current is interrupted, or cleared.

Arc Voltage:- The highest fuse voltage during the Operating Time of the fuse.

Arcing withstand Time:- Longest time between separation of the melting element and the faultless interruption of the current through the fuse-switch. Typical values are above 100 ms.

Breaking Capacity:- The breaking capacity is the highest value (for ac the rms. value of the ac component) of prospective current that a fuselink is capable of breaking at a stated voltage under specified conditions of use and behaviour. The rating which defines the fuses ability to safely interrupt and clear short circuits. This rating is much greater than the ampere rating of a fuse. The highest current at rated voltage that an over current protective device is intended to interrupt under specified conditions. During a fault or short circuit condition, a fuse may receive an instantaneous overload current many times greater than its normal operating current. Safe operation requires that the fuse remain intact (no explosion or body rupture) and clear the circuit. Also known as interrupting rating or short circuit rating.

Breaking Range:- Breaking range is a range of prospective currents within which the breaking capacity of a fuselink is assured.

Clearing Time:- The total time from the beginning of the over current to the final opening of the circuit at rated voltage by an over current protective device. Clearing time is the total of the melting time and the arcing time.

Conventional Non-Fusing Current I_{nf}:- A value of current specified as that which the fuselink is capable of carrying for a specified time (conventional time) without melting. The conventional time relates to the thermal time constant of the fuselink and varies between one and four hours depending on the current rating.

Conventional Fusing Current I_f:- Current specified as that which causes operation of the fuselink within a specified time (conventional time). The conventional time relates to the thermal time constant of the fuselink and varies between one and four hours depending on the current rating.

Coordination:- The use of over-current protective devices which will isolate only that portion of an electrical system which has been overloaded or faulted.

Current-Limiting Fuselink:- A current-limiting fuse link limits the current to a substantially lower value than the peak value of the prospective current during and by its operation in a specified current range.

Current Limitation:- Fuse operation relating to short circuits only. When a fuse operates in its current limiting range, it will clear a short circuit in less than ½ cycle. Also, it will limit the instantaneous peak let-thru current to a value substantially less than that obtainable in the same circuit if that fuse were replaced with a solid conductor of the same impedance.

Current Rating:- The nominal amperage value of the fuse. It is established as a value of current which the fuse can carry, based on a controlled set of test conditions

Cut-Off Current:- The cut-off or let-through current is the maximum instantaneous value reached by the current during the breaking operation of a fuselink when it operates in such a manner as to prevent the current from reaching the otherwise attainable maximum. In case of a short-circuit, the maximum value of the short circuit current. This value is required for the analysis of the dynamic impact of the short-circuit current on the protected equipment.

Cut-off (current) characteristic:- The cut-off (current) characteristic or let-through current characteristic is a curve giving the cut-off current as a function of the prospective current, under specified operating conditions.

Derating:- Term for reducing influences on the Rated Breaking Current of the fuse. The Derating value is multiplied by the Rated Current then divided by the loading current. Typical influencing factors include high surrounding temperature, terminal cross section, installation volume, pulse load, shock load, and over-waves.

Discrimination:- Classification of relevant parameters (Time/Current-Characteristic; Integrals; Operating Times etc.) of two or more overload protection devices to each other. In the case of overloads, only the protection device should react. Sequential fuses with the same characteristic, are selected in the proportion 1:1.6. A fuse with a rated current of 100 A should be downstream of a fuse rated 160 A. For the short-circuit range the comparison of the melting integrals versus the Operating integral of the downstream fuse is important.

Dissipated Power:- When a current passes through a fuse link, a small amount of energy is dissipated due to the fuse links resistance.

Dual Element Fuse:- Often confused with time delay, dual element is a term describing fuse element construction. A fuse having two current responsive elements in series.

Element:- A calibrated conductor inside a fuse which melts when subjected to excessive current. The element is enclosed by the fuse body and may be surrounded by an arc-quenching medium such as silica sand. The element is sometimes referred to as a link.

Fast-Acting Fuse:- Fast-acting fuses have no intentional built in slow-blow and are used in circuits without transient inrush currents. Fast-acting fuses open quickly on overload and short-circuits. This type of fuse is not designed to withstand temporary overload currents.

Fault current:- A current resulting from a fault, a circuit condition in which the current flows through an abnormal, unintended path.

Fusing factor:- The fusing factor is the ratio, greater than unity, of the minimum fusing current to the fuse current rating.

Fuse:- A fuse is a device that by the fusing of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a sufficient time. An over-current protective device containing a calibrated current carrying member which melts and opens a circuit under specified over-current conditions. It is common practice to refer to a 'fuselink' as a 'fuse'.

Fuse Element:- Part of the Fuse-Link, which melts when the fuse operates. It consists of perforated metal stripes. The dimension of the perforation reflects the Characteristic and the Rated Current of the Fuse-Link. Depending on the Rated Current the Fuse-Links contain several paralleled Fuse Elements. Typical materials are copper and pure silver.

Fuse initiated opening time:- Time between separating of the melting elements and the faultless interruption of the failure current through the fuse. Typically between 30 and 100 ms.

Fuse Selection Guide:- The fuse must carry the normal circuit load current without nuisance openings. However, when an over-current occurs the fuse must interrupt the over-current, limit the energy let-through, and withstand the voltage across the fuse during arcing. To select a fuse the following must be considered:

Normal operating current (The current rating of a fuse is typically derated 25% for operation at 25°C to avoid nuisance blowing. For example, a fuse with a 10A current rating is not usually recommended for operation at more than 7.5A in a 25°C ambient.)
Overload current and time interval in which the fuse must open.
Application voltage (AC or DC Voltage).
Inrush currents, surge currents, pulses, start-up currents characteristics.
Ambient temperature.
Applicable standards agency requirements, such as UL, CSA, VDE.

Other considerations include: Reduce installation cost, ease of removal, mounting type/form factor, etc.

Fuse Type:- There are three basic types of fuses:

1. Slow Blow/Time Lag/Time Delay fuses
2. Fast acting fuses
3. Very fast acting fuses

A major type of Time Delay fuse is the dual-element fuse. This fuse consists of a short circuit strip, soldered joint and spring connection. During overload conditions, the soldered joint gets hot enough to melt and the spring shears the junction loose. Under short circuit conditions, the short circuit element operates to open the circuit. Slow-blow fuse allows temporary and harmless inrush currents to pass without opening, but is so designed to open on sustained overloads and short circuits. Slow-blow fuses are ideal for circuits with a transient surge or power-on inrush. These circuits include: motors, transformers, incandescent lamps and capacitate loads. This inrush may be many times the circuit's full load amperes. Slow-blow fuses allow close rating of the fuse without nuisance opening. Typically, Slow Blow fuses are rated between 125% to 150% of the circuit's full load amperes.

Fusing Current:- Value of fuse current which will be interrupted within a given time. Valid for general purpose fuse-links. Normally the testing current is about 1.6 times the Rated Current.

Gate:- Limiting values within which the characteristics, for example time-current characteristics, shall be contained.

High Speed Fuses:- Fuses with no intentional time-delay in the overload range and designed to open as quickly as possible in the short circuit range. Often used to protect solid-state devices.

Homogeneous Series of Fuselinks:- A series of fuselinks, within a given size.

I^2t (Joule Integral) :- See Joule integral.

I^2t (Ampere Squared Seconds):- A measure of the thermal energy associated with current flow. I^2t is equal to $I_{RMS}{}^2 \times t$, where t is the duration of current flow in seconds.

Clearing I^2t is the total I^2t passed by a fuse as the fuse clears a fault, with *t* being equal to the time elapsed from the initiation of the fault to the instant the fault has been cleared.

Melting I^2t is the minimum I^2t required to melt the fuse element.

I^2t *Characteristic*:- A curve giving I^2t values (pre-arcing I^2t and/or operating I^2t) as a function of prospective current under specific operating conditions.

Interrupting Rating (Abbreviated IR):- Same as breaking capacity or short circuit rating. The maximum current a fuse can safely interrupt at rated voltage. Some special purpose fuses may also have a *Minimum Interrupting Rating*. This defines the minimum current that a fuse can safely interrupt. Safe operation requires that the fuse remain intact. Interrupting ratings may vary with fuse design and range from 35A AC for some 250V metric size (5 x 20mm) fuses up to 200kA AC for the 600V industrial fuses.

Joule integral:- The I^2t or Joule integral is a measure of the thermal stress or thermal energy let through by the fuse during short circuit interruption. It is the integral of the square of the current over a given time and is expressed in ampere square seconds.

Two values of I^2t are provided for MV-fuse links:

- Pre arcing or melting I^2t - for high short circuit currents - this is practically a constant.
- Operation I^2t – this varies with circuit conditions.

Let-through current:- The cut-off or let-through current is the maximum instantaneous value of current attained during the breaking operation of a MV-fuse link. This important when the MV-fuse link operates in such that the circuit prospective peak current is not reached.

Let-through current characteristic:- The cut-off (current) characteristic or let-through current characteristic is a curve giving the cut-off current as a function of the prospective current, under specific operating conditions.

Melting Current:- Current during an increase in prospective Short-Circuit Current, at which the Fuse Element melts. This current is usually lower than the Cut-off Current, because this normally increases during the Quenching Time.

Melting Integral:- Current Integral for the Melting time of the fuse. The Melting Integral depends on the size of the Melting Elements and is therefore independent of voltage. The minimum value is normally given, for analysing discrimination.

Melting time:- The amount of time required to melt the fuselink during a specified over current. The pre-arcing time or melting time is the interval of time between the beginning of a current large enough to cause a break in the fuse element and the instant when an arc is initiated. The Time/Current-Characteristic provides the virtual Melting Time for different current closing angles. Virtual Melting Time = Melting Integral / failure current.

Minimum Breaking Current:- Smallest failure current at which a back-up fuse can operate at its rated voltage. Values are often between 3 to 4 times Rated Current. The minimum breaking current is a minimum value of prospective current that a link is capable of breaking at a stated voltage under specified conditions.

Non fusing Current:- Defined value of current, at which (under certain circumstances) a fuse-link must not operate within a given time, Conventional Time. For a General Purpose Fuse, this value is normally 1.25 times Rated Current.

Operating time:- The operating time or total clearing time is the sum of the pre-arcing time and the arcing time. Also the summation of Melting Time and Arc Quenching Time of the Fuse. Over a Melting Time of 100ms the Operating Time can generally be equated with the Melting Time. For shorter Melting Times, the Operating Time can be more than double of the Melting Time. Below 5ms, the Operating Time should be calculated via the Operating Integral.

Operating Integral:- Current integral over the operating time of the fuse. Information is particularly valid for melting times less than 5ms, whence the fuse has operated with current limitation. Usually the datasheet value is the highest expect for the given reference voltage. Values at lower service voltage are calculated through the conversion diagram.

Overcurrent:- An over-current is a current exceeding the rated current, normal load current, conductor ampacity or equipment continuous current rating. An over-current can be an overload current, fault current or short circuit current.

Overcurrent Discrimination:- Co-ordination of the relevant characteristics of two or more over-current protective devices such that, on the occurrence of over-currents within specific limits, the device intended to operate within these limits does so, while the others do not.

Overload:- Classified as an overcurrent which exceeds the circuit normal full load current. The operation of conductors or equipment at a current level that will cause damage if allowed to persist. The current does not leave the normal current carrying path of the circuit, that is, it flows from the source, through the conductors, through the load, back through the conductors to the source.

Overload current:- A current resulting from an overload occurring in a normally working electrically circuit, for example an overloaded motor. If there is no protective device operating in a limited time of several seconds, the electrical system would overheat and cable isolation, etc. would melt and cause damage.

Overload Curve of an Fuselink:- A curve showing the time for which a fuselink shall be able to carry the current without deterioration.

Peak Let-Thru Current, I_P:- The instantaneous value of peak current let-thru by a current limiting fuse, when clearing a fault current of specified magnitude in its current limiting range.

Power Dissipation:- Power dissipation is the power released in a fuse link carrying a stated current under specified conditions of use and behaviour, usually including a constant rms. current until steady temperature conditions are reached.

Pre-Arcing Time:- The pre-arcing time or melting time is the interval between the beginning of a current large enough to cause a break in the fuse element and the instant when an arc is initiated.

Prospective Current of a Circuit (with respect to the fuse):- The prospective current is the current that would flow in a circuit if a fuse situated therein were replaced by a link of negligible impedance. The prospective current is the quantity to which the breaking capacity and characteristics of the fuse are normally referred, for example, I^2t and cut-off current characteristic.

Prospective Short Circuit Current:- The prospective short circuit current is the value of the current that would flow if there was no protection in the circuit. The lower the power factor of the installation, the higher the peak value of this destructive current.

Rated Breaking Capacity (Low/High Voltage Fuses):- Capacity of a fuse to operate between the lowest and the Rated Breaking Current, which is a certified, effective value. Normally fuses can operate at higher currents. Typical values for Low-Voltage fuses are: 100, 120, 200 or 300 kA and for High-Voltage fuses 20kA to 63 kA. For miniature fuses, it is the current at which a fuse can operate normally under specified conditions at a fixed Voltage.

Rated Current of a Fuselink I_n:- A value of current that the fuselink can carry continuously without deteriorating or without operating under specified standardised conditions, including in free air with a defined cable cross-sections. Often the Rated Current has to be reduced by the Derating-value.

Rated Frequency:- The rated frequency is the frequency for which the fuse link has been designed and to which the values of the other characteristics correspond. Standard values of rated frequency are 50 Hz and 60 Hz.

Rated Insulation Level:- The rated insulation level (of a MV-fuse base) is the voltage values (both power-frequency and impulse) which characterize the insulation of the fuse base with regards to its capability of withstanding the dielectric stresses.

Rated Values:- Rated values, usually stated for HV-fuse links, are

- voltage
- current
- breaking capacity
- frequency

All given for specified operating conditions.

Rated Voltage:- The Rated voltage, V_n, is the maximum value of voltage at which an fuse link can be used, and safely interrupt an over-current. This rated voltage must be higher or equal to the highest voltage of the system in which the fuse link is installed. Effective value of the Operating Voltage of a fuse; normally an alternating voltage, at a frequency between 42 to 62 Hz.

Recovery Voltage:- The recovery voltage is the voltage which appears across the terminals of a fuse after the breaking of the current. This voltage is considered in two successive intervals of time, one during which a transient voltage exists, followed by a second during which the power frequency or the steady-state recovery voltage alone exists.

Selectivity:- A main fuse and a branch fuse are said to be selective if the branch fuse will clear all over-current conditions before the main fuse opens. Selectivity is desirable because it limits outage to that portion of the circuit which has been overloaded or faulted. Also called *selective coordination*.

Short Circuit:- A high value of over-current resulting from a fault of negligible impedance between conductors with difference potential and under normal operating conditions. A short circuit current can be many hundreds or even thousands of times larger than the normal load current.

Striker:- A striker is a mechanical device forming part of a fuselink which, when the fuse operates, releases the energy required to cause operation of other apparatus or indicators or to provide interlocking.

Switching voltage:- The switching voltage is the maximum instantaneous value of voltage, which appears across the terminals of a fuse during its operating time. Under short circuit conditions this will often exceed the peak system voltage for a period of time. It is typically two to three times the Rated Voltage.

Time-current characteristic:- The time-current characteristic is a curve giving the time, for example pre-arcing time (or operating time), as a function of the prospective current and respectively short-circuit currents. under specified operating conditions. The time-current curve is used to achieve co-ordination with the other fuses or devices in the same installation.

Time/Current-Curve:- Curve for calculating the Melting Time of the fuse at designed overload and respectively short-circuit current. The opening time is considered nominal. Time/Current-Curves refer to a temperature between 20°C and 30°C, are given for times between 4ms and 10000s, and are drawn as a family of curves on a double logarithmic grid (opening time in seconds for the fuse for a range of over-currents).

Time Delay Fuse:- A fuse which will carry an over-current of a specified magnitude for a minimum specified (in standards) time without opening.

Take-Over Current:- at operating the Striker Pin: Value of the symmetrical three phase current at which the breaking varies between the fuse and the switch. Below this value the current will be interrupted in the first quenching pole through a fuse and the current in both other poles through the switch. Above the value, the current is interrupted in all 3 poles only through the fuses. Depending on the Rated Voltage of the switch, values are between 600A and 3000A.

Threshold Current:- The minimum available fault current at which a fuse is current limiting.

Total clearing time:- The operating time or total clearing time is the sum of the pre arcing time and the arcing time.

Very Fast-Acting Fuses:- Very fast-acting (Current-Limiting) fuses will limit both the magnitude and duration of current flow under short circuit conditions. Because of their high current limiting ability, these fuses are frequently used to protect semiconductor circuits.

Virtual time:- The virtual time is the value of Joule integral divided by the square of the prospective current value. Usually stated for a MV-fuse link, are the values of pre-arcing time and of operating time.

Virtual Melting time:- Standardised value of melting time, which considers currents of types AC or DC and the different current curves and switching angles. The Melting Time in the Time/Current-Characteristics is generally given by the Virtual Melting Time. The value is calculated by the Melting integral of the Rated Current.

Voltage Rating:- The maximum voltage at which a fuse is designed to operate. The maximum open circuit voltage in which a fuse can be used, yet safely interrupt an overcurrent. Exceeding the voltage rating of a fuse impairs its ability to clear an overload or short circuit safely. Voltage ratings are assumed to be for AC, unless specifically labelled as DC.

Glossary of Relay terminology

Arc:- An electric discharge between mating relay contacts when an energized circuit is interrupted. Plasma current flow between opening relay contacts. An arc is enabled by the electric power of the load circuit (turn off spark) ionizing the gas between the contacts. The stability of the arc depends on various parameters such as contact material, air pressure, contact gap, etc. An arc locally produces high temperature causing contact erosion. In cases of strong erosion, spark suppression becomes necessary.

Arc suppression:- An arc will form as contacts come together and currents flow, and when they break apart. With ac current the condition is seldom a problem in relays, but with high dc loads the arc can be substantial causing contact damage. Arc suppression can be achieved using a blow out magnet.

Bounce:- Occurs as a moving contact strikes a fixed contact and ‘bounces’ before remaining full at rest. This has to be minimised, as creates signal noise and contact wear.

Bounce, armature:- See *rebound, armature*.

Bounce Time:- The time from the first to the last closing or opening of a relay contact.

Break:- The opening of closed contacts to interrupt an electrical circuit.

Break-Before-Make:- Disconnecting the present circuit before connecting a new circuit. Also known as Break/Make.

Break Contact:- NC contact. The break contact is closed in the release (rest) state of a monostable relay and opens (breaks) when the armature moves to the core (operate state).

Bridging:- (1) Normal bridging: The normal make-before-break action of a make-break or D contact combination. In a stepping switch, the coming together momentarily of two adjacent contacts by a wiper shaped for that purpose in the process of moving from one contact to another. (2) Abnormal bridging: The undesired closing of open contacts caused by a metallic bridge or protrusion developed by arcing.

Bunching, contact:- The undesired, simultaneous closure of make-and-break contacts during vibration, shock, or acceleration. Also, the simultaneous closure of the contacts of a continuity transfer or bridging contact combination.

Changeover Contact:- Contact configuration with make and break contact. Changing the switch position opens the closed contact first and then closes the formerly open contact.

Chatter, armature:- The undesired vibration of the armature due to inadequate ac performance or external shock and vibration.

Chatter, Contact:- Externally caused, undesired vibration of mating contacts during which there may or may not be actual physical contact opening. If there is no actual opening but only a change in resistance, it is referred to as dynamic resistance.

Closing Time:- Time between energization of the coil until the moment the contacts of the first current path to be closed actually close.

Coil:- That part of a relay which is energised to create a magnetic field that attracts a lever that in turn carries out the switching function. An assembly consisting of one or more windings, usually wound over an un-insulated iron core on a bobbin or spool. May be self-supporting, with terminals and any other required parts such as a sleeve or slugs.

1. Concentrically Wound-: A coil with two or more insulated windings wound one over the other.
2. Double Wound-: A coil consisting of two windings wound on the same core.
3. Parallel Wound:- A coil having multiple windings wound simultaneously, with the turns of each winding being contiguous, termed bifilar wound.
4. Sandwich Wound:- A coil consisting of three concentric windings in which the first and third windings are connected series aiding to match the impedance of the second winding. The combination is used to maintain transmission balance.
5. Tandem Wound:- A coil having tow or more windings, one behind the other, along the longitudinal axis. Also referred to as a two, three, or four-section coil, etc.

Coil Hi-Pot:- The minimum voltage (potential) which the relay coil terminals will isolate when the relay is properly mounted.

Coil Operating Range:- Expressed as a multiple of the rated control circuit voltage V_c for the lower and upper limits.

Coil Resistance:- The DC resistance of the energised relay coil measured at 25°C, not including a parallel device for coil suppression. *Shock* - The number of gravities (G's) a relay can sustain when tested by a ½ sine pulse (calibrated impact) for 11 milliseconds without the closed contacts opening or the open contacts closing. *Vibration* - The simple harmonic motion at rated gravities and frequency (G/Hz) that a relay can sustain without uncontrolled opening of closed contacts or closing of open contacts.

Coil Suppression Circuit:- Circuit to reduce the inductive switch off voltage peak of the relay coil (EMC protection, switch off voltage peak). Note that most of the circuits reduce the armature release speed, which can decrease the relay lifetime, especially valid for diodes in parallel to the coil. From the various solutions, the use of a Zener diode is particularly suitable.

Cold:- An unenergized electrical circuit.

Cold Switching:- Closing the relay contacts before applying voltage and current, plus removing voltage and current before opening the contacts. (Contacts do not make or break current.) Also termed Dry Circuit Switching. Larger currents may be carried through the contacts without damage to the contact area since contacts will not arc when closed or opened. Maximises contact life.

Contact:- Made out of contact material and part of the contact set where the electrical load circuit is opened or closed.

Contact Arrangement:- Relays are typically one of the following arrangements and contact forms:

single pole single throw (SPST) - Normally Open, NO, NO-double make
Normally Closed, NC, NC-double break
latching
single pole double throw (SPDT) - latching
double pole double throw (DPDT)
four pole double throw (4PDT)

Contact, Auxiliary:- A contact combination used to operate a visual or audible signal to indicate the position of the main contacts, establish interlocking circuits, or hold a relay operated when the original operating circuit is opened.

Contact Bounce:- The intermittent undesirable opening of closed mechanical contacts or closing of open contacts. Internally caused intermittent and undesired opening of closed contacts, or closing of open contacts, of a relay, caused by one or more of the following:

(1) Impingement of mating contacts;
(2) Impact of the armature against the coil core on pickup or against the backstop on dropout;
(3) Momentary hesitation or reversal of the armature motion during the pickup or dropout stroke.

Contact bounce period depends upon the type of relay and varies from ½ms for small reed relays to 10-20ms for larger solenoid types. Solid-state or mercury wetted contacts (Hg) do not have a contact bounce characteristic.

Contact, Break:- See contact, normally closed.

Contact, break-before-make:- A contact combination in which one contact opens its connection to another contact and then closes its connection to a third contact.

Contact, break-make:- See contact, break-before-make.

Contact Capacitance:- The capacitance of the relay measured (a) between the open contact, or (b) between contact terminals and ground. Measured at 1 kHz.

Contact Configuration:- Relay switch configuration (make, break or changeover contact). According to the application, various contact configurations are used. Contacts which are moved by the armature system are called → movable contacts, and non moving contacts stationary contacts.

Contact, Double Break:- A contact combination in which contact on a single conductive support simultaneously open electrical circuits connected to two independent contacts. This provides two contact air gaps in series when the contact is open Note: In B combination is terminal is brought out form the movable contact. In the Y combination, it is not.

Contact, Double Make:- A contact combination in which contacts on a single conductive support simultaneously close electrical circuits connected to the contact of two independent contacts, and provides two contact air gaps in series when the contact is open. (Sometimes called normally open, double-make contact.) Note: In U combination a terminal is brought out from the movable arm. In the X combination it is not.

Contact, Double Throw:- A contact combination having two positions as in break-make, make-break, and the like.

Contact Erosion:- Material loss at the contact surfaces, for example due to material evaporation by an arc.

Contact Force:- The force which two contact tips (points) exert against each other in the closed position under specified conditions.

Contact Gap:- The gap between the contact tips (points) under specified conditions, when the contact circuit is open.

Contact Interrupter:- On a stepping relay or switch, a contact combination operated directly by the armature that opens and closes the winding circuit, permitting the device to step itself.

Contact Life:- The maximum number of expected closures before failure. Life is dependent on the switched voltage, current, and power. Failure is usually when the contact resistance exceeds an end of life value. Typical failure mode is non-closure of the contact as opposed to a contact sticking closed.

Contact, Low Level:- Contact that control only the flow of relatively small currents in relatively low-voltage circuits; e.g., alternating currents and voltages encountered in voice or tone circuits, direct currents in the order of microamperes, and voltages below the softening voltages of record for various contact materials (that is, 0.080 volt for gold, 0.25 volt for platinum, etc.) Also defined as contacts switching loads where there is no electrical arc transfer of detectable thermal effect and where only mechanical forces can change the conditions of the contact interface.

Contact, Main:- The primary set of contacts of a relay, usually defined as those having the highest current rating.

Contact, Make:- See contact, normally open.

Contact, make-before-break:-See contact, continuity transfer.

Contact, make-break:- See contact, continuity transfer.

Contact Material:- For relays a variety of contact materials are in use. They operate under a wide range of loads in terms of voltage and current. Inductive loads can cause high switch off voltages and strong arcs, capacitors create inrush current peaks. Arcs and improper coil suppression can reduce the lifetime of a contact. So far, no universal contact material is known, that can be used on all load types with optimum performance. Contact manufacturers, relay developers, and users have established the following criteria to describe a contact:

• Electrical resistance

• Resistance to contact erosion
• Resistance to material transfer
• Resistance to welding

Contact, Normally Closed:- A contact combination which is closed when the armature is in its unoperated position. A pair of contacts are together at rest making an electrical circuit.

Contact, Normally Open:- A contact combination that is open when the armature is in its unoperated position. A pair of contacts are separated at rest with no electrical connection. (Generally applies to monostable relays.)

Contact, Off:- normal-A form C contact combination on a stepping switch that is in one condition when the relay or stepping switch is in its normal position and in the opposite condition for any other position of the relay or stepping switch; i.e., when not in its reset or home position.

Contact, Operate Time:- Time from initial energization to the first opening of closed contact or first closing of open contact, prior to bounce.

Contact Potential:- A voltage produced between contact terminals due to the temperature gradient across the relay contacts, and the reed-to-terminal junctions of dissimilar metals. (The temperature gradient is typically caused by the power dissipated by the energized coil.) Also known as contact offset voltage, thermal EMF, and thermal offset. This is a major consideration when measuring voltages in the microvolt range. There are special low thermal relay contacts available to address this need. Special contacts are not required if the relay is closed for a short period of time where the coil has no time to vary the temperature of the contact or connecting materials (welds or leads).

Contact Rating:- The voltage, current, and power capacities of relay contacts under specified environmental conditions.

Contact, Reed:-

1. A glass-enclosed, magnetically operated contact using thin, flexible, magnetic conducting strips as the contacting members.
2. Contact assembly, the contact members of which are blades either fully or partly of magnetic material and which are moved directly by a magnetic force.

Contact Release Time:- Time form initial de-energization of the relay coil to the first opening of a closed contact prior to bounce.

Contact Resistance:- The resistance between closed load contacts. In vacuum relays, this measurement is typically made at 6V dc with a 1A rms load. In gas-filled relays, 1A at 28V dc is used to measure contact resistance. 'Kelvin' connections should be used to obtain accurate readings. The resistance can be obtained from the ratio of the voltage drop across the relay and the load current (Ohm's law). Surface layers (fritting) can result in non-linear contact resistances and increased voltage.

Contact Transfer Time:- Time during which the moving contact first opens from a closed position and first makes with the opposite throw of the contact. It is floating in a non-contacting position prior to bounce and after energizing or de-energizing the coil.

Contact Weld:- A contact failure due to fusing of contacting surfaces to the extent that the contacts fail to separate when intended.

Continuous Current, Carry:- The maximum current that can be carried by the closed contacts of the relay for a sustained time period. This current rating is determined by the relay envelope temperature rise and must be derated at RF frequencies. A glass relay is allowed a 62°C rise, and a ceramic relay a 100°C temperature rise. Current ratings can be increased by external cooling, such as by forced air or heat sinks.

Crosstalk:- The electrical coupling between a closed contact circuit and other open or closed contact on the same relay or switch, expressed in decibels down form the signal level.

Current, maximum rate of rise on state (*di/dt*):- The maximum non-repetitive rate of current rise the output can withstand without being damaged.

1. With the relay output(s) turned on by the application or removal of the control voltage and/or current.
2. With the relay output(s) driven into break-over with the input at non-operate level.

Current, minimum load, $I_{Tmin(rms)}$:-The minimum current required to maintain the relay in the on-state (nominal load voltage applies). Applies mainly to solid-state relays.

Current, non-repetitive surge, I_{TSM}:- The maximum allowable, non-repetitive, peak, sinusoidal current that may be applied to the output for one full cycle at nominal line frequency. Relay control may be lost during and following the surge until the junction temperature falls below the maximum rated temperature.

Current rated contact:- The current which the contacts are designed to handle for their rated life.

Current, repetitive overload, $I_{TO(rms)}$ -The maximum allowable repetitive rms overload current that may be applied to the output for a specific duration and duty cycle while still maintaining output control. Applies mainly to solid state relays.

De-energize:- To remove power from a relay coil.

Dielectric:- An insulating medium capable of recovering, as electrical energy, all or part of the energy required to establish an electrical field (voltage stress). The field, or voltage stress, is accompanied by displacement or charging currents. A vacuum is the only perfect dielectric.

Dielectric strength, V_{ISO}:- The maximum allowable ac rms voltage (50/60Hz) which may be applied between two specified test points such as input-output, input-case, output-case in solid state relays, and between current-carrying and non-current-carrying metal members in electromechanical relays, without a leakage current in excess of 1mA.
Dropout, to drop out:- A monostable relay drops out when it changes from an energized to an un-energized condition. Not applicable latching relays.
Dropout, time:- See time, release.
Dropout Voltage:- The maximum coil voltage at which an operating relay releases and all normally closed contacts close. The voltage at which a relay (coil) de-energises sufficiently for the operating lever to move back to its rest position. It is normally expressed as a % of the nominal coil voltage.
Dry Circuit Switching:- Switching below specified levels of voltage and current to minimize any physical and electrical changes in the contact junction. Also see Cold Switching.
Dry reed relay:- See relay, reed.
Dynamic contact resistance:- A change in contact electrical resistance due to a variation in contact pressure on a contacts mechanically closed; occurrence is during non-bounce condition.
Electrical Endurance:- Number of on-load operating cycles (i.e. with current on the main contacts) a contactor can achieve, without failure, varies depending on the utilization category. The lifetime varies with the load. If not stated otherwise, the reference values apply for resistive or inductive loads with suitable spark suppression.
Electrostatic screening:- Screening plate between coil and contact to provide electrostatic screening in reed relays.
Energization:- The application of power to a coil winding of a relay to generate a magnetic field to move the armature. With respect to an operating coil winding, use of the word commonly assumes enough power to operate the fully. The energizing value is the product of the coil current and the number of wire turns of the coil.
Expected Mechanical Life:- The minimum number of operations for which a relay can be expected to operate reliably. "Cold" switching applications approach this figure.
Form:- A: Configuration which has one single-pole single-throw normally open (SPST no) contact.
B: Configuration which has one single-pole single-throw normally closed (SPST nc) contact.
C: Contact configuration which has one single pole-double throw (SPDT) contact. (One common point connected to one normally open and one normally closed contact.) Sometimes referred to as a transfer contact.
Freezing, magnetic:- Sticking of the relay armature to the core due to residual magnetism.
Fritting:- Electrical breakdown which can occur under special conditions (voltage, current) whenever thin contact films prevent electrical conductivity between closed contacts. Fritting is a process which generates (A-fritting) and/or widens (B-fritting) a conducting current path through such a semi-conducting film on a contact surface. During A-fritting, electrons are injected into the undamaged film. The electron current alters the condition of the film producing a ‘conductive channel’. During the following B-fritting, the current widens the channel increasing the conductivity.
Gaging, relay contact:- The setting of relay contact spacing to determine the point in the armature's stoke at which specified contacts function.
Gap, contact:- The distance between a pair of mating relay contacts when the contacts are open.
Gap, heel:- A gap or nonmagnetic separation in the magnetic circuit other than between the armature and pole face. Generally, located between the heel piece and pole piece of an ac relay.
Gap, residual:- The thickness of nonmagnetic material in the magnetic circuit between the pole face centre and the nearest point on the armature when the armature is in the fully seated position.
Grass:- See *dynamic contact resistance*.
Hard failure:- Permanent failure of the contact being tested.
Hermetic seal:- An enclosure that is sealed by fusion to ensure a low rate of gas leakage. In a reed switch, a glass-to-metal seal is employed.
Hesitation, armature:- Delay or momentary reversal of armature motion in either the pickup or dropout stroke.
Hold value specified:- As the current or voltage on an operated relay is decreased, the value at or above which all relay contacts must restore to their un-operated positions.
Hold Voltage:- The lowest voltage that can be applied without any change in state of the contacts from their energized position. This is just above the maximum drop-out voltage.
Hot:- An energized electrical circuit.
Hot switching:- A circuit design that applies the switched load to the switch contacts at the time of opening and closure.
Inrush:- Inrush current is the peak current passing across the contacts of a relay when the contact is first

made and is dependent on the load being switched. A relay which has contacts rated for a continuous current, the nominal contact current, may be capable of withstanding much higher currents for short periods. Inrush current can form a surge flowing through a relay switching a low impedance source load - typically a highly reactive circuit, or one with a non-linear load characteristic such as a tungsten lamp load. Such abusive load surges are sometimes encountered when reed relays are inadvertently connected to test loads containing undischarged capacitors, or to long transmission lines with appreciable amounts of stored capacitive energy. Excessive inrush currents can cause switch contact welding or premature contact failure.
Insulation resistance, R_{ISO}:- The minimum allowable dc resistance between input and output of solid state relays and between contacts and coil for electromechanical and reed relays, at a specified voltage, usually 500V dc.
Isolation:- The value of insulation resistance, dielectric strength, and capacitance measured between the input and outputs, input to case, output to case, and output to output when applicable.
Latching:- In relay or switching technology, this refers to the ability to keep the contact status in place even if power is removed from the equipment.
Latching relay:- In a latching relay, after the coil input voltage is disconnected, the contacts remain in the last reached switching position. Normally latching relays are reset contact position. Latching relays only require a short set respectively reset impulse. A permanent coil power supply after setting/resetting the relay is neither necessary nor allowed: maximal pulse durations depend on the relay family. Hence the distinguishing characteristic of monostable relays in respect to a fail safe behaviour is the fact that the predefined contact rest position will be reached at break down of the power supply. This behaviour cannot be shown by latching relays due to the bistable working principle they are based on.
Leakage Current:- The rms current conducted by the output circuit of the relay at maximum rated voltage with the contacts open.
Limiting continuous current:- The highest current (effective value for AC loads) a relay can carry under specified conditions without exceeding its specified upper limit temperature. This is not the current that can be switched with any load over the specified lifetime.
Load:- The electrical circuit which is being switched is measured and defined by

1. current in amperes, A
2. voltage in volts, V: dc or ac, and
3. load type (Inductive or resistive current flow when the contact is first made).

A relay is generally limited by the amount of heat that occurs when an electrical current passes across its contacts. This represents the ‘load’ that a relay can switch and is normally presented as an electrical value This is usually stated as a contact current in A then a voltage often standardised at 250Vac/dc followed by a maximum capacity at a resistive load. This is the result of multiplying current by voltage, expressed as VA. It is usually the maximum permissible load at any time including starting and stopping.
Load, curve:- The static force/displacement characteristics of the total spring-load of the relay.
Load Life:- The minimum number of cycles the relay will make, carry, and break the specified load without contact sticking or welding, and without exceeding the electrical specifications of the device. Load life is established using various methods including Weibull probability methods.
Magnet, blowout:- A device that establishes a magnetic field in the contact gap to help extinguish the arc by displacing it.
Magnetic interaction:- Mainly relevant to reed relays. The tendency of a relay to be influenced by an external magnetic field. This influence can result in depression or elevation of the pull-in and drop out voltage of the affected relay, possibly causing operation outside its specification. Magnetic interaction can be minimized by alternating the polarity of adjacent relay coils, by magnetic shielding, or by placing two relays at right angles to each other.
Magnetic shield:- Mainly relevant to reed relays. A ferromagnetic material used to minimize magnetic coupling between the relay and external magnetic fields.
Make:- The closure of open contacts to complete an electric circuit.
Maximum operate voltage (or must operate voltage):- Voltage at room ambient temperature (RT) a relay must operate at. To guarantee proper function of all relays, the applied coil voltage in the application must be above this specified operating voltage. The actual operate voltage of an individual relay, the maximum operate voltage and the application system value are sometimes all called operate voltage.
Maximum voltage U_{max} or V_{max}:- Maximum coil voltage at RT, at which the coil reaches the specified upper limit temperature without contact load (maximum continuous thermal load at 23°C).
Maximum switching power:- Maximum permissible power switched by the relay contacts, i.e. the product of the switching current and switching voltage.
Mechanical Endurance:- Number of off-load operating cycles (i.e. without current on the main contacts) a contactor can achieve.
Mechanical Life:- This is the number of operations which a relay can be expected to perform while

maintaining mechanical integrity. Mechanical life is normally tested with no load or voltage applied to the power contacts and is established using various methods including Weibull analysis.

Mechanical shock, non-operating:- The mechanical shock level (amplitude, duration and wave shape) to which the relay may be subjected without permanent electrical or mechanical damage (during storage or transportation).

Mechanical shock, operating:- That mechanical shock level (amplitude, duration and wave shape) to which the relay may be subjected without permanent electrical or mechanical damage during its operating mode.

Mercury wetted (contact) relay:- A form of reed relay in which the contacts are wetted by a film of mercury (Hg) obtained by a capillary action from a mercury pool encapsulated within the reed switch. Usually has a required operating position (usually vertical) to avoid liquid mercury from shorting the contacts; other types are position insensitive. This type of relay is usually higher power and longer life, but at a higher dollar cost. Another benefit of this type of contact is the repeatability of contact resistance and virtually no contact bounce.

Minimum recommended voltage:- Minimum load voltage to ensure an adequate contact cleaning (see also 'fritting').

Minimum voltage U_{min} or V_{min}:- Minimum coil voltage at RT where a relay is still able to operate.

Minimum release voltage (must release voltage):- Voltage at RT a relay must release at. To guarantee proper function of all relays, the limit in the application must be below this specified release voltage .The release voltage of an individual relay, the guaranteed minimum (must) release voltage and the system value are sometimes all called release voltage.

Minimal operation time:- Shortest control duration to ensure complete closing or opening of a contactor.

NC contact (normally closed):- Same as break contact. The break contact is closed in the release (rest) state of a monostable relay and opens (breaks) when the armature moves to the core (operate state).

NO contact (normally open):- Same as make contact. Contact is open in the release (rest) state of a monostable relay and closes (makes) when the relay coil is energized (operate state).

Nonpickup value, specified:- As the current or voltage on an unoperated relay is increased, the value which must be reached before any contact change occurs.

Nonrelease, specified:- See operating characteristics, hold value.

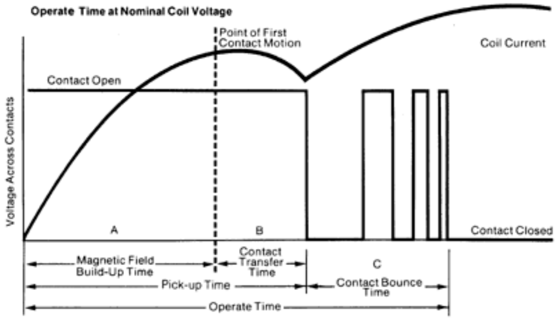
Offstate dv/dt:- The application of both position and negative voltages with maximum specified rate of rise to the output terminals.

Operate:- A relay operates when sequentially it starts, it passes from an initial condition towards the prescribed operated condition, and it switches.

Operating characteristics:- Pickup, non-pickup, hold and dropout, voltage and current.

Operating temperature range:- The ambient temperature range over which an un-mounted relay is specified to operate.

Opening time:- Time from the beginning of state causing breaking until the moment when the contacts of the last current path to be opened are open.



Operate time:- The time in milliseconds between voltage being first applied to the relay coil and final closure of all normally open contacts or the time from energizing the relay coil till the first break of the NC contact. This includes time for the coil to build up its magnetic field (a significant limiting factor) and transfer time of the moveable contact between stationary contacts, and bounce time after the initial contact make. As the coil resistance depends on the ambient temperature, the operate time varies with the operate voltage and the ambient temperature.

Overdrive:- A term used to indicate use of greater than normal coil current (applied voltage), and usually employed in obtaining well-controlled bounce and fast operate time or pulse response.

Overload current:- Test done to make sure that relays withstand overload conditions, e.g. withstand short circuit conditions until the fuse opens. Relay will carry the specified currents at 23°C (I_{rated} = rated current as given in contact data section for each relay).

Overtravel armature dropout:- The portion of the armature travel that occurs between closure of the normally closed contact(s) and the fully released static position of the armature.

Overtravel armature pickup:- The portion of the armature travel occurring between closure of the normally open contact(s) and the fully operated static position of the armature.

Paschen test:- Test to detect sealing damage to a hermetically seal capsule. In the case of a cracked switch capsule or damaged switch seal, atmospheric oxygen can leak into the switch and eventually oxidize the switch contacts, causing increased contact resistance and possible contact failure. The presence of oxygen causes the breakdown avalanche voltage to increase, due to the ability of the electronegative oxygen to scavenge free electrons. The Paschen test observes the variation and magnitude of the breakdown voltage as a switch is opened, hence used to diagnose the presence of oxygen.

Peak Test Voltage:- The peak AC voltage (at 60 Hz) which can be applied between external high voltage terminals or between the open terminals and ground for up to one minute with no evidence of failure. Peak test voltages must not be exceeded, even for very short pulses.

Pole, double:- A term applied to a contact arrangement to denote that it includes two separate contact combinations, that is, two single-pole contact assemblies.

Pole piece:- The end of an electromagnet, sometimes separable from the main section, and usually shaped so as to distribute the magnetic field in a pattern best suited to the application.

Pole, single:- A term applied to a contact arrangement to denote that all contacts in the arrangement connect in one position or another to a common state.

Pull-in Voltage:- The minimum coil voltage required to operate a relay for all normally open contacts to close. The voltage at which a relay (coil) operates and switches. It is normally expressed as a % of the nominal coil voltage. Sometimes known as threshold voltage. It is affected by temperature.

Race, relay:- A deficient circuit condition wherein successful operation depends upon a sequence of two or more independent contacts and in which the sequence is not insured by electrical or mechanical interlocking restraints. Ratchet relay. See relay, stepping.

Relay:- An electrically controlled mechanical device that opens and closes electrical contacts when a voltage (or current) is applied to a coil. A relay provides isolation of control signals from switched signals.

Rated breaking capacity; Rated making capacity:- Value of rms current a contactor can break or make at a fixed voltage value, within the conditions specified by the standards, depending on the utilization category.

Rated impulse withstand voltage, V_{imp}:- The highest peak value of an impulse voltage of prescribed form 1.2/50, which does not cause breakdown under specified conditions of test.

Rated insulation voltage, V_i:- Voltage value which designates the unit and to which dielectric tests, clearance and creepage distances are referred.

Rated operating current, I_e:- Current value stated by the manufacturer and taking into account the rated operating voltage, V_e, the rated frequency, the rated duty, the utilization category, the electrical contact life and the type of the protective Hammond Enclosure.

Rated operating voltage, V_e:- Voltage value to which utilization characteristics of the contactor are referred, i.e. phase to phase voltage in 3 phase circuits. The voltage which can safely be applied to the relay for sustained periods of time without failure. This voltage rating decreases as AC frequency increases. Rated operating voltages approach peak test voltage only at lower frequencies.

Rating, contact:- The electrical load-handling capability of relay contacts under specified conditions and for a prescribed number of operations.

Rating, short time:- The value of current or voltage that the relay can stand, without injury, for specified short time intervals. (For ac circuits, the rms total value, including the dc component, should be used). The rating recognized the limitations imposed by both thermal and electromagnetic effects.

Rebound, armature:- (1) The return motion or bounce-back toward the unoperated position after the armature strikes the pole face during pickup, referred to as armature pickup rebound; (2) The forward motion or bounce in the direction of the operated position when the armature strikes its backstop on dropout, referred to as armature dropout rebound.

Relay:- An electric device that is designed to interpret input conditions in a prescribed manner and after specified conditions are met to respond to cause contact operation or similar abrupt change in an associated electric control circuit. Notes: (a) Inputs are usually electric, but may be mechanical, thermal or other quantities. (b) A relay may consist of several units, when responsive to specified inputs, the combination providing the desired performance characteristic.

Relay, alternating current (ac):- A relay designed for operation from an alternating-current source.

Relay, direct current (dc):- A relay designed for operation from a direct-current source.
Relay, electrical:- A device designed to produce sudden, predetermined changes in one or more electrical output circuits, when certain conditions are fulfilled in the electrical input circuits controlling the device.
1. The term relay shall be restricted to a relay unit having a single relaying function between its input circuits and its output circuits.
2. The term relay includes all the components which are necessary for its specified operation.
3. The adjective 'electrical' can be deleted when no ambiguity may occur.
Relay, electromechanical:- An electrical relay in which the designed response is developed by the relative movement of mechanical elements under the action of a current in the input circuits.
Relay, latching:- A relay that maintains its contacts in the last position assumed without the need of maintaining coil energization.
1. Magnetic latching- A relay that remains operated, held either by remanent magnetism in the structure or by the influence of a permanent magnet, until reset.
2. Mechanical latching- A relay in which the armature or contacts may be latched mechanically in the operated or unoperated position until reset manually or electrically.
Relay, mercury contact:-
1. Mercury-wetted contact-A form of reed relay in which the reeds and contacts are glass enclosed and are wetted by a film of mercury obtained by capillary action from a mercury pool in the base of a capsule vertically mounted.
2. Mercury contact-A relay mechanism in which mercury establishes contact between electrodes in a sealed capsule.
Relay, over current:- A relay that is specifically designed to operate when its coil voltage reaches or exceeds a predetermined value.
Relay, polarized:- A relay whose operation is dependent upon the polarity of the energizing current.
1. Bistable. A tow-position relay that will remain in its last operated position keeping the operated contacts closed after the operating winding is de-energized.
2. Centre-stable. A polarized relay that is operated in one of two energized positions, depending on the polarity of the energizing current, and that returns to a third, off position, when the operating winding is de-energized.
3. Double-biased. See bistable.
4. Magnetic latching. See bistable.
5. Monostable. A monostable polarized relay is a two-position relay that requires current of a pre-determined polarity for operation and returns to the off position when the operating winding is de-energized or is energized with reversed polarity.
6. Single-biased. See monostable.
7. Single-side-stable. See centre-stable.
8. Three-position centre-off. See centre-stable.
9. Un-biased. See centre-stable.
Relay, reed:- A relay using glass-enclosed, hermetically sealed, magnetically actuated reeds as the contact members. No mercury or other wetting material is used. Typical atmosphere inside the glass enclosure is nitrogen.
Relay, RF switching:- A relay designed to switch electrical ac energy frequencies >20kHz.
Relay, solid state (SSR):- A relay with isolated input and output whose functions are achieved by means of electronic components and without moving parts.
Relay, undercurrent:- A relay specifically designed to function when its energizing current falls below a predetermined value. (See relay, current sensing.)
Relay, undervoltage:- A relay specifically designed to function when its energizing voltage falls below a predetermined value.
Relay, vacuum:- A relay whose contacts are sealed in a low pressure environment.
Release Time:- The time in milliseconds between removal of power from the relay coil and final closure of all normally closed contacts. This time includes contact bounce.
Resistance, contact:- The electrical resistance of closed contacts measured at the associated terminals.
Resistance, dynamic contact:- Variation in contact resistance due to changes in contact pressure during the period in which contacts are motion, before opening or after closing.
Resistance to shock:- Requirements applicable for instance to vehicles, crane operation or switchgear slide-in module systems. At the quoted permissible 'g' values, contactors must not undergo a change in switching state and O/L relays must not trip.
Resistance to vibration:- Requirements applicable to all the vehicles, vessels and other similar transport systems. At the quoted amplitude and vibration frequency values, the unit must be capable to achieve the required duty.
Resistance, winding:- The total terminal-to-terminal resistance of a winding at a specified temperature.
Self de-energize:- The removal of power from a relay coil by an auxiliary switch or contact within the relay itself. Usually applies to latching relays only.

Self de-energizing switch:- A secondary relay or auxiliary contact usually enclosed within the primary relay which removes power from the primary relay coil after it has transferred position. Usually applies to latching relays only.
Shield, electrostatic:- A conductive metallic sheath surrounding the relay's reed switch, connected to at least one external relay pin, and designed to minimize capacitive coupling between the switch and other relay components, thus reducing high frequency noise pickup. Similar to a coaxial shield, but not necessarily designed to maintain a 50 Ohm RF impedance environment.
Shield, magnetic:- An optional plate or shell constructed of magnetically permeable material such as nickel-iron or mu-metal, fitted external to the relay's coil. Its function is to reduce the effects of magnetic interaction between adjacent relays, and to improve the efficiency of the relay coil. A magnetic shell also reduces the influence of external magnetic fields, which is useful in security applications. Magnetic shields can be fitted externally, or may be buried inside the relay housing.
Soft failure:- Intermittent, self-recovering failure of a contact.
Static contact resistance:- The DC resistance of closed contacts as measured at their associated contact terminals. Measurement is made after stable contact closure is achieved.
Sticking (contacts):- A reed switch failure mechanism, whereby a closed contact fails to open by a specified time after relay de-energization. Can be sub-classified as hard or soft failures.
Switch, dry reed:- See contact, reed.
Switch, stepping:- A class of electromagnetically operated, multiposition switching devices. Their wipers are rotated in steps so that contact is successively made between the wiper tips and contacts that are separated electrically and mounted in a circular arc called a bank.
Switching Capacity:- Switching capacity is the product of switching voltage and switching current. The current which a relay will switch will vary according to the voltage being used. Note that the maximum often includes the value occurring at peaks (see 'inrush'). A minimum also applies, because contact materials that can withstand high current loads may be poor at making contact at low current loads.
Switching frequency:- Number of operating cycles per hour.
Short time current permissible:- Value of current which the contactor can withstand in closed position for a short time period and within specified conditions.
Time, actuation:- The time interval from coil energization or de-energization to the functioning of a specified contact; same as time, contact actuation, subdivided as follows:
1. Time, final actuation-The sum of the initial actuation time and the contact bounce intervals following such actuation.
2. Time, initial actuation-The time from coil energization or de- energization to the first closing of a previously open contact or the first opening of a previously closed contact.
Time, bridging:- The time in which all contacts of a continuity transfer combination are electrically connected during the transfer.
Time constant:- Ratio of inductance to the resistance : L/R = mH/Ohm, ms.
Time, contact bounce:- The time interval from initial actuation of a contact to the end of bounce.
Time, contact stagger:- The time interval between the functioning of contacts on the same relay.(For example, the time difference between the opening of two normally closed contacts on pickup.)
Time, operate:- (1) The time interval from coil energization to the functioning of the last contact to function. Where not otherwise stated, the functioning time of the contact in question is taken as its initial actuation time (that is, it does not include contact bounce time).
(2) For a solid state or hybrid relay in a non-operated state, the time from the application of the pickup voltage to the change of state of the output.
Time, release:- (1) The time interval from coil de-energization to the functioning of the last contact to function. Where not otherwise stated, the functioning time of the contact in question is taken as its initial actuation time (that is, it does not include contact bounce time).
(2) For a solid state or hybrid relay in an operated state, the time from the application of the dropout voltage to the change of state of the output.
Time, seating:- The time interval from coil energization to the seating of the armature.
Time transfer:- The time interval between opening the closed contact and closing the open contact of a break-before-make contact combination.
Type 1 co-ordination:- There has been no discharge of parts beyond the enclosure. Damage to the contactor and the overload relay is acceptable.
Type 2 co-ordination:- No damage to the overload relay or other parts has occurred, except that welding of contactor or starter contacts is permitted, if they are easily separated.
Voltage Breakdown:- An undesirable condition of arcing within a relay due to over-voltage.
Voltage, off state:- In solid state relay, the following determine whether the relay will stay off under each load voltage condition:
1. Critical rate of rise of commutation voltage, *dv/dt*. The maximum value of the rate of rise of principal voltage which will cause switching from the off state to the on state.
2. Maximum off state voltage, $V_{D\ max\ rms}$. The maximum effective steady state voltage

that the output is capable of withstanding when in off state.

3. Maximum rate of rise of off state voltage, dv/dt. The rate of rise of the off-state voltage which the output can withstand without false operation.

4. Minimum off state voltage, $V_{D\ min\ rms}$. The minimum effective voltage which the relay will switch.

5. Non-repetitive peak voltage, V_{DSM}. The maximum off-state voltage that the output terminals are capable of withstanding without breakover or damage.

Voltage, on state:- In solid state relays, the output terminal wave form at rated current consists of repetitive half-cycles (+and-) of distinctive voltage drops. Each voltage state is necessary for load current conduction and may be specified for specific applications, as follows:

1. Instantaneous on state voltage, V_T. The instantaneous voltage across the output when in the on condition.

2. Maximum RMS on state voltage, $V_{T\ RMS}$. Maximum RMS voltage drop across the relay output at maximum load current $I_{T\ RMS}$.

3. Minimum power factor load, PF_{MIN}. The minimum power factor load the relay will switch and still meet all of its electrical specifications.

4. Peak on state voltage, V_{TM}. The maximum value of V_T excluding ± 20° of zero crossing of the voltage waveform.

Voltage, rated coil:- The coil voltage at which the relay is intended to operate for the prescribed duty cycle. Note: The use of any coil voltage less than rated may compromise the performance of the relay.

Voltage, reverse polarity:- The maximum allowable reverse voltage which may be applied to the input of a solid state relay without permanent damage.

Winding, non-inductive:- A winding in which the magnetic fields produced by two parts of the winding cancel each other and provide non-inductive resistance.

Glossary of Varistor terminology

AC Standby Power (Varistor), P_D:- Varistor AC power dissipation measured at rated rms voltage $V_{M(ac)}$.

Capacitance (Varistor), C:- Capacitance between the two terminals of the varistor measured at C specified frequency and bias.

Clamping Voltage, V_C:- Peak voltage across the varistor measured under conditions of a specified peak VC pulse current and specified waveform. Peak voltage and peak currents are not necessarily coincidental in time.

Dynamic Impedance (Varistor), Z_X:- measure of small signal impedance at a given operating point as defined by: $Z_X = dV_X / dI_X$

Lifetime Rated Pulse Currents (Varistor):- Derated values of I_{TM} for impulse durations exceeding that of an 8/20μs wave-shape, and for multiple pulses which may be applied over device rated lifetime.

Nominal Varistor Voltage, $V_{N(dc)}$:- Voltage across the varistor measured at a specified pulsed DC current, $I_{N(dc)}$, of specific duration, $I_{N(dc)}$ of specific duration. $I_{N(dc)}$ is specified by the varistor manufacturer.

Nonlinear Exponent, α:- A measure of varistor nonlinearity between two given operating currents, I_1 and I_2, as described by $I = kV^{\alpha}$

where k is a device constant, $I_1 \le I \le I_2$, and $\alpha_{12} = \log I_2 / I_1 / \log V_2 / V_1$

Overshoot Duration (Varistor):- The time between the point voltage level (V_C) and the point at which the voltage overshoot has decayed to 50% of its peak. For the purpose of this definition, clamping voltage is defined with an 8/20μs current waveform of the same peak current amplitude as the waveform used for this overshoot duration.

Peak Nominal Varistor Voltage, $V_{N(ac)}$ Voltage across the varistor measured at a specified peak AC current, $I_{N(ac)}$, of specific duration. $I_{N(ac)}$ is specified by the varistor manufacturer.

Rated DC Voltage (Varistor), $V_{M(dc)}$:- Maximum continuous DC voltage which may be applied.

DC Standby Current (Varistor), I_D:- Varistor current measured at rated voltage, $V_{M(dc)}$.

Rated Peak Single Pulse Transient Currents (Varistor), I_{TM}:- Maximum peak current applied for a single 8/20μs impulse, with rated line voltage also applied, without causing device failure.

Rated Recurrent Peak Voltage (Varistor), V_{PM}:- Maximum recurrent peak voltage which may be applied for a specified duty cycle and waveform.

Rated RMS Voltage (Varistor), $V_{M(ac)}$:- Maximum continuous sinusoidal RMS voltage which may be applied.

Rated Single Pulse Transient Energy (Varistor), W_{TM}:- Energy which may be dissipated for a single impulse of maximum rated current at a specified wave-shape, with rated RMS voltage or rated DC voltage also applied, without causing device failure.

Rated Transient Average Power Dissipation (Varistor), $P_{T(av)M}$:- Maximum average power which may be dissipated due to a group of pulses occurring within a specified isolated time period, without causing device failure.

Resistance (Varistor), R_X:- Static resistance of the varistor at a given operating point as defined by:

$R_X = V_X / I_X$

Response Time (Varistor):- The time between the point at which the wave exceeds the clamping voltage level (V_C) and the peak of the voltage overshoot. For the purpose of this definition, clamping voltage as defined with an 8/20μs current waveform of the same peak current amplitude as the waveform used for this response time.

Varistor Voltage, V_X:- Voltage across the varistor measured at a given current, I_X.

Voltage Clamping Ratio (Varistor), V_C / V_P:- A figure of merit measure of the varistor clamping effectiveness as defined by the symbols $V_C / V_{M(ac)}$, $V_C / V_{M(dc)}$.

Voltage Overshoot (Varistor), V_{os}:- The excess voltage above the clamping voltage of the device for a given current that occurs when current waves of less than 8μs virtual front duration are applied. This value may be expressed as a % of the clamping voltage (V_C) for an 8/20μs current wave.

Glossary of PTC and NTC Thermistor terminology

Amorphous:- Without crystallization in the ultimate texture of a solid substance. Used to describe the device material structure in the tripped state.

Breakdown voltage:- The maximum voltage that a PTC thermistor can support under stipulated time and temperature conditions. The PTC thermistor will breakdown when exceeding this voltage.

Carbon Black:- A conductive material used in PTC devices to provide a path for current flow under normal operating conditions.

Conductive Plastic:- A plastic material, such as a polymer, containing conductive particles, such as carbon black, that provide a path for current flow.

Current-time characteristic:- The current-time characteristic is the relationship at a specified ambient temperature between the current through a thermistor and time, upon application or interruption of voltage to it.

Current, Hold, I_{hold}:- The maximum current a PTC device can pass without interruption.

Current, Maximum, I_{max}:- The maximum fault current a PTC device can withstand without damage at the rated voltage.

Current Rating:- The nominal amperage value marked on the fuse. It is established by the manufacturer as a value of current which the fuse can be loaded to, based on a controlled set of test conditions (see Rerating).

Current, Trip, I_{trip}:- The minimum current that will switch a device from the low resistance to the high resistance state.

Curie point temperature (Resistance - temperature characteristics):- A PTC fuse maintains almost the same resistance, until certain temperature. After this temperature is exceeded, the resistance rises up sharply. This transition point is called the Curie point. The critical temperature is defined to be the Curie point temperature, where the actual resistance value is twice the reference value measured at 25°C.

Derating:- Fuses are essentially temperature-sensitive devices. Even small variations from the controlled test conditions can greatly affect the predicted life of a fuse when it is loaded to its nominal value, usually expressed as 100% of rating. The fuse temperature generated by the current passing through the fuse increases or decreases with ambient temperature change.

Dissipation constant:- The dissipation constant is the ratio, (W/°C) at a specified ambient temperature, of a change in power dissipation in a thermistor to the resultant body temperature change.

Electrode:- A device or material that emits or controls the flow of electricity. Nickel and Copper elements are used in PTC devices to aid even distribution of current across the surface of the device.

Fault Current:- The peak current that flows through a device or wire during a short circuit or arc back.

Form Factor:- The package that holds the chemical make-up of polymer and carbon. PTCs are packaged in the following forms; radial, axial, surface mount chips, disks, and washers.

Fuse:- A current limiting device used for protection of equipment. Typically a wire or chemical compound which breaks a circuit when the current exceeds a rated value.

Fuse Resistance:- The resistance of a fuse is usually an insignificant part of the total circuit resistance. Since the resistance of fractional amperage fuses can be several ohms, this fact should be considered when using them in low-voltage circuits. Most fuses are manufactured from materials which have positive temperature coefficients, and therefore, it is common to refer to cold resistance and hot resistance (voltage drop at rated current), with actual operation being somewhere in between. The factory should be consulted if this parameter is critical to the design analysis. Resistance data on all of our fuses is available on request.

Heat capacity, *H*:- The heat capacity of a thermistor is the amount of heat required to increase the body temperature of it by one degree centigrade, 1°C. Heat capacity is a common rating of standard PTC thermistors and is expressed in Joules per cubic centimetre per degree C (J/cm^3/°C). The heat capacity per unit volume relationship of standard PTC thermistors is approximately 5 J/cm^3/°C.

Hysteresis:- The period between the actual beginning of the signalling of the device to trip and the actual tripping of the device.

Initial current (I_{in}):- the current that results instantaneously in the circuit switch when starting to closing.

Initial resistance ($R_{25°C}$):- This is the part's resistance value at 25°C which is measured under conditions of 1.0V dc or less, and 10mA or less without self-heating.

Inrush current:- Inrush current is the initial surge of current that results when power is first applied to a load having a low starting impedance, such as a discharged capacitor, a cold lamp filament, or a stopped motor's winding.

Inrush current limiter:- Specially designed and constructed NTC thermistors may be used as inrush current limiters. Available in a wide range of current handling and zero-power resistance value combinations.

Insulation thermistor:- thermistor stipulated insulation resistance and voltage test requirement.

Interrupting Rating:- Also known as breaking capacity or short circuit rating, the interrupting rating is the maximum approved current which the fuse can safely interrupt at rated voltage. During a fault or short circuit condition, a fuse may receive an instantaneous overload current many times greater than its normal operating current. Safe operation requires that the fuse remain intact (no explosion or body rupture) and clear the circuit.

Leakage Current:- An undesirable small value of stray current that flows through a device after the device has changed state to a high resistance mode.

Let through Current:- The amount of current though a circuit after a device is signalled to trip and the device is at full operation limiting current.

Low category temperature:- Minimum ambient temperature at which a PTC thermistor can operate continuously.

Material constant (Beta , ß in K):- The material constant of a NTC thermistor is a measure of its resistance at one temperature compared to its resistance at a different temperature. Its value may be calculated by the formula shown below and is expressed in degrees Kelvin (K). The reference temperatures used in this formula for determining material constant ratings of thermistors are 298.15°K and 348.15°K.

Maximum Fault Current:- The Interrupting Rating of a fuse must meet or exceed the maximum fault current of the circuit.

Maximum Inrush Current:- The maximum current (effective value) through the PTC thermistor under maximum rated voltage. Exceeding this current may result in PTC device damage.

Maximum operating temperature:- The maximum operating temperature is the maximum body temperature at which the thermistor will operate for an extended period of time with acceptable stability of its characteristics. This temperature is the result of internal or external heating, or both, and should not exceed the maximum value specified.

Maximum operating voltage, V_{max}:- The maximum operating voltage is the maximum rated voltage, either direct current or 50/60 Hz rms alternating current, expressed in volts (Vdc or Vac), that a standard PTC thermistor will continuous withstand for an extended period without affecting its normal characteristics.

Maximum power rating:- The maximum power rating of a thermistor is the maximum power which a thermistor will dissipate for an extended period of time with acceptable stability of its characteristics.

Maximum steady-state current (I_{max}):- The maximum steady-state current is the rating of the maximum current, normally expressed in amperes (A), allowable to be conducted by an inrush limiting NTC thermistor for an extended period of time.

Maximum surge current:- The maximum surge current is the maximum permissible surge current in a circuit and, in conjunction with the maximum peak voltage, determines the minimum required zero-power resistance of the thermistor required to limit it adequately.

Minimum switching current (I_s):- The minimum switching current is the minimum amount of current, normally expressed in amperes (A), that, when conducted by a standard PTC thermistor, is required to cause it to switch to its high resistance state.

Negative temperature coefficient (NTC):- A NTC thermistor is one in which the zero-power resistance decreases with an increase in temperature.

Non-insulation thermistor:- thermistors that do not require an insulation voltage and insulation resistance test.

Non-trip Current:- Also called rated current or holding current, or non-operating current, means the current at which PTC thermistor resistance does not exceed the specified value for designated time and temperature conditions.

Overload Current Condition:- The current level for which protection is required. Fault conditions may be specified, either in terms of current or, in terms of both current and maximum time the fault can be tolerated before damage occurs. Time-current curves are used to match the fuse characteristic to the circuit needs, noting that the curves are based on average data.

Peak current ($I_{in\ p\text{-}p}$):- Peak-peak value of initial current.

Polymer:- A synthetic plastic material consisting of large molecules made up of a linked series of repeated simple monomers. The insulating medium used in PTC devices which maintains the carbon chains in suspension during over-current while permitting the carbon chains to form during normal operation.

Polymeric Positive Temperature Coefficient (PPTC):- A characteristic of PTC devices that describes a large increase in resistance as the device reaches its trip temperature.

Positive temperature coefficient (PTC):- A PTC thermistor is one in which the zero-power resistance increases with an increase in temperature.

Pulses:- The general term 'pulses' is used in this context to describe the broad category of wave shapes referred to as surge currents, start-up currents, inrush currents, and transients, Electrical pulse conditions can vary considerably from one application to another. Different fuse constructions may not all react the same to a given pulse condition. Electrical pulses produce thermal cycling and possible mechanical fatigue that could affect the life of the fuse. The start-up pulse should be defined and then compared to the time-current curve and I^2t rating for the fuse. Nominal melting I^2t is a measure of the energy required to melt the fusing element and is pressed as Ampere squared seconds, (A^2s).

Recovery time:- The recovery time of a thermistor is the approximate time required for it to cool sufficiently after power is removed and allow it to provide the characteristics required when power is reapplied.

Resistance at maximum current, R_{Imax}:- The resistance at maximum current is the approximate resistance of an inrush current limiting thermistor, expressed in ohms, when it is conducting its rated maximum steady-state current.

Resistance ratio characteristic:- The resistance ratio characteristic identifies the ratio of the zero-power resistance of a thermistor measured at 25°C to that resistance measured at 125°C.

Resistance-temperature characteristic:- The resistance-temperature characteristic is the relationship between the zero-power resistance of a thermistor and its body temperature.

Resistance, Initial (R_{min} - R_{max}):- The resistance range of the PTC devices, before circuit insertion.

Resistance, Post Trip (R_{1max}):- The maximum post-trip resistance one hour after a PTC device has been tripped and power has been removed.

Resistance, Post Reflow (R_{1max}):- The maximum resistance one hour after a PTC surface mount device has been reflow soldered.

Restore time:- Time to restore PTC thermistor resistance to twice the zero-power resistance after the power is removed.

Silicon PTC thermistor:- A silicon PTC thermistor is a type PTC thermistor that has an approximately linear resistance-temperature characteristic and a temperature coefficient of resistance of approximately +0.7%/°C. Silicon PTC thermistors are distinguished from standard PTC thermistors.

Stability:- Stability of a thermistor is the ability of a thermistor to retain specified characteristics after being subjected to designated environmental or electrical test conditions.

Standard PTC thermistor:- A standard PTC thermistor is a type of PTC thermistor that has a switch temperature. Standard PTC thermistors are distinguished from silicon PTC thermistors.

Standard Reference Temperature:- The standard reference temperature is the thermistor body temperature at which nominal zero-power resistance is specified, 25°C.

Switch Temperature:- The temperature at which the resistance value of the PTC thermistor increases to twice the zero-power resistance, also called Curie temperature, or reference temperature or transition temperature.

Switching time, t_s:- If V_{max} and I_{max} are known, the PTC thermistor's switch-off behaviour can be described in terms of switching time t_s. This is the time it takes at applied voltage for the current passing through the PTC to be reduced to half of its initial value, at T_A = 25 °C.

Temperature - wattage characteristics:- The temperature-wattage characteristic of a thermistor is the relationship at a specified ambient temperature between the thermistor temperature and the applied steady state wattage.

Temperature at minimum resistance (T_{rmin}):- Temperature corresponding to minimum resistance.

Temperature coefficient of resistance, α:- The temperature coefficient of resistance is the ratio at a specified temperature, T, of the rate of change of zero-power resistance with temperature to the zero-power resistance of the thermistor. The temperature coefficient is commonly expressed in percent per degree C (%/°C).

Temperature range under maximum voltage:- Operating ambient temperature range that the PTC thermistor can continuously operate under maximum voltage.

Thermal cooling time constant τ_{th}:- The thermal cooling time constant refers to the time necessary for an unloaded (zero power conditions) thermistor to vary its temperature by 63.2% of the difference between its mean temperature and the ambient temperature.

Equation for temperature change: $T(t_2) = T(t_1) \pm 0.632x(T(t_1) - T_A)$ with $t_2 - t_1 = \tau_{th}$

Thermistor:- A thermistor is a thermally sensitive resistor whose primary function is to exhibit a change in electrical resistance with a change in body temperature.

Trip Current:- Initial current which causes PTC thermistor resistance to leap, also called operating current.
Trip Endurance:- A test used to determine the duration of time a PTC device will sustain its maximum rated voltage in the tripped state without failure.
Trip Cycle Life:- A test used to determine the number of trip cycles (at V_{max} and I_{max}) a PTC device will sustain without failure.
Upper category temperature:- Maximum ambient temperature at which a PTC thermistor can operate continuously.
Zero-power resistance, R_T:- The zero-power resistance is the dc resistance value of a thermistor measured at a specified temperature with a power dissipation by the thermistor low enough that any further decrease in power will result in not more than 0.1% (or 1/10 of the specified measurement tolerance, whichever is smaller) change in resistance.
Zero-power temperature coefficient of resistance, α_T:- The Zero-power temperature coefficient of resistance is the ratio at a specified temperature, *T*, of the rate of change of zero-power resistance with temperature to the zero-power resistance of the thermistor.

Glossary of Electrochemical Battery terminology

Absorption:- The retention of Hydrogen by the Misch Metal (Hydrogen-absorbing) alloys of the negative electrode.
Active Material:- Chemicals that give rise to electro-chemical reactions, and which generate electrical energy in the battery.
Ageing:- Permanent loss of capacity with frequent use or the passage of time due to unwanted irreversible chemical reactions in the cell.
AGM (Absorbed Glass Mat) battery:- A lead acid battery using a micro-glass mat (which also act as a separator) to promote recombination of the gases produced by the charging process.
AGM (Absorbed Glass Mat):- Micro-glass material used to contain the electrolyte and also function as a separator in a valve-regulated lead acid battery.
Alkaline Electrolyte:- An aqueous alkaline solution (such as potassium hydroxide) which provides a medium for the ionic conduction between the positive and negative electrodes of a cell.
Ampere (A):- A unit of electrical current or rate of flow of electrons. One volt across one ohm of resistance causes a current flow of one ampere. One ampere is equal to 6.235×10^{18} electrons per second passing a given point in a circuit.
Ampere hours (Ah):- The unit of measure used for comparing the capacity or energy content of a batteries with the same output voltage. For automotive (Lead Acid) batteries the SAE defines the Amp-hour capacity as the current delivered for a period of 20 hours until the cell voltage drops to 1.75 V.
Strictly - One Ampere hour is the charge transferred by one amp flowing for one hour. 1Ah = 3600 Coulombs. One C, 1C, means Ah current for 1 hour, ½C means current of half Ah for 2 hours, etc.
Ampere-Hour Capacity:- The number of ampere-hours that can be delivered by a storage battery under specified conditions as to temperature, rate of discharge and final voltage.
Ampere-Hour Efficiency:- The electrochemical efficiency of a storage battery expressed as the ratio of ampere-hours output to the ampere-hours input required for recharge.
Anode:- An electrode through which current enters any non-metallic conductor. The electrode in an electrochemical cell where oxidation takes place, releasing electrons. During discharge the negative electrode of the cell is the anode. During charge the situation reverses and the positive electrode of the cell is the anode.
Battery:- Two or more electrochemical cells enclosed in a container and electrically inter-connected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels. Under common usage, the term battery also applies to a single cell if it constitutes the entire electrochemical storage system.
Battery Life:- End of Life. The period during which a cell or battery is capable of operating above a specified capacity or efficiency performance level. For example, with lead-acid batteries, end-of-life is generally taken as the point in time when a fully charged cell can deliver only 80% of its rated capacity. Beyond this state of aging, deterioration and loss of capacity begins to accelerate rapidly. Life may be measured in cycles and/or years, depending on the type of service for which the cell or battery is intended.
Burning Centre:- The centre-to-centre distance between adjacent plates of the same polarity.
C Rate:- The discharge or charge current in amperes, expressed in multiples of the rated capacity. For example, the C5 rate is the capacity in ampere hours available at the 5-hour discharge rate to a specified end voltage. A discharge of 0.5C5 is a discharge at 50% of the C5 rate.
Cadmium Electrode:- A third electrode in lead-acid battery for separate measurements of the electrode potential of positive and negative plate groups.

Capacity:- The amount of electrical energy that can be supplied by a cell/battery - expressed in Ah, and in specified discharge conditions.
Capacity Test:- A test that discharges the battery at constant current at room temperature to a cutoff voltage of usually 1.75V/cell in the case of a lead-acid battery.
Cathode:- An electrode through which current leaves any non-metallic conductor. The electrode in an electrochemical cell where reduction takes place, gaining electrons. During discharge the positive electrode of the cell is the cathode. During charge the situation reverses and the negative electrode of the cell is the cathode.
Cell (Primary):- A cell designed to produce electric current through an electrochemical reaction that is not efficiently reversible and hence the cell, when discharged, cannot be efficiently recharged by an electric current.
Cell (Storage):- An electrolytic cell for generation of electric energy, in which the cell after discharge may be restored to a charged condition by an electric current flowing in a direction opposite to the flow of current when the cell discharges.
Cell reversal:- A condition which may occur multi cell series chains in which an over discharge of the battery can cause one or more cells to become completely discharged. The subsequent volt drop across the discharged cell effectively reverses its normal polarity.
Charge acceptance:- quantifies the amount of electric charge which accumulates in a battery.
Charge Efficiency:- The ratio of the output of a cell during discharge to the input of a cell during charge. This ratio can be expressed in Efficiency of Capacity, Nominal Voltage, or Power.
Charge:- The operation which inputs electrical energy to a cell/battery.
Charge equalization:- brings all of the cells in a battery or string to the same state of charge.
Charge Rate:- The current applied to a cell to restore its capacity. The charge rate is usually expressed in terms of the cells C Rate.
Charge retention:- refers to a battery's ability to hold a charge. It diminishes during storage.
Charged and Dry:- A battery assembled with dry, charged plates and no electrolyte.
Charged and Wet:- A fully charged battery containing electrolyte and ready to deliver current.
Charge, state of:- Available or remaining capacity of a battery expressed as a % of the rated capacity.
Cold Cranking Amps:-A performance rating for automobile starting batteries. It is defined as the current that the battery can deliver for 30 seconds and maintain a terminal voltage greater than or equal to 1.20 volts per cell, at -18°C, when the battery is new and fully charged. Starting batteries may also be rated for Cranking Amps, which is the same thing but at a temperature of 0°C.
Constant Current Charge:- A charge that maintains the current at a constant value. For some types of batteries this may involve two rates, called a starting and a finishing rate. This procedure may damage the battery if performed on a repetitive basis.
Constant Potential Charge or Constant Voltage Charge:- A charge that holds the voltage at the terminals at a constant value and the current is limited only by the resistance of the battery and/or the capacity of the charge source.
Copper Contamination:- The formation of copper sulphate on the negative plates, usually caused by unintentional exposure of terminal posts' copper inserts to the electrolyte.
Coulombic Efficiency:- The ratio (expressed as a percentage) between the energy removed from a battery during discharge compared with the energy used during charging to restore the original capacity. Also called Charge Efficiency or Charge Acceptance.
Coup-de-Fouet:- The voltage dip followed by a subsequent voltage recovery that occurs when initially discharging a battery that has been on long-term float operation.
Cut-off Voltage:- A set voltage that determines when the discharging of a cell/battery should end.
Cycle:- A discharge and its subsequent recharge.
Cycle Life:- The total number of charge/discharge cycles before the battery reaches end of life (generally 80% of rated capacity).
Deep cycle battery - A battery designed to be discharged to below 80% Depth of Discharge. Used in marine, traction and EV applications.
Deep discharge - Discharge of at least 80% of the rated capacity of a battery.
Dendritic growth:- The formation from small crystals in the electrolyte of tree like structures which degrade the performance of the cell.
Depth of discharge DOD:- The ratio of the quantity of electricity or charge removed from a cell on discharge to its rated capacity discharge, expressed as a percent of rated capacity. For example, the removal of 25 ampere-hours from a fully charged 100 ampere-hours rated cell results in a 25% depth of discharge. Under certain conditions, such as discharge rates lower than that used to rate the cell, depth of discharge can exceed 100%.
Discharged:- A storage cell when, as a result of delivering current, in the case of the lead-acid cell, the plates are sulphated, the electrolyte is exhausted, and there is little or no potential difference between the terminals.
Discharge Factor:- A number equivalent to the time in hours during which a battery is discharged at constant current usually expressed as a percentage of the total battery capacity, i.e., C/5 indicates a discharge factor of 5 hours. Related to discharge rate.

Discharge Rate:- Any specified amperage rate at which a battery is discharged.
Efficiency:- The ratio of the output of a rechargeable cell or battery on discharge to the input required to restore it to the initial state of charge.
Electrochemical Cell:- A device containing two conducting electrodes, one positive and the other negative, made of dissimilar materials (usually metals) that are immersed in a chemical solution (electrolyte) that transmits positive ions from the negative to the positive electrode and thus forms an electrical charge. One or more cells constitute a battery.
Electrode:- Positive or negative plate containing materials capable of reacting with electrolyte to produce or accept current.
Electrode (Electrolyte) potential:- The voltage developed by a single electrode, determined by its propensity to gain or lose electrons. The difference in potential between the electrode and the immediately adjacent electrolyte, expressed in terms of a standard electrode potential difference.
Electrolysis:- Electrochemical reaction that causes the decomposition of a compound.
Electrolyte:- A substance which dissociates into ions (charged particles) when in aqueous solution or molten form and is thus able to conduct electricity. It is the medium which transports the ions carrying the charge between the electrodes during the electrochemical reaction in a battery.
End Gravity:- The specific gravity of a lead-acid cell at the end of a prescribed discharge.
Energy density:- The amount of energy stored in a battery. It is expressed as the amount of energy stored per unit volume or per unit weight (Wh/L or Wh/kg).
Equalisation:- The process of bringing every cell in a battery chain to the same state of charge (SOC)
Equalizing charge:- Charge applied to a battery which is greater than the normal float charge and is used to completely restore the active materials in the cell, bringing the cell float voltage and the specific gravity of the individual cells back to 'equal' values.
Fauré Plate:- see Pasted Plate.
Final Voltage:- The cut-off voltage of a battery. The prescribed voltage reached when the discharge is considered complete. Also known as end point voltage or EPV. This voltage is almost equivalent to limit of practical use. Typical values:

1.0 V per cell for NiCd and NiMH
1.75 V per cell for sealed lead acid
2.75 V per cell for lithium ion and lithium polymer
2.0 V per cell for primary lithium
0.9 V per cell for alkaline and carbon zinc

Finishing Rate:- The rate of charge, in amperes, to which charging current is reduced near the end of the charge for some types of batteries to prevent gassing and temperature rise.
Float Plate:- A pasted plate.
Float Charging:- A recharge at a very low rate, accomplished by connection to a bus whose voltage is slightly higher than the open circuit voltage of the battery. A method of maintaining a battery in a charged condition by continuous, long term, constant voltage charging at level sufficient to balance self-discharge.
Flooded Lead Acid cell:- In 'flooded' batteries, the oxygen created at the positive electrode is released from the cell and vented into the atmosphere. Similarly, the hydrogen created at the negative electrode is also vented into the atmosphere. This can cause an explosive atmosphere in an unventilated battery room. Furthermore the venting of the gasses causes a net loss of water from the cell. This lost water needs to be periodically replaced. Flooded batteries must be vented to prevent excess pressure from the build up of these gasses. *Sealed Lead Acid* (SLA) and *Valve Regulated Lead Acid* (VRLA) Cells overcome these problems.
Fuel Cell:- An electrochemical generator in which the reactants are stored externally and may be supplied continuously to a cell.
Gas Recombination:- The process by which oxygen gas generated from the positive plate during the final stage of charge is absorbed into the negative plate, preventing loss of water.
Gassing:- The generation or evolution of a gaseous product at one or both electrodes as a result of the electrochemical action. Gassing commonly results from local action (self discharge) or from the electrolysis of water in the electrolyte during charging. In lead acid batteries *gassing* produces hydrogen and oxygen. Significant gassing occurs when the battery is nearing the fully charged state while recharging or when the battery is on equalizing charge.
Gel cell:- An SLA battery which uses gelled electrolyte, an aqueous electrolyte that has been immobilised by the addition of a gelling agent.
Grid:- A metallic framework used in a battery for conducting electric current and supporting the active material.
Half Cell Reaction:- The electrochemical reaction between the electrode and the electrolyte.
Hydration (Lead):- Reaction between water and lead or lead compounds. Gravities lower than those found in discharged cells are apt to produce hydration, which appears as a white coating on plate groups and separators in a cell. A condition whereby lead dissolves into the electrolyte in a discharged cell and plates out onto the separator during recharge, resulting in numerous short circuit paths between the positive and negative plates.

Hydrometer:- A tool for testing the specific-gravity of a fluid, such as the electrolyte in a flooded battery. Typically a squeeze-bulb is used to suck up a sample of the fluid, and a float indicates the specific gravity.
Immobilized Electrolyte:- A lead-acid batteries technique where the electrolyte (the acid) is held in place against the plates instead of being a free-flowing liquid. The two most common techniques are gel and glass mat.
Impedance:- The resistive value of a battery to an AC current expressed in ohms (W). Generally measured when fully charged, at 1000 Hz.
Intercalation:- This insertion of ions into the crystalline lattice of a host electrode without changing its crystal structure. A reaction where lithium Ions are reversibly removed or inserted into a host without a significant structural change to the host.
Internal Pressure:- The pressure within a sealed cell caused by oxygen or hydrogen evolution.
Internal Resistance:- The opposition or resistance to the flow of a direct electric current within a cell or battery; the sum of the ionic and electronic resistance of the cell components. Its value varies with the current, state of charge, temperature, and age. With an extremely heavy load, such as an engine starter, the cell voltage may drop significantly. This voltage drop is due to the internal resistance of the cell. A cell that is partly discharged has a higher internal resistance than a fully charged cell, hence it will have a greater voltage drop under the same load. This change in internal resistance is due to the accumulation of lead sulphate in the plates.
Interstitial:- A space between things closely set, or between the parts, which compose a body; a narrow chink; a crack; a crevice; a hole.
Lithium Cobaltite:- ($LiCoO_2$) Dark blue powder; insoluble in water. The compound exhibits both the fluxing property of lithium oxide and the adherence-promoting property of cobalt oxide. Intercalates lithium ions in battery applications.
Manchex:- A type of Planté cell in which the positive plate is cast with openings provided for the active material, which are buttons of soft-lead ribbon. The active material is corrugated and rolled into spirals, which are forced into the grids by hydraulic pressure.
Memory effect (Voltage Depression):- Reversible, progressive capacity loss in nickel based batteries found in NiCad and to a lesser extent in NiMH batteries. It is caused by a change in crystalline formation from the desirable small size to a large size which occurs when the cell is repeatedly recharged before it is fully discharged.
Metal Hydride (MH):- The negative electrode composed of Misch metal (Hydrogen-storing) alloys.
MF (Maintenance Free Battery):- A VRLA sealed absorbed glass mat (AGM) battery.
Microporous Separator:- A veneer or grooved-type separator made of any material that has many microscopically small pores.
Migration:- The movement of charged ions under the influence of a potential gradient.
Misch Metal (M):- The matrix of the negative electrode composed of Hydrogen-storing alloys.
Nickel Metal Hydride (NiMH): A cell or battery system composed of a Nickel (Ni) positive electrode and a metal hydride (MH) negative electrode.
Negative Plate:- The grid and active material that current flows to from the external circuit when a battery is discharging.
Negative Terminal:- The terminal from which current flows through the external circuit to the positive terminal when the cell discharges.
Nernst equation:- Used by cell designers to calculate the voltage of a chemical cell from the standard electrode potentials, the temperature and to the concentrations of the reactants and products.
Nominal Voltage:- A general value to indicate the voltage of a battery in application.
Open Circuit Voltage:- The voltage of a battery when it is not delivering or receiving power, and has been at rest long enough to reach a steady state (normally, at least 4 hours).
Overcharge:- The forcing of current through a cell after all the active material has been converted to the charged state. In other words, charging continued after 100% state of charge is achieved. The result will be the decomposition of water in the electrolyte into hydrogen and oxygen gas, heat generation, and corrosion of the positive electrode.
Oxygen Recombination:- The process in which oxygen generated at the positive electrode during over-charge reacts with hydrogen at the negative electrode to produce water.
Pasted (Fauré) Plate:- A plate consisting of a grid filled with active material applied as a paste.
Peukert's equation:- A formula that shows how the available capacity of a lead-acid battery changes according to the rate of discharge. The capacity of a battery is expressed in Amp-Hours, but it turns out that the simple formula of current times hours does not accurately represent the situation. Peukert found that the equation:

$$C = I^n \times t$$

fits the observed behaviour of batteries. '*C*' is the theoretical capacity of the battery, I is the current, *t* is time, and *n* is the Peukert number, a constant for the given battery. The equation captures the fact that at higher currents, there is less available energy in the battery.
Peukert number:- A value that indicates how well a lead-acid battery performs under heavy currents. The Peukert number is the exponent in Peukert's equation. A value close to 1 indicates that the

battery performs well; the higher the number, the more capacity is lost when the battery is discharged at high currents. The Peukert number of a battery is determined empirically.

Planté Plate:- A formed lead plate of large area, the active material of which is formed directly from a lead substrate.

Polarization:- Change in voltage at terminals when a specified current is flowing; equal to the difference between the actual and the equilibrium (constant open circuit condition) potentials of the plates, exclusive of the internal resistance drop.

Positive Plates:- The grid and active materials of a storage battery from which current flows to the external circuit when the battery is discharging.

Positive Terminal:- The terminal that current flows toward in the external circuit from the negative terminal.

Potassium Hydroxide (KOH):- The electrolyte provides the ion transport mechanism between the electrodes, used in NiMH cells.

Primary cell:- A cell that is non-rechargeable. A cell or battery that can be discharged only once.

Prismatic cell:- A slim rectangular sealed cell in a metal case. The positive and negative plates are stacked usually in a rectangular shape rather than rolled in a spiral as done in a cylindrical cell.

Rapid Charge:- A rate of charging a cell or battery that results in fully charging a battery to full capacity between 2½ to 6 hours.

Rated Capacity:- Ampere hours of discharge that can be removed from a fully charged cell or battery, at a specific constant discharge rate at a specified temperature and at a specified cut-off voltage.

Recombinant system:- Sealed secondary cells in which gaseous products of the electrochemical charging cycle are made to recombine to recover the active chemicals. A closed cycle system preventing loss of active chemicals. Used in NiCd and *SLA* batteries.

Resealable Safety Vent:- The resealable vent built into cylindrical and prismatic cells to prevent the build up of high internal pressures.

Reversal:- A change in the normal polarity of a cell or battery.

Safety Vent:- This is a device to release the gas when the internal pressure of the battery exceeds the pre-set value.

Sealed cells:- A cell which remains closed and does not release gas or liquid when operated within the limits of charge and temperature specified by the manufacturer. An essential component in *recombinant* cells.

Secondary cell:— the process is reversible so that charging and discharging may be repeated over and over.

Sediment:- The sludge or active material shed from plates that drops to the bottom of cells.

Sediment Space:- The portion of a container beneath the element; sediment from the wearing of the plates collects here without short-circuiting.

Self-discharge:- Loss of charge due to local action, without external current flow. The decrease in the state of charge of a cell or a battery, over a period of time during storage or not in use, due to internal electrochemical losses. Typical values:
1% per day for NiCd
2% per day for NiMH
~0% per day for Lithium Ion and Lithium Polymer

Self Discharge Rate:- the percent of capacity lost on open circuit over a specified period of time.

Separator:- A device in a storage battery that prevents metallic contact between plates of opposite polarity in a cell. In sealed lead acid batteries it normally is absorbent glass fibre to hold the electrolyte in suspension.

Shelf Life:- The duration under specified conditions that at the end a cell or battery can be stored and retain its performance.

SLA Battery:- Sealed Lead Acid battery. In sealed batteries the generated oxygen combines chemically with the lead and then the hydrogen at the negative electrode, and then again with reactive agents in the electrolyte, to recreate water. A *recombinant system*. The net result is no significant loss of water from the cell.

Spalling:- Shedding of active material, usually from positives, during formation due to incomplete or improper plate curing.

Sponge Lead (Pb):- A porous mass of lead crystals and the chief material of a full-charged negative plate.

Standby Service:- An application in which the battery is maintained in a fully charged condition by trickle of float charging.

State of Charge:- The amount of electrochemical energy left in a cell or battery. The available ampere hours in a battery at any given time relative to its full charge capacity.

Starved Electrolyte:- A term occasionally applied to a VRLA cell, meaning that the cell contains little or no free electrolyte.

Sulphation:- Growth of lead sulphate crystals in Lead-Acid batteries which inhibits current flow. Refers to the formation of hard lead sulphate crystals in the plates that are difficult, if not impossible, to reconvert to active material. Sulphation is caused by storage at low state of charge.

Stratification:- Layering of high specific gravity electrolyte in lower portions of a cell, where it does not circulate normally and is of no use.

Temperature Correction:- In storage cells, specific gravity and charging voltage vary inversely with temperature, while the open circuit voltage varies directly though slightly with temperature.

Thermal Runaway:- A condition in which a cell or battery (especially valve-regulated types) on constant potential charge can destroy itself through internal heat generation being greater than that which can be externally dissipated. Can cause failure through cell dry-out, shortened life, and/or melting of the battery.

Treeing:- Growth of a lead dendrite or filament through a crack or hole of a separator, short-circuiting the cell.

Trickle Charge:- A low-rate continuous charge approximately equal to a battery's internal losses and capable of maintaining the battery in a fully-charged state. Method of charging in which the battery is either continuously or intermittently connected to a constant current charging source to maintain the battery in a fully charged condition. Not recommended for use with AGM batteries.

Tubular Plate:- A plate in which the active material is contained in porous tubes, each tube having a centrally located grid.

Vent:- An opening that permits the escape of gas from a cell or mould.

Venting:- A release of gas either controlled (through a vent) or accidental from a battery cell.

Vent Valve:- A normally closed check valve located in a cell which allows the controlled escape of gases when the internal pressure exceeds its rated value.

Volt Efficiency:- The ratio of the average voltage of a cell or battery during discharge to the average voltage during subsequent recharge.

VRLA (Valve Regulated Lead Acid):- Sealed batteries which feature a safety valve venting system designed to release excessive internal pressure, while maintaining sufficient pressure for recombination of oxygen and hydrogen into water.

Watthour:- A unit of electrical energy or work, equal to one watt acting for one hour.

Watthour Capacity:- The number of watthours a storage battery can deliver under specific conditions of temperature, rate of discharge and final voltage.

Watthour Efficiency:- A storage battery's energy efficiency expressed as ratio of watthour output to the watthours of the recharge.

Wet Shelf Life:- The time a wet secondary cell can be stored before its capacity falls to the point that the cell cannot be easily recharged.

Glossary of Fuel Cell terminology

Alkali:- A chemical base produces negative ions, the opposite of an acid. Certain types of alkalis (especially potassium hydroxide) are used as fuel cell electrolytes.

Alkaline Fuel Cell (AFC):- A type of hydrogen/oxygen fuel cell in which the electrolyte is concentrated KOH (varies between 35 to 85 wt% depending on the intended operating temperature) and hydroxide ions(OH^-) are transported from the cathode towards the anode. Temperature of operation can vary from <120°C to approximately 250°C depending upon electrolyte concentration.

Anode reaction: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$
Cathode reaction: $O_2 + 2H_2O + 2e^- \rightarrow 4OH^-$
Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Anion:- A negative ion. Alkali, molten carbonate and solid oxide fuel cells are anion-mobile cells - anions migrate through the electrolyte toward the anode.

Anode:- One of two electrodes in a fuel cell or battery. In a fuel cell it is where the fuel reacts or oxidizes, and releases electrons, that is, where the chemical reaction produces positive ions. For cells that create potential, it is also the electrode towards which the negative ion flows.

Biomass:- All organic substances: plants, wood chips, bales of straw, liquid manure, organic wastes, etc.

Bipolar plates:- Electrical conductive plate in a fuel cell stack that acts as an anode for one cell and a cathode for the adjacent cell. The plate may be made of metal or a conductive polymer (which may be a carbon-filled composite). The plate usually incorporates flow channels for the fluid feeds and may also contain conduits for heat transfer.

Catalyst:- A substance that causes or speeds a chemical reaction, by lowering the amount of energy needed to cause the reaction, without itself being affected. The catalyst lowers the activation energy required, allowing the reaction to proceed more quickly or at a lower temperature. In a fuel cell, there will typically be a catalyst used for the electrodes (to break down hydrogen into electrons and protons). Catalysts are also often used in reforming fuel.

Catalyst loading:- This is related to the amount of catalyst used in a fuel cell or fuel cell system. It often refers specifically to the mass of catalyst per unit area of an electrode.

Cathode:- One of two electrodes in a fuel cell or battery. In a fuel cell, it is where oxygen (usually taken from the air) reduction occurs – electrode where negative ions are produced.

Cation:- A positive ion. Phosphoric acid and PEM fuel cells are cation-mobile cells – the cation migrates through the electrolyte toward the cathode.

CHP:- Combined Heat and Power. This is the additional production of electricity from processes which otherwise produce only space heat or domestic hot water (DHW); also known as cogeneration.

Cogeneration:- The simultaneous use of waste heat from industrial processing, a steam turbine, or a fuel cell to generate electricity. Harnessing otherwise wasted heat boosts the efficiency of power-generating systems.

Cryoadsorption storage:- (Greek krýos: cold, frost.) special type of graphite storage. Carbon is able to adsorb hydrogen. Different qualities of carbon can adsorb higher quantities of hydrogen under certain temperature and pressure conditions than could be stored without the carbon under the same conditions. Temperatures are below 0°C (cryogenic) and above boiling temperature of hydrogen (20 K). The pressure levels are above 5 MPa.

Desulphuriser:- Some fuels contain sulphur which can be damaging to fuel cell performance. A desulphuriser may therefore be used to remove sulphur from the gas stream entering the fuel cell stack and maintain peak electrical output.

Diffusion:- Diffusion is the movement of a chemical, usually under a pressure differential. In fuel cells, diffusion may happen through a palladium membrane to purify hydrogen or through the fuel cell electrodes before splitting of a hydrogen molecule.

Direct Fuel Cell:- A type of fuel cell in which a hydrocarbon fuel is fed directly to the fuel cell stack, without requiring an external reformer to generate hydrogen.

Direct Methanol Fuel Cell (DMFC):- A type of fuel cell in which the fuel is methanol (CH_3OH), in gaseous or liquid form. The methanol is oxidized directly at the anode with no reformation to hydrogen. The electrolyte is typically a PEM.

Anode reaction: $2CH_3OH + 2H_2O \rightarrow 2CO_2 + 12H^+ + 12e^-$
Cathode reaction: $12H^+ + 3O_2 + 12e^- \rightarrow 6H_2O$
Overall reaction: $2CH_3OH + 2H_2O + 3O_2 \rightarrow 2CO_2 + 6H_2O$

Distributed generation:- Distributed generation involves the small-scale production of electrical power much closer to the end user than conventional power supply does. Distributed generation often requires lower power units.

Electrode:- An electrical terminal that conducts an electric current into or out of a fuel cell. The electrode is where reaction of a chemical species occurs and electrons are either released or accepted.

Electrolyte:- A chemical compound that conducts ions from one electrode to the other inside a fuel cell. The electrolyte does not react with the ions and does not conduct free electrons.

Electrolyser:- In an electrolyser, an electric current splits water into hydrogen and oxygen. Reverse process of the fuel cell.

External reforming:- External reforming occurs where a fuel is reformed to hydrogen - hydrocarbon fuel (methanol, gasoline, natural gas, propane, etc.) prior to entering a fuel cell stack.

Fuel:- A fuel is a chemical which can be used in a fuel cell system to produce electricity. The fuel is typically either hydrogen or something which can produce hydrogen when reformed.

Fuel Cell:- A electrochemical device for generating continuous electricity by the chemical combination a fuel and oxygen or oxidant, without combustion. A fuel cell will continuously produce electricity as long as fuel is supplied to it. Reverse process of electrolyser.

Fuel processor:- A fuel processor is a device that is capable of reforming a fuel to produce a gas stream containing hydrogen and then clean this up to produce a gas flow of sufficiently high quality to be used as the input for a fuel cell stack.

Graphite:- A soft form of the element carbon. It is used as a lubricant, as a moderator in nuclear reactors, and for other products. It does not burn easily or fuse at high temperatures, and is an important material in the construction of phosphoric acid fuel cells. Carbon is able to adsorb hydrogen. The amount of adsorbed hydrogen depends on temperature, pressure and the quality/ structure of the carbon used. Carbon structures in the nanometre range (one nanometre corresponds to 10^{-9} meters), e.g. balls, tubes or fibres

Grid-connected:- A grid-connected fuel cell is designed to function when connected to the electrical grid.

Hydrocarbon:- A chemical compound consisting of hydrogen and carbon formed in a variety of bond structures, such as oil, methane, propane, butane, etc. These are often used as fuels.

Hydrogen:- H_2. A chemical element consisting of one proton and one electron. Two hydrogen atoms combine with one oxygen atom to form a molecule of water. Hydrogen serves as the fuel for most fuel cells.

Internal reforming:- Some fuel cells operate at sufficiently high temperatures to be able to internal convert a hydrocarbon fuel to hydrogen within the fuel cell stack.

Ion:- An atom that carries a positive or negative charge due to the loss or gain of an electron.

IR Loss (Ohmic Polarization):- Losses created by the resistance to the flow of ions in the electrolyte and resistance to flow of electrons through the electrode and bipolar plate materials. Because both the electrolyte and fuel cell electrodes obey Ohm's law, the ohmic losses can be expressed by the equation $V=IR$

I^2R Loss:- Power loss due to the current I flow through the resistance R of a conductor.

Islanding:- Operation of a separate non-utility power source with or without a portion of an electric utility system- isolated from the remainder of the utility system. When a fuel cell is grid-connected, islanding of the fuel cell is required to allow safe work on the grid.

kWh:- Kilowatt-hour (1,000 watts for one hour). A measure of electric power consumption.

Matrix:- A framework within a fuel cell that supports an electrolyte.

Membrane:- The separating layer in a fuel cell that acts as electrolyte (a ion-exchanger) as well as a barrier film separating the gases in the anode and cathode compartments of the fuel cell.

Metal hydride storage:- Device that can store hydrogen by use of a metal alloy. The hydrogen is soaked into the alloy like into a sponge and fills the spaces in the crystal lattice of the alloy. The storage is filled applying a modest over-pressure and is usually operated in the temperature range of 20-80°C.

MPa:- mega Pascals (SI pressure unit); one MPa corresponds to a pressure of 10 atmospheres (10 bars).

Molten Carbonate:- A type of fuel cell electrolyte that contains carbon, oxygen and another element. Solid at room temperature, it must be melted in order to function.

Molten Carbonate Fuel Cell (MCFC):- A type of fuel cell consisting of a molten electrolyte of Li_2CO_3/ Na_2CO_3 in which the species CO_3^{2-} is transported from the cathode to the anode. Operating temperatures are typically near 650°C.

Anode reaction: $2H_2 + 2CO_3^{2-} \rightarrow 2H_2O + 2CO_2 + 4e^-$
Cathode reaction: $O_2 + 2CO_2 + 4e^- \rightarrow 2CO_3^{2-}$
Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Nafion:- A sulphuric acid in a solid polymer form. It is usually the electrolyte of PEM fuel cells.

Outage:- An outage occurs when a fuel cell or other power source which is producing electricity fails.

Oxygen:- O_2. A chemical diatomic element consisting of eight protons, eight neutrons and eight electrons. Two hydrogen atoms combine with one oxygen atom to form a molecule of water.

Phosphoric Acid:- A solution of the elements phosphorus, hydrogen, and oxygen that serves as the electrolyte for one type of fuel cell. Chemically- H_3PO_4.

Phosphoric Acid Fuel Cell (PAFC):- A type of fuel cell in which the electrolyte consists of concentrated phosphoric acid (H_3PO_4) and protons (H^+) are transported from the anode to the cathode. The operating temperature range is generally 160 - 220°C.

Anode reaction: $2H_2 \rightarrow 4H^+ + 4e^-$
Cathode reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Photobiological water splitting:- A biological processes that liberates hydrogen or where hydrogen is produced as an intermediate product. For example, photosynthesis use the solar radiation as source of energy, while fermentation processes that take place in the absence of light take advantage of the energy stored in the feedstock (e.g. glucose).

Polymer:- A natural or synthetic compound composed of repeated links of simple molecules.

Potassium Hydroxide:- A solution of the elements potassium, hydrogen, and oxygen that serves as the electrolyte for one type of fuel cell. Chemically:- KOH.

Power density:- The power density of an individual fuel cell is the power produced related to the active area or volume of the cell.

Proton Exchange Membrane (PEM):- A polymer sheet that serves as the electrolyte in PEM fuel cell. The film prevents hydrogen and oxygen meeting and also carries protons across to complete the electrical circuit.

Proton Exchange Membrane Fuel Cell (PEMFC):- A type of acid based fuel cell in which the exchange of protons (H^+) from the anode to the cathode is achieved by a solid, aqueous membrane impregnated with an appropriate acid. The electrolyte is a called a proton-exchange membrane (PEM). The fuel cells typically run at low temperatures (<100°C) and pressures (< 5 atm).

Anode reaction: $2H_2 \rightarrow 4H^+ + 4e^-$
Cathode reaction: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Overall reaction: $2H_2 + O_2 \rightarrow 2H_2O$

Reformate:- Fuel processor output gas stream containing hydrogen, carbon monoxide and carbon dioxide. This reformate gas stream will eventually pass to the fuel cell stack, possibly after purification.

Reformer:- A device that extracts pure hydrogen from hydrocarbons which have reacted with water vapour and heat in the presence of a catalyst.

Reforming:- The process of producing a hydrogen-rich gas stream for eventual use in a fuel cell from a feedstock. The thermal or catalytic conversion of a hydrocarbon fuel into more volatile products with higher calorific ratings.

Regenerative Fuel Cells:- A regenerative (or reversible) fuel cell is able to react a fuel and an oxidant to produce electricity and other chemical species or operate in reverse. This allows ready production of power when it is economically viable. Several fuel cell types in which fuel and, in some types, the oxidant are regenerated from the oxidation product.

Renewable energy:- Energy sources that do not require the use of limited fossil fuel resources. They include wind power, hydroelectric or geothermal power and photovoltaics. They can often be used to produce hydrogen for use in fuel cells.

Reversible fuel cell:- A reversible, or regenerative, fuel cell is able to react a fuel and an oxidant to produce electricity and other chemical species or operate in reverse, such that the cell may be recharged with a separate power source if desired. Where hydrogen and water are the fuels, water and electricity are produced. When required, water can be electrolysed, and hydrogen and oxygen produced, upon the input of electricity. For example, the hydrogen/oxygen fuel cell may be recharged by providing power for water electrolysis with hydrogen storage. Also called a Regenerative Fuel Cell.

Shift conversion:- The reaction of carbon monoxide CO and water to give hydrogen and carbon dioxide. This provides more hydrogen to create power in the fuel cell and removes carbon monoxide which is detrimental to some types of fuel cell. This process is performed immediately after the reformer and before the preferential oxidizer to reduce CO from approximately 10% down to 0.5% to 0.1% usually through a water gas shift reaction.

Solid Oxide:- A solid combination of oxygen and another element (often zirconium) that serves as the electrolyte for a particular fuel cell.

Solid Oxide Fuel Cell (SOFC):- A type of fuel cell in which the electrolyte is a solid, nonporous metal oxide, typically ZrO_2 doped with Y_2O_3, and O^{2-} is transported from the cathode to the anode. Any carbon monoxide (CO) in the reformate gas is oxidized to carbon dioxide (CO_2) at the anode. Temperatures of operation are typically 800 to 1000°C.

Anode reactions: $H_{2(g)} + O^{2-} \rightarrow H_2O_{(g)} + 2e^-$

$2CO_{(g)} + O^{2-} \rightarrow CO_{2(g)} + 2e^-$

Cathode reaction: $O_2 + 4e^- \rightarrow 2O^{2-}$

Overall reaction: $O_2 + H_2 + CO \rightarrow H_2O + CO_2$

Specific power:- The specific power of a system is the power produced divided by the weight of the system.

Stack:- arrangement of individual fuel cells connected in series within a generating assembly.

Standard Conditions:- The performance of most fuel cells will be quoted under standard conditions in order to allow easy comparison.

Steam reforming:- The catalytic reaction of a hydrocarbon fuel with water to produce hydrogen. More hydrogen is produced for the same amount of fuel than by auto thermal reforming or partial oxidation but heat input is required to maintain the reaction.

Tubular cells:- The two common designs of solid oxide fuel cells are tubular and planar. A tubular system separates the fuel or reformate from the oxidant, inside and outside the tube. Fuel Cells that are formed in cylindrical fashion and allow fuel and oxidant to flow on the inner or outer surfaces of the pipe.

Water-gas shift reaction:- This reaction between carbon monoxide and water produces hydrogen and carbon dioxide. It is therefore used after the fuel has been reformed to provide more hydrogen to power a fuel cell and to remove carbon monoxide which may poison performance.

Glossary of Solar Electric terminology

Absorbers:- Dark-coloured objects that soak up heat in thermal solar collectors. In a photovoltaic device, the material that readily absorbs photons to generate charge carriers (free electrons or holes).

Amorphous semiconductor:- A non-crystalline semiconductor material. Easier and cheaper

Amorphous Silicon:- A thin-film, silicon photovoltaic cell having no crystalline structure. Manufactured by depositing layers of doped silicon on a substrate. See also single-crystal silicon an polycrystalline silicon.

Angle of incidence:- Angle between the normal to a surface and the direction of incident radiation; applies to the aperture plane of a solar collector. Most modern solar panels have only minor reductions in power output within plus/minus 15°.

Antireflection coating:- A thin coating of a material, which reduces the light reflection and increases light transmission, applied to a photovoltaic cell surface.

Array:- Any number of photovoltaic modules connected together to provide a single electrical output. Arrays are often designed to produce significant amounts of electricity.

Autonomous system:- A stand-alone PV system that has no back-up generating source. May or may not include storage batteries. Most battery systems are designed for a certain minimum "days of autonomy" - which means that the batteries can supply sufficient power with no sunlight to charge the batteries. This varies from 3 to 5 days in the sunbelt, to 5 to 10 days elsewhere.

Azimuth:- Angle between the north direction and the projection of the surface normal into the horizontal plane; measured clockwise from north. As applied to the PV array, 180° azimuth.

Band Gap:- In a semiconductor, the energy difference between the highest valence band and the lowest conduction band.

Band Gap Energy (E_g):- The amount of energy (in electron volts) required to free an outer shell electron from its orbit about the nucleus to a free state, and thus promote it from the valence to the conduction level.

Barrier Energy:- The energy given up by an electron in penetrating the cell barrier; a measure of the electrostatic potential of the barrier.

Baseline performance value:- Initial values of I_{sc}, V_{oc}, P_{mp}, I_{mp} measured by the accredited laboratory and corrected to Standard Test Conditions.

Cathodic protection:- A method of preventing oxidation (rusting) of exposed metal structures, such as bridges and pipelines, by imposing between the structure and the ground a small electrical voltage that opposes the flow of electrons and that is greater than the voltage present during oxidation.

Cell:- The basic unit of a photovoltaic panel or battery.

Cell barrier:- A very thin region of static electric charge along the interface of the positive and negative layers in a photovoltaic cell. The barrier inhibits the movement of electrons from one layer to the other, so that higher-energy electrons from one side diffuse preferentially through it in one direction, creating a current and thus a voltage across the cell. Also called depletion zone, cell junction, or space charge.

Cell junction:- The area of immediate contact between two layers (positive and negative) of a photovoltaic cell. The junction lies at the centre of the cell barrier or depletion zone.

Chemical Vapour Deposition (CVD):- A method of depositing thin semiconductor films used to make certain types of photovoltaic devices. With this method, a substrate is exposed to one or more vaporized compounds, one or more of which contain desirable constituents. A chemical reaction is initiated, at or near the substrate surface, to produce the desired material that will condense on the substrate.

Cleavage of Lateral Epitaxial Films for Transfer (CLEFT):- A process for making inexpensive Gallium Arsenide (GaAs) photovoltaic cells in which a thin film of GaAs is grown atop a thick, single-crystal GaAs (or other suitable material) substrate and then is cleaved from the substrate and incorporated into a cell, allowing the substrate to be reused to grow more thin-film GaAs.

Combined collector:- A photovoltaic device or module that provides useful heat energy in addition to electricity.

Concentrator:- A PV module that uses optical elements to increase the amount of sunlight incident on a PV cell. Concentrating arrays must track the sun and use only the direct sunlight because the diffuse portion cannot be focused onto the PV cells. Efficiency is increased, but lifespan is usually decreased due to the high heat.

Concentrator (module, array, or collector):- An arrangement of photovoltaic cells that includes optical components such as lenses (Fresnel lens) to direct and concentrate sunlight onto a PV cell of smaller area. Concentrators can increase the power flux of sunlight hundreds of times.

Conduction Band (or conduction level):- An energy band in a semiconductor in which electrons can move freely in a solid, producing a net transport of charge.

Conversion efficiency (cell or module):- The ratio of the electric energy produced by a photovoltaic device (under one-sun conditions) to the energy from sunlight incident upon the cell.

Copper Indium Diselenide ($CuInSe_2$, or CIS):- A polycrystalline thin-film photovoltaic material (sometimes incorporating gallium (CIGS) and/or sulphur).

Crystalline Silicon:- A type of photovoltaic cell made from a slice of single-crystal silicon or poly-crystalline silicon.

Current at maximum power (I_{mp}):- The current at which maximum power is available from a module.

Cycle life:- Number of discharge-charge cycles that a battery can tolerate under specified conditions before it fails to meet specified criteria as to performance (e.g., capacity decreases to 80% of the nominal capacity).

Dangling Bonds:- A chemical bond associated with an atom on the surface layer of a crystal. The bond does not join with another atom of the crystal, but extends in the direction of exterior of the surface.

Dendrite:- A slender threadlike spike of pure crystalline material, such as silicon.

Dendritic Web Technique:- A method for making sheets of polycrystalline silicon in which silicon dendrites are slowly withdrawn from a melt of silicon whereupon a web of silicon forms between the dendrites and solidifies as it rises from the melt and cools.

Depletion Zone:- Same as cell barrier. The term derives from the fact that this microscopically thin region is depleted of charge carriers (free electrons and hole).

Diffuse insolation:- Sunlight received indirectly as a result of scattering due to clouds, fog, haze, dust, or other obstructions in the atmosphere. Opposite of direct insolation.

Direct insolation:- Sunlight falling directly upon a collector. Opposite of diffuse insolation.

Direct Beam Radiation:- Radiation received by direct solar rays. Measured by a pyrheliometer with a solar aperture of 5.7° to transcribe the solar disc.

Distributed systems:- Systems that are installed at or near the location where the electricity is used, as opposed to central systems that supply electricity to grids. A residential

Edge-Defined Film-Fed Growth (EFG):- A method for making sheets of polycrystalline silicon for photovoltaic devices in which molten silicon is drawn upward by capillary action through a mould.

Efficiency:- The ratio of power output of a Photovoltaic cell to the incident power from the sun or simulated sun sources under specified standard insolation conditions.

Electrodeposition:- Electrolytic process where a metal is deposited at the cathode from a solution of its ions.

Energy:- The ability to do work. Stored energy becomes working energy when we use it.

Energy Levels:- The energy represented by an electron in the band model of a substance.

Epitaxial Growth:- The growth of one crystal on the surface of another crystal. The growth of the deposited crystal is oriented by the lattice structure of the original crystal.

EVA:- (Ethylene Vinyl Acetate) An encapsulant between the glass cover and the PV cells in PV modules. It is durable, transparent, resistant to corrosion, and flame retardant.

Fill Factor:- The ratio of a photovoltaic cell's actual power to its power if both current and voltage were at their maxima. A key characteristic in evaluating cell performance.

Fixed Tilt Array:- A photovoltaic array set in at a fixed angle with respect to horizontal.

Flat-plate PV:- Refers to a PV array or module that consists of non-concentrating elements. Flat-plate arrays and modules use direct and diffuse sunlight, but if the array is fixed in position, some portion of the direct sunlight is lost because of oblique sun-angles in relation to the array.

Full Sun:- The full sun condition is the amount of power density received at the surface of the earth at noon on a clear day - about 100 mW/cm^2. Lower levels of sunlight are often expressed as ½sun or 0.1 sun. A figure of 0.5 sun means that the power density of the sunlight is one-half of that of a full sun.

Fresnel Lens:- An optical device that focuses light like a magnifying glass; concentric rings are faced at slightly different angles so that light falling on any ring is focused to the same point.

Gallium (Ga):- A chemical element, metallic in nature, used in making certain kinds of PV cells and semiconductor devices.

Gallium Arsenide (GaAs):- A crystalline, high-efficiency compound used to make certain types of PV cells and semiconductor material.

Grid-connected (PV system):- A PV system in which the PV array acts like a central generating plant, supplying power to the grid.

Heterojunction:- A region of electrical contact between two different materials.

Hole:- The vacancy where an electron would normally exist in a solid; behaves like a positively charged particle.

Homojunction:- Region between n-layer and p-layer in a single material, photovoltaic cell.

Incident light:- Light that shines onto the face of a PV cell or module.

Indium Oxide:- A wide band gap semiconductor that can be heavily doped with tin to make a highly conductive, transparent thin film. Often used as a front contact or one component of a heterojunction PV cell.

Infrared Radiation:- Electromagnetic radiation whose wavelengths lie in the range from 0.75 micrometer to 1000 micrometers; invisible long wavelength radiation (heat) capable of producing a thermal or photovoltaic effect, though less effective than visible light.

Irradiance:- The direct, diffuse, and reflected solar radiation that strikes a surface. Usually expressed in kW/m^2. Irradiance multiplied by time equals insolation.

Insolation:- Sunlight, direct or diffuse; from 'incident solar radiation.'

Interconnect:- A conductor within a module or other means of connection which provides an electrical interconnection between the PV cells. [UL 1703]

I-V curve:- A graphical presentation of the current versus the voltage from a photovoltaic device as the load is increased from the short circuit (no load) condition to the open circuit (maximum voltage) condition. The shape of the curve characterized cell performance.

I-V data:- The relationship between current and voltage of a photovoltaic device in the power-producing quadrant, as a set of ordered pairs of current and voltage readings in a table, or as a curve plotted in a Cartesian coordinate system. [ASTM E 1036]

Junction diode:- A semiconductor device with a junction and a built-in potential that passes current better in one direction than the other. All PV cells are junction diodes.

kilowatt-hour (kWh):- One thousand watts acting over a period of 1 hour. The kWh is a unit of energy. 1 kWh=3600 kJ.

Light-induced defects:- Defects, such as dangling bonds, induced in an amorphous silicon semiconductor upon initial exposure to light.

Light trapping:- The trapping of light inside a semiconductor material by refracting and reflecting the light at critical angles; trapped light will travel further in the material, greatly increasing the probability of absorption and hence of producing charge carriers.

Maximum Power Point (MPP):- The point on the current-voltage (I-V) curve of a module under illumination, where the product of current and voltage is maximum. [UL 1703] For a typical silicon cell panel, this is about 17 volts for a 36-cell configuration. MPP tracking will typically increase

power delivered to the system by 10% to 40%, depending on climate conditions and battery state of charge. For a typical silicon cell, this is at about 0.45 volts.

Microgroove:- A small groove scribed into the surface of a cell which is filled with metal for contacts.

Module:- A number of PV cells connected together, sealed with an encapsulant, and having a standard size and output power; the smallest building block of the power generating part of a PV array. Also called panel.

Monolithic:- Fabricated as a single structure.

Multicrystalline:- Material that is solidified at such as rate that many small crystals (crystallites) form. The atoms within a single crystallite are symmetrically arranged, whereas crystallites are jumbled together. These numerous grain boundaries reduce the device efficiency. A material composed of variously oriented, small individual crystals. (Sometimes referred to as polycrystalline or semicrystalline).

Multijunction device:- A photovoltaic device containing two or more cell junctions, each of which is optimized for a particular part of the solar spectrum, to achieve greater overall efficiency.

n-type semiconductor:- A semiconductor produced by doping an intrinsic semiconductor with an electron-donor impurity (e.g., phosphorous in silicon).

NOCT:- Nominal Operating Cell Temperature. The PV cell temperature at a reference environment defined as 800 W/m^2 irradiance, 20°C ambient air temperature, and 1 m/s wind speed with the cell or module in an electrically open circuit state.

Open-circuit voltage (Voc):- The maximum possible voltage across a photovoltaic cell or module; the voltage across the cell in sunlight when no current is flowing.

Peak load; peak demand:- The maximum load, or usage, of electrical power occurring in a given period of time, typically a day.

Peak Sun Hours:- The equivalent number of hours per day when solar irradiance averages 1,000 W/m^2. For example, six peak sun hours means that the energy received during total daylight hours equals the energy that would have been received had the irradiance for 6 hours been 1,000 W/m^2.

Peak Watt:- A unit used to rate the performance of PV cells, modules, or arrays; the maximum nominal output of a photovoltaic device, in watts (W_p) under standardized test conditions, usually 1,000 W/m^2 of sunlight with other conditions, such as temperature specified.

Photon:- A particle of light that acts as an individual unit of energy.

Photovoltaic (PV):- Pertaining to the direct conversion of light into electricity.

Photovoltaic (PV) array:- An interconnected system of PV modules that function as a single electricity-producing unit. The modules are assembled as a discrete structure, with common support or mounting. In smaller systems, an array can consist of a single module.

Photovoltaic (PV) cell:- The smallest semiconductor element within a PV module to perform the immediate conversion of light into electrical energy (dc voltage and current).

Photovoltaic (PV) conversion efficiency:- The ratio of the electric power produced by a photovoltaic device to the power of the sunlight incident on the device.

Photovoltaic (PV) efficiency:- The ratio of electric power produced by a cell at any instant to the power of the sunlight striking the cell. This is typically about 9% to 14% for commercially available cells.

Photovoltaic (PV) generator:- The total of all PV strings of a PV power supply system, which are electrically interconnected.

Photovoltaic (PV) module:- The smallest environmentally protected, essentially planar assembly of PV cells and ancillary parts, such as interconnections, terminals, [and protective devices such as diodes] intended to generate dc power under unconcentrated sunlight. The structural (load carrying) member of a module can either be the top layer (superstrate) or the back layer (substrate). [UL 1703]

Photovoltaic (PV) panel:- often used interchangeably with PV module (especially in one-module systems), but more accurately used to refer to a physically connected collection of modules (i.e., a laminate string of modules used to achieve a required voltage and current).

Photovoltaic (PV) peak watt:- Maximum "rated" output of a cell, module, or system. Typical rating conditions are 1000 watts per square meter of sunlight, 20°C ambient air temperature and 1 m/s wind speed.

Photovoltaic (PV) system:- Thee set of components for converting sunlight into electricity by the photovoltaic process, including the array and balance of system components.

Photovoltaic-thermal (PV/T) system:- A photovoltaic system that, in addition to converting sunlight into electricity, collects the residual heat energy and delivers both heat and electricity in usable form. Also called a total energy system.

Physical Vapour Deposition:- A method of depositing thin semiconductor photovoltaic films. With this method, physical processes, such as thermal evaporation or bombardment of ions, are used to deposit elemental semiconductor material on a substrate.

P-I-N:- A semiconductor photovoltaic (PV) device structure that layers an intrinsic semiconductor between a p-type semiconductor and an n-type semiconductor; this structure is most often used with amorphous silicon PV devices.

Polycrystalline:- See Multicrystalline.

Polycrystalline Silicon:- A material used to make photovoltaic cells, which consist of many crystals unlike single-crystal silicon.
PV:- Abbreviation for photovoltaic(s).
Pyronometer:- An instrument for measuring total hemispherical solar irradiance on a flat surface, or "global" irradiance; thermopile sensors have been generally identified as pyranometers, however, silicon sensors are also referred to as pyranometers.
Pyrheliometer:- An instrument used for measuring direct beam solar irradiance. Uses an aperture of 5.7° to transcribe the solar disc.
Recombination:- The action of a free electron falling back into a hole. Recombination processes are either radiative, where the energy of recombination results in the emission of a photon, or non-radiative, where the energy of recombination is given to a second electron which then relaxes back to its original energy by emitting phonons. Recombination can take place in the bulk of the semiconductor, at the surfaces, in the junction region, at defects, or between interfaces.
Resistive voltage drop:- The voltage developed across a cell by the current flow through the resistance of the cell.
Ribbon (Photovoltaic) Cells:- A type of photovoltaic device made in a continuous process of pulling material from a molten bath of photovoltaic material, such as silicon, to form a thin sheet of material.
Semiconductor:- Any material that has a limited capacity for conducting an electric current. Generally falls between a metal and an insulator in conductivity. Certain semiconductors, including silicon, gallium arsenide, copper indium diselenide, and cadmium telluride, are uniquely suited to the photovoltaic conversion process.
Semicrystalline:- See 'Multicrystalline.'
Series connection:- A way of joining photovoltaic cells or batteries by connecting positive leads to negative leads; such a configuration increases the voltage.
Series resistance:- Parasitic resistance to current flow in a cell due to mechanisms such as resistance from the bulk of the semiconductor material, metallic contacts, and interconnections.
Short-circuit current (I_{sc}):- The current flowing freely from a photovoltaic cell through an external circuit that has no load or resistance; the maximum current possible.
Silicon (Si):- A chemical element, atomic number 14, semi-metallic in nature, dark gray, an excellent semiconductor material. A common constituent of sand and quartz (as the oxide). Crystallizes in face-centred cubic lattice like a diamond. The most common semiconductor material used in making photovoltaic devices.
Single-crystal material:- A material that is composed of a single crystal or a few large crystals.
Solar cell:- See 'Photovoltaic cell.'
Solar constant:- The strength of sunlight; 1353 watts per square meter in space and about 1000 watts per square meter at sea level at the equator at solar noon.
Solar energy:- Electromagnetic energy transmitted from the sun (solar radiation). The amount that reaches the earth is equal to one billionth of total solar energy generated, or the equivalent of about 420 trillion kilowatt-hours.
Solar-grade silicon:- Intermediate-grade silicon used in the manufacture of PV cells. Less expensive than electronic-grade silicon.
Solar noon:- That moment of the day that divides the daylight hours for that day exactly in half. To determine solar noon, calculate the length of the day from the time of sunset and sunrise and divide by two. Solar noon may be quite a bit different from 'clock' noon.
Solar spectrum:- The total distribution of electromagnetic radiation emanating from the sun. The different regions of the solar spectrum are described by their wavelength range. The visible region extends from about 390 to 780 nanometres (a nanometre is one billionth of one meter). About 99 percent of solar radiation is contained in a wavelength region from 300 nm (ultraviolet) to 3,000 nm (near-infrared). The combined radiation in the wavelength region from 280 nm to 4,000 nm is called the broadband, or total, solar radiation.
Solar thermal electric:- Method of producing electricity from solar energy by using focused sunlight to heat a working fluid, which in turn drives a turbogenerator.
Split-spectrum cell:- A compound photovoltaic device in which sunlight is first divided into spectral regions by optical means. Each region is then directed to a different photovoltaic cell optimized for converting that portion of the spectrum into electricity. Such a device achieves significantly greater overall conversion of incident sunlight into electricity. See 'mulitjunction device.'
Sputtering:- A process used to apply photovoltaic semiconductor material to a substrate by a physical vapour deposition process where high-energy ions are used to bombard elemental sources of semiconductor material, which eject vapors of atoms that are then deposited in thin layers on a substrate.
Stand-alone (PV system):- An autonomous or hybrid photovoltaic system not connected to a grid. May or may not have storage, but most stand-alone systems require batteries or some other form of storage.
Stand-off mounting:- Technique for mounting a PV array on a sloped roof, which involves mounting the

modules a short distance above the pitched roof and tilting them to the optimum angle.
Standard Test Conditions (STC):- Conditions under which a module is typically tested in a laboratory [IEC 1215]:
i. Irradiance intensity of 1000 W/square meter;
ii. AM1.5 solar reference spectrum; and
iii. A cell (module) temperature of 25 degrees C, plus or minus 2 degrees C.
Substrate:- The physical material upon which a photovoltaic cell is made.
Superstrate:- The covering on the sun side of a PV module, providing protection for the PV materials from impact and environmental degradation while allowing maximum transmission of the appropriate wavelengths of the solar spectrum.
Staebler-Wronski Effect:- The tendency of the sunlight to electricity conversion efficiency of amorphous silicon photovoltaic devices to degrade (drop) upon initial exposure to light.
String:- A number of photovoltaic modules or panels interconnected electrically in series to produce the operating voltage required by the load.
Substrate:- The physical material upon which a photovoltaic cell is applied.
Superstrate:- The covering on the sunny side of a photovoltaic (PV) module, providing protection for the PV materials from impact and environmental degradation while allowing maximum transmission of the appropriate wavelengths of the solar spectrum.
Thermal electric:- Electric energy derived from heat energy, usually by heating a working fluid, which drives a turbogenerator. See 'solar thermal electric.'
Thermophotovoltaic (TPV) device:- A device that converts secondary thermal radiation, re-emitted by an absorber or heat source, into electricity; The device is designed for maximum efficiency at the wavelength of the secondary radiation.
Thick-crystalline materials:- Semiconductor material, typically measuring from 200-400 microns thick, that is cut from ingots or ribbons.
Thin film:- A layer of semiconductor material, such as copper indium diselenide, cadmium telluride, gallium arsenide, or amorphous silicon, a few microns or less in thickness, used to make photovoltaic cells. Commonly called amorphous.
Thin Film Photovoltaic Module:- A photovoltaic module constructed with sequential layers of thin film semiconductor materials. See amorphous silicon.
Tilt Angle:- The angle at which a photovoltaic array is set to face the sun relative to a horizontal position. The tilt angle can be set or adjusted to maximize seasonal or annual energy collection.
Total internal reflection:- The trapping of light by refraction and reflection at critical angles inside a semiconductor device so that it cannot escape the device and must eventually be absorbed by the semiconductor.
Tracking array:- PV array that follows the path of the sun to maximize the solar radiation incident on the PV surface. The two most common orientations are:
i. one axis where the array tracks the sun east to west and
ii. two-axis tracking where the array points directly at the sun at all times.
Tracking arrays use both the direct and diffuse sunlight. Two-axis tracking arrays capture the maximum possible daily energy. Typically, a single axis tracker will give you 15% to 25% more power per day, and dual axis tracking will add about 5% to that. Depends somewhat on latitude and season.
Two-axis tracking:- A system capable of rotating independently about two axes (e.g., vertical and horizontal) and following the sun for maximum efficiency of the solar array.
Tunnelling:- Quantum mechanical concept whereby an electron is found on the opposite side of an insulating barrier without having passed through or around the barrier.
Ultraviolet:- Electromagnetic radiation in the wavelength range of 4 to 400 nanometres.
Vacuum Evaporation:- The deposition of thin films of semiconductor material by the evaporation of elemental sources in a vacuum.
Valence Band:- The highest energy band in a semiconductor that can be filled with electrons.
Valence Level Energy/Valence State:- Energy content of an electron in orbit about an atomic nucleus. Also called bound state.
Vertical Multijunction (VMJ) Cell:- A compound cell made of different semiconductor materials in layers, one above the other. Sunlight entering the top passes through successive cell barriers, each of which converts a separate portion of the spectrum into electricity, thus achieving greater total conversion efficiency of the incident light. Also called a multiple junction cell. See multijunction device and split-spectrum cell.
V_{mp}:- Voltage at maximum power . The voltage at which maximum power is available from a photovoltaic module.
V_{oc}:- Open-circuit voltage
Voltage at maximum power (V_{mp}):- The voltage at which maximum power is available from a module.
Wafer:- A thin sheet of semiconductor material made by mechanically sawing it from a single-crystal or multicrystal ingot or casting.
Watt-hour (Wh):- See 'Kilowatt-hour.'

Window:- A wide band gap material chosen for its transparency to light. Generally used as the top layer of a photovoltaic device, the window allows almost all of the light to reach the semiconductor layers beneath.

Work Function:- The energy difference between the Fermi level and vacuum zero. The minimum amount of energy it takes to remove an electron from a substance into the vacuum.

Zenith Angle:- the angle between the direction of interest (of the sun, for example) and the zenith (directly overhead).

Glossary of Capacitor terminology

AC voltage:- The sum of the dc and peak ac voltage applied to the capacitor should not exceed the rated dc voltage, nor should the rms voltage exceed the Corona Start Voltage.

Aerogel Capacitor:- these capacitors use carbon aerogel to attain immense electrode surface area, can attain huge values, up to thousands of farads. EDLCs can be used as replacements for batteries in applications where a high discharge current is required, e.g. in electric vehicles. They can also be recharged hundreds of thousands of times, unlike conventional batteries which last for only a few hundred or thousand recharge cycles. However, capacitor voltage drops faster than battery voltage during discharge, so a dc to dc converter may be used to maintain voltage and to make more of the energy stored in the capacitor usable.

Aluminium Electrolytic Capacitor:- are compact but 'lossy'. A capacitor made up of two aluminium electrodes separated by paper saturated with an electrolyte. The dielectric is the oxide of the anode. They are available in the range of less than 1μF to 1,000,000μF with working voltages over five hundred volts dc. The dielectric is a thin layer of aluminium oxide. They contain corrosive liquid and can burst if the device is connected backwards. The electrolyte will tend to dry out in the absence of a sufficient rejuvenating voltage, and eventually the capacitor will fail. Bipolar electrolytics contain two capacitors connected in series opposition and are used for coupling ac signals. Poor frequency and temperature characteristics make them unsuited for high-frequency applications.

Capacitance (Capacity):- That property of a system of conductors and dielectrics which permits the storage of electricity when potential difference exists between the conductors. A measure of the energy storage ability of a capacitor, given as C = k A/d, where A is the area of the electrodes, d is their separation, and k is a function of the dielectric between the electrodes. The formula yields a result in farads (F), but a farad is so large that the most commonly used values are expressed in microfarads (μf = 10^{-6}F) or picofarads (pf = 10^{-12}F). Capacitance is always positive.

Capacitive Reactance (X_c):- The opposition to the flow of alternating or pulsating current by a capacitor measured in ohms. The imaginary component of the impedance of a capacitor. The non-heating impedance component of the capacitor when ac flows: $X_c = 1/2\pi fC$.

Capacitor:- An electrical/electronic part that stores electrical charges. In its simplest form it consists of two conducting surfaces separated by a dielectric. A passive circuit element capable of storing electrical energy and releasing it at a predetermined time and at a predetermined rate.

Charge:- The amount of electricity present upon the capacitor's plates. Also, the act of forcing of electrons onto the capacitor's plates. See Coulomb.

Corona:- A luminous discharge due to ionization of the gas surrounding a conductor around which exists a voltage gradient exceeding a certain critical value. Any electrically detectable, field intensified ionization that does not result immediately in complete breakdown of the insulation and electrode system in which it occurs. A type of discharge -sometimes visible- in the dielectric of an insulation system caused by an electric field and characterized by the rapid development of an ionized channel which does not completely bridge the electrode. May be continuous or intermittent. Not a materials property, but related to the system, including electrodes. Its incidence can be reduced or avoided through special designs.

Corona Resistance:- The time that insulation will withstand a specified level field-intensified ionization that does not result in the immediate complete breakdown of the insulation.

Creepage:- Electrical leakage on a solid dielectric surface

Critical Voltage (of gas):- The voltage at which a gas ionizes and corona occurs, preliminary to dielectric breakdown of the gas.

Ceramic Capacitor:-This capacitor is so named because it contains a ceramic dielectric. One type of ceramic capacitor uses a hollow ceramic cylinder as both the form on which to construct the capacitor and as the dielectric material. The plates consist of thin films of metal deposited on the ceramic cylinder. The other type of ceramic capacitor is manufactured in the shape of a disk. After leads are attached to each side of the capacitor, the capacitor is completely covered with an insulating moisture-proof coating. Ceramic capacitors usually range in value from 1pF to 0.1μF and may be used with voltages as high as 30kV.

Coulomb:- A coulomb is the unit of electric charge.1 coulomb is the amount of electric charge transported by a current of one ampere in one second. It can also be defined in terms of capacitance and voltage, where one coulomb is defined as one farad of capacitance times one volt of electric potential difference.

Dielectric:- The insulating material between the plates of the capacitor. The material is chosen for its ability to permit electrostatic attraction and repulsion to take place across it. The material will have the property that energy required to establish an electric field is recoverable in whole or in part, as electric energy. In other words, a good dielectric material is a poor conductor of electricity while being an effective supporter of electrostatic fields.

Dielectric Absorption (DA):-That property of an imperfect dielectric whereby there is an accumulation of electric charges within the body of the material when it is placed in an electric field. An apparent 'recovery voltage' measured after the capacitor is discharged and expressed as a percent of the initial charge voltage. DA is due largely to the dipole moment of the dielectric and to lesser degree the migration of free electrons to the surface of the dielectric. A measure of the reluctance of a capacitor's dielectric to discharge completely - usually measured in percent of original charge.

Dielectric Constant:- That property of a dielectric which determines the electrostatic energy stored per unit volume for unit potential gradient.

Dielectric Loss:- The time rate at which electric energy is transformed into heat in a dielectric when it is subjected to a changing electric field.

Dielectric Loss Angle:- The difference between 90° and the dielectric phase angle.

Dielectric Phase Angle:- The angular difference in phase between the sinusoidal alternating potential difference applied to a dielectric and the component of the resulting alternating current having the same period as the potential difference.

Dielectric Power Factor:- The cosine of the dielectric phase angle (or sine of the dielectric loss angle).

Dielectric Strength:- The voltage which an insulating material can withstand before breakdown (puncture) occurs, usually expressed as a voltage gradient (such as volts per mil). The voltage figure used is the average RMS voltage gradient between two electrodes at the time of failure.

Displacement Current:- A current which exists in addition to ordinary conduction current in AC circuits. It is proportional to the rate of change of the electric field.

Disruptive Discharge:- The sudden and large increase in current through an insulation medium due to the complete failure of the medium under the electrostatic stress.

Dissipation Factor (DF) tanδ:-The tangent of the loss angle of the insulating material. A measure of the deviation from the ideal capacitance value. A measure of the power factor (or losses) of a capacitor, given as $\tan\delta = DF = 2\pi \times fRC \times 100\%$, where R is the equivalent series resistance (ESR) of the capacitor, f is the frequency (Hz.), and C is capacitance (Farads). Dissipation Factor varies with frequency and temperature.

dv/dt:- Change in Voltage divided by Change in Time, usually expressed in Volts per us. Is the maximum allowed change in volts per microsecond at the rated voltage. The maximum voltage rise (or discharge) time a capacitor can withstand being damaged.

EDLC:- Electric Double Layer Capacitor - is a next-generation energy storage device that will be used as an auxiliary power supply and the combined use with photovoltaics equipment and hybrid electric cars. Also known as supercapacitors or ultracapacitors, have very high capacitance values but low voltage ratings. They use a molecule-thin layer of electrolyte, rather than a manufactured sheet of material, as the dielectric. As the energy stored is inversely proportional to the thickness of the dielectric, these capacitors have an extremely high energy density. The electrodes are made of activated carbon, which has a high surface area per unit volume, further increasing the capacitor's energy density.

Electrolytic Capacitor:- is used where a large amount of capacitance is required. As the name implies, an electrolytic capacitor contains an electrolyte. This electrolyte can be in the form of a liquid (wet electrolytic capacitor). The wet electrolytic capacitor is no longer in popular use due to the care needed to prevent spilling of the electrolyte. A dry electrolytic capacitor consists essentially of two metal plates separated by the electrolyte. In most cases the capacitor is housed in a cylindrical aluminium container which acts as the negative terminal of the capacitor. The positive terminal (or terminals if the capacitor is of the multisection type) is a lug (or lugs) on the bottom end of the container. The capacitance value(s) and the voltage rating of the capacitor are generally printed on the side of the aluminium case

A polarized capacitor exhibiting a high capacitance/volume ratio that consists of two electrodes immersed in an electrolyte, with a chemical film that acts as a dielectric on one or both electrodes. Electrolytic capacitors are made by winding either plain or etched foils on which an oxide has been formed on the surface of one (either anode or cathode) film. The etching of the foil increases the surface area and a considerable increase in capacitance is obtained.

Equivalent Series Resistance (ESR):- A resistive series element of the capacitor model found in both the AC and DC domains. Contributing factors: electrodes, leads, dielectric. This value can change with frequency, time, etc. A measure of the total lossiness of a capacitor which includes the

leads, electrodes, dielectric losses, leakage (IR) and most important, the end spray connecting the leads to the metallised film. The lower the ESR the higher the current carrying ability the capacitor will have. It is related and dependant on temperature and frequency and generally when either these factors increase, a reduction in ESR results.
The sum of all the internal resistances of a capacitor measured in ohms. Expressed mathematically as ESR = DF×X_c.

Farad:- A farad is defined as the amount of capacitance for which a potential difference of one volt results in a static charge of one coulomb. It has the base SI representation of $s^4 \cdot A^2 \cdot m^{-2} \cdot kg^{-1}$. Since an ampere is the rate of electrical flow (current) of one coulomb per second, an alternate definition is that a farad is the amount of capacitance that requires one second for a one ampere flow of charge to change the voltage by one volt.
The basic unit of a measure of a capacitor. A capacitor charged to 1 volt with a charge of 1 coulomb would have a capacitance of 1 Farad. 1 μF = .000001 Farads.

Film Capacitor:- Made from high quality polymer film (usually polycarbonate, polystyrene, polypropylene, polyester (Mylar), and for high quality capacitors polysulphone), and metal foil or a layer of metal deposited on surface. They have good quality and stability, and are suitable for timer circuits and for high frequencies.

Fixed Capacitor:- is constructed in such manner that it possesses a fixed value of capacitance which cannot be adjusted. A fixed capacitor is classified according to the type of material used as its dielectric, such as paper, oil, mica, or electrolyte.

I_{rms}:- The maximum rms ripple current in amps at a given frequency.

I_{peak}:-The maximum peak current in amps at +25°C for non-repetitive pulses or where the pulse time off is sufficient to allow cooling so overheating will not result.

Inductance ESL:- Some series inductance is present in all capacitor, which dominates impedance at very high frequencies. Most significant in aluminium electrolytic capacitors, with values usually less than a few tens of nH.

Insulation:- Material having a high resistance to the flow of electric current, which prevents leakage of current from a conductor.

Insulation Resistance (IR):- The ratio of the applied Voltage to the total current between two electrodes in contact with a specific insulator. A measure of the resistance to a dc current flow through the capacitor under steady state conditions. Values for film and ceramic capacitors are usually expressed in megohm-microfarads for a given design and dielectric. The actual resistance of the capacitor is obtained by dividing the megohm-microfarads by the capacitance.
A measure of the resistance to a dc current flow through the capacitor under steady state conditions. Values for film and ceramic capacitors are usually expressed in megohm-microfarads for a given design and dielectric. The actual resistance of the capacitor is obtained by dividing the megohm-microfarads by the capacitance.
The ratio of the dc voltage applied to the terminals of a capacitor and the resultant leakage current flowing through the dielectric and over its surface after the initial charging current has ceased expressed in megohms or as time constant megohm × microfarads.

Impedance (Z_c):- The total opposition offered to alternating or pulsating current measured in ohms. Impedance is the vector sum of the resistive and reactive series components of a capacitor expressed mathematically as $Z_c = \left(ESR^2 + \left(X_l - X_c\right)^2\right)^{½}$. Impedance is dominated by the capacitive reactance at low frequencies and by the inductive reactance at high frequencies. At the series resonant frequency *Z=ESR*.

Insulator:- A material of such low electrical conductivity that the flow of current through it can usually be neglected.

Ion, Ionization:- An electrified portion of matter of sub-atomic, atomic, or molecular dimensions such as is formed when a molecule of gas loses an electron (when the gas is stressed electrically beyond the critical voltage) or when a neutral atom or group of atoms in a fluid loses or gains one or more electrons. Ionization is the dissociation of an atom or molecule into positive or negative ions or electrons. Restrictively, the state of an insulator whereby it facilitates the passage of current due to the presence of charged particles usually induced artificially.

Joule (watt second):- Joule = ½×Capacitance (Farads)×Voltage^2. The Joule is a measure of the amount of energy delivered by one Watt of power in one second or 1 million watts of power in one microsecond. The Joule rating of a surge protection device is the amount of energy that it can absorb before it becomes damaged.

Leakage Current:- Measure of the stray direct current flowing through capacitor after dc voltage is impressed on it.
After charging a capacitor to a set voltage, initially, a high current flows which decreases rapidly until a constant small value is reached, the final leakage current. The leakage current value increases both with voltage and temperature. In the case of electrolytic capacitors, after a long storage period, the leakage current value can exceed the rated value and leakage measurement is after a short re-anodization period.

Metallised Capacitor:- A capacitor where a thin layer of metal is vacuum-deposited directly onto the dielectric.

Mica Capacitor:- is made of metal foil plates that are separated by sheets of mica (the dielectric). The whole assembly is encased in moulded plastic. Since the capacitor parts are moulded into a plastic case, corrosion and damage to the plates and dielectric are prevented. Also the moulded plastic case makes the capacitor mechanically stronger. Various types of terminals are used on mica capacitors to connect them into circuits. The terminals are also moulded into the plastic case.

Oil Capacitors (Self Healing):- these are often used in high-power electronic equipment. An oil-filled capacitor is nothing more than a paper capacitor that is immersed in oil. Since oil impregnated paper has a high dielectric constant, it can be used in the production of capacitors having a high capacitance value. Many capacitors will use oil with another dielectric material to prevent arcing between the plates. If arcing should occur between the plates of an oil-filled capacitor, the oil will tend to reseal the hole caused by the arcing. These are referred to as a self healing capacitor.

Overvoltage:- A voltage above the normal operating voltage of a device or circuit. In a dielectric withstand test, capacitors are overvoltage-tested (Hi-potted) at 1.5× or 2× its rated voltage to assure quality.

Partial Discharge:- A partial discharge is an electric discharge that only partially bridges the insulation between conductors when the voltage stress exceeds a critical value. Partial discharges may, or may not, occur adjacent to a conductor. Partial discharge is often referred to as corona but the term corona is preferably reserved for localized discharges in cases around a conductor, bare or insulated, remote from any other solid insulation.

Polychlorinated Biphenyls PCB:- Chemical pollutant formerly used in oil-filled capacitors which have been outlawed since the 1970's and are no longer used in the capacitor and transformer industries.

Permittivity:- Preferred term for dielectric constant.

Polycarbonate Resins:- Polymers derived from the direct reaction between aromatic and aliphatic dihydroxy compounds with phosgene or by the ester exchange reaction with appropriate phosgene derived precursors.

Polyester:- A resin formed by the reaction between a dibasic acid and a dihydroxy alcohol.

Polyethylene:- A thermoplastic material composed of polymers of ethylene.

Polymer:- A compound formed by polymerization which results in the chemical union of monomers or the continued reaction between lower molecular weight polymers.

Polymerize:- To unite chemically two or more monomers or polymers of the same kind to form a molecule with higher molecular weight.

Polypropylene:- A plastic made by the polymerization of high-purity propylene gas in the presence of an organometallic catalyst at relative low pressures and temperatures.

Polystyrene:- A thermoplastic produced by the polymerization of styrene (vinyl benzene).

Pulse Operation:- Capacitors subjected to dc pulses or non-sinusoidal voltages with fast rise or drop times (high *dv/dt*) will be exposed to high current. This current must be limited to within the maximum peak current allowed. These peak currents refer to an unlimited number of pulses charging or discharging the capacitors.

Rated Capacitance C_R:- The rated capacitance, defined at specific frequency and temperature, for example, 100 Hz and 20°C, is the capacitance of an equivalent circuit having capacitance and resistance series connected.

Rated Voltage V_R:- The rated voltage is the voltage value that can be applied continuously within the operating temperature range of capacitors. When using a capacitor with AC voltage superimposed on a DC voltage, the peak value of AC voltage plus the DC voltage must not exceed the rated voltage.

Ripple Current:- The total amount of alternating and direct current that can be applied to a capacitor under specific conditions without causing a failure. It depends mostly on the allowable temperature rise due to the ESR I^2R heat production. Since ripple current raises the core temperature, it is important in specifying operational life of the component.

Shelf Life:- The voltage free storage life, most important with electrolytic based capacitors. Period based on specified drift in ESR and impedance. At 20°C, the shelf life of a high voltage (>100V) electrolytic capacitor, is as short as two years.

Sparkover:- A disruptive discharge between electrodes of a measuring gap, such as a sphere gap or oil testing gap.

Surface Leakage:- The passing of current over the boundary surfaces of an insulator as distinguished from passage through its volume.

Surge:- A transient variation in the current and/or potential at a point in the circuit.

Surge Voltage (SV) V_p:- The maximum dc voltage a capacitor can tolerate under any circumstances for a short period of time without suffering any damage. The surge voltage is the maximum overvoltage including DC, peak AC and transients to which the capacitor can be subjected for short periods of time. Typically, not more then 30 seconds in any 5 minute period, at maximum operational temperature, where the charge is held for 30 seconds for 1000 cycles, then the capacitor is allowed to discharge without load for 5 minutes.

SuperCapacitors:- another word for Ultracapacitors - Made from carbon aerogel, carbon nanotubes, or highly porous electrode materials. Extremely high capacity. Can be used in some applications instead of rechargeable batteries.

Tantalum Capacitor:- compact, low-voltage devices up to several hundred µF, these have a lower energy density and are more accurate than aluminium electrolytics. These capacitors are comprised of a permeable tantalum centre section surrounded by tantalum pentoxide. A tantalum wire is inserted into the centre section and then extends axially from the component. There are many advantages of using tantalum capacitors over other types: They have higher volumetric efficiency (CV/cc); They have superior frequency characteristics; They are highly reliable and do not degrade over time. Tantalum capacitors do not lose capacitance like electrolytic capacitors. Unlimited shelf life.

Temperature Coefficient (TC):-The change in capacitance with temperature expressed linearly as parts per million per degree centigrade (ppm/°C), or as a percent change over a specified temperature range. Most film capacitors are not linear and TC is expressed in percent. The change in capacitance with temperature expressed linearly as parts per million per degree centigrade (ppm/°C), or as a percent change over a specified temperature range. Most film capacitors are not linear and TC is expressed in percent.

Thermal Conductivity:- Ability of a material to conduct heat.

Transients:- High voltage surges through an electrical system caused by lightning strikes to nearby transformers, overhead lines, or the ground. May also be caused by switching of motors and compressors, as well as by short circuits or utility system switching.

Voltage Sag:- Drop in voltage levels of electrical distribution system which interferes with the operation of electrical and electronic equipment. Commonly called brownout. Results when demand for electricity exceeds capacity of the distribution system.

Volumetric efficiency:- Energy density in µf-volts per cubic centimetre, from: (capacitance) X (working voltage) ÷ (volume). Longer capacitors are more efficient than shorter units, because of volume used by encapsulation and unused dielectric at the capacitor ends (the margins). Cylindrical units have a smaller volume than rectangular units, although rectangular units can be stacked more compactly.

Working voltage (WV_{dc}, WV_{ac}):- The maximum continuous voltage that should be applied to a capacitor. Rated voltages for dc and ac operation are usually not the same. The maximum dc voltage applied to a capacitor for continuous operation at maximum rated temperature.

X Capacitor:- RFI Capacitor used in positions where if failed would not be hazardous to anyone who touches the case of the equipment. The X capacitors are connected across the line conductors. There are three sub-classes of X capacitors: X1, X2 and X3. The most common is X2 sub-class, used for IEC-664 Installation Category II. The X2 capacitors are rated for peak pulse voltage in service of less or equal to 2.5KV.

Y Capacitor:- RFI Capacitor used in positions where if failed could be hazardous to somebody who touches the case of the equipment. The Y capacitors are connected between power lines and chassis/earth. There are four sub-classes of Y capacitors: Y1, Y2, Y3 and Y4. The most common is Y2 sub-class, used across a Basic or Supplementary insulation. The Y2 capacitors are rated for nominal working voltages less or equal to 250Vac and for peak impulse voltage before endurance test of less or equal to 5KV. Because Safety Standards stipulate maximum current towards earth for different applications, the capacitance of Y capacitors must be limited to a certain value depending on the type of equipment in which the capacitor is used.

Glossary of Thermoelectric terminology

Active heat Load:-The amount of heat (in Watts) being generated by the device that is on top of the TE Cooler. Typically, the input power of this device, voltage x current minus the output power.

Alumina:- Ceramics made of aluminium oxide (Al_2O_3). These ceramics are used on most of our standard TECs. A positive of Al_2O_3 is that it is inexpensive and can be designed for snap states instead of dice, which considerably reduces production costs. Negative aspects of this material are its lower thermal conductivity and it is difficult to use in 3 to 6 stage coolers.

Ambient temperature:- Temperature of the air or environment surrounding a thermoelectric cooling system; sometimes called room temperature.

Aspect ratio:- The numerical ratio of the length (height) to cross-sectional area of a thermoelectric element. An element's *L/A* aspect ratio is inversely proportional to its optimum current.

BeO:- Ceramics made of beryllium oxide. Typically used in multi-stage coolers due to its higher thermal conductivity. The advantages to this material are that it enhances the thermal performance of the TE Cooler as well as makes it easier to assemble because of the high heat conductance. Disadvantages are that it is expensive and can be toxic when its dust is inhaled. The dust comes from dicing and sanding of the material, both of which are performed on a TE Cooler in its final condition. The risks of BeO sometimes prohibit it as an option.

Bismuth Telluride:- A thermoelectric semiconductor material that exhibits optimum performance in a 'room temperature' range. An alloy of bismuth telluride most often is used for thermoelectric cooling applications.

Bismuth Antimony:- A thermoelectric semiconductor material that exhibits optimum performance characteristics at relatively low temperatures.

Burn-in test:- A power cycling test performed by repeatedly powering on and off the TE Cooler for short intervals of time. The test is designed to detect latent manufacturing or material defects that would cause premature failure of the TE Cooler.

Cascaded module (multi-stage module):- A thermoelectric cooler configuration whereby one cooler is stacked on top of another so as to be thermally in series. This arrangement makes it possible to reach lower temperatures than can be achieved with a single-stage cooler.

Ceramic:- A patterned substrate (at least one side) for a TE Cooler. This material conducts heat and insulates electric current. Typically comprised of Al_2O_3 Al_2N_5 BeO
Thermal Conductivity (W/in °C) .051, 4.0, 6.5, CTE (10^{-6}/°C) 7.0 ,4.0, 9.0,

Coefficient of performance (COP):- A measures of the efficiency of a thermoelectric cooler, device or system. Mathematically, COP is the total heat transferred through the thermoelectric device divided by the electric input power (COP = P_c/W). COP can be stated as COPR (Coefficient of Performance as a Refrigerator) or as COPH (Coefficient of Performance as a Heater).

Cold side of a thermoelectric module:- The side of a cooler that normally is placed in contact with the object being cooled. When the positive and negative cooler leads are connected to the respective positive and negative terminals of a dc power source, the cooler's cold side will absorb heat. Typically, the leads of a TE cooler are attached to the hot side.

Conduction (thermal):- The transfer of heat within a material caused by a temperature difference through the material. The actual material may be a solid, liquid or gas (or a combination) where heat will flow by means of direct contact from a high temperature region to a lower temperature region.

Convection (thermal):- The transfer of heat by air (gas) movement over a surface. Convection is a combined heat transfer process involving conduction, mixing action, and energy storage.

Couple:- A pair of thermoelectric elements consisting of one N-type and one P-type connected electrically in series and thermally in parallel. Because the input voltage to a single couple is quite low, a number of couples normally are joined together to form a 'cooler'.

Delta-T, ΔT:- The temperature difference between the cold and hot sides of a thermoelectric cooler.

DT_{max}, ΔT_{max}:- The maximum obtainable temperature difference between the cold and hot side of the thermoelectric elements within the module with I_{max} and no heat load applied to the module and the hot-side of the elements within the module being at 300K. Virtually impossible to remove all sources of heat in order to achieve the true DT_{max}. Therefore, the number only serves as a standardized indicator of the cooling capability of a thermoelectric module.

ΔT Test:- Test performed in which the TE Cooler is placed on a temperature controlled base plate (typically 27°C) and powered at I_{max}. A thermocouple is pressed onto the top ceramic using a spring plunger and the cold side temperature as well as voltage is measured.

Efficiency:- For thermoelectric coolers, mathematical efficiency is the heat pumped by a cooler divided by the electrical input power; for thermoelectric generators, efficiency is the electrical output power from the cooler divided by the heat input (Q_c/Q_h). To convert to percent, multiply by 100. See definition of Coefficient of Performance.

Figure-of-merit, (Z factor):- A measure of the overall performance of a thermoelectric device or material. Material having the highest figure-of-merit also has the highest thermoelectric performance. A good thermoelectric material will have a high Z, high Seebeck coefficient and low thermal conductivity and resistively.
The *Z* is a direct measure of the cooling performance of a thermoelectric module. $Z = S^2/\rho\times\kappa$ where *S* is the Seebeck Coefficient, *ρ* is electrical resistivity and *κ* is the thermal conductivity of the thermoelectric material. *Z* is temperature dependent though, so, when comparing one module to another, they must be based on the same hot-side temperatures.

Heat load:- The quantity of heat presented to a thermoelectric device that must be absorbed by the device's cold side. The term heat load, when used by itself, tends to be somewhat ambiguous and it is preferable to be more specific. Terms such as active heat load, passive heat load or total heat load are more descriptive and less uncertain as to meaning.

Heat pump:- A general term describing a thermoelectric cooling device, often being used as a synonym for a thermoelectric cooler. In somewhat less common usage, the term heat pump has been applied to a thermoelectric device operating in the heating mode.

Heat pump capacity:- The amount of heat that a thermoelectric device is capable of pumping at a given set of operating parameters. Frequently, this term will be used interchangeably with the expression maximum heat pumping capacity. The two terms are not strictly synonymous, however, because maximum heat pumping capacity specifically defines the maximum amount of heat that a cooler will pump at the maximum rated input current and at a zero temperature differential.

Heat Sink/Cold Sink:- A heat sink is a device that is attached to the hot side of thermoelectric module in order to facilitate the transfer of heat from the hot side of the module to the ambient. A cold sink is attached to the cold of the module to facilitate heat transfer from whatever is being cooled (liquid, gas, solid object) to the cold side of the module. The most common heat sink (or cold sink) is an aluminium plate that has fins attached to it. A fan is used to move ambient air through the heat sink to pick up heat from the module. Another style uses a plate with embedded tubing through which liquid is pump to pick up heat from the module.

Heat transfer coefficient:- A numerical value that describes the degree of coupling that exists between an object and a cooling or heating fluid. The heat transfer coefficient actually is an extremely complex value that encompasses many physical factors.

Hot side of a thermoelectric module:- The face of a thermoelectric cooler that usually is placed in contact with the heat sink. When the positive and negative cooler leads are connected to the respective positive and negative terminals of a DC power source, the cooler's hot side will reject heat. Normally, the wire leads are attached to the hot side ceramic substrate.

I_{max}:- Current which, the maximum ΔT is produced, with the hot side held at 300K. Generally, it is not good to operate a TE cooler at I_{max} because the amount of input power increases significantly without a significant change in ΔT. 70 - 80 % of I_{max} is usually an optimal operating condition.

Interstage temperature:- The temperature between specific stages or levels of a multi-stage or cascade cooler.

Joule heating:- The passage of an electrical current through a conductor or material due to the internal resistance, resulting in Heat

Kinetic viscosity:- The ratio of a fluid's viscosity to its density; typically units are centimetres squared per second and feet squared per second.

Latent heat:- Thermal energy required to cause a change of state of a substance such as changing water into ice or water into steam.

Lead telluride:- A thermoelectric semiconductor that exhibits its optimum performance within a temperature range of 250-450°C. Lead telluride is used most often for thermoelectric power generation applications.

Maximum heat pump capacity (maximum P_c):- The maximum quantity of heat that can be absorbed at the cold face of a thermoelectric cooler when the temperature differential between the cold and hot cooler faces is zero and when the cooler is being operated at its rated optimum current. P_{max} is a significant thermoelectric cooler/device specifications.

Maximum temperature differential (maximum ΔT):- The largest difference that can be obtained between the hot and cold faces of a thermoelectric cooler when heat applied to the cold face is effectively zero. ΔT_{max} or DT_{max} is one of the significant thermoelectric cooler/device specifications.

Metallisation:- The conductive copper pattern printed on the ceramics.

Module:- A thermoelectric cooling component or device fabricated with multiple thermoelectric couples that are connected thermally in parallel and electrically in series.

Multi-stage module (cascade module):- A thermoelectric configuration whereby one TEC is mechanically stacked on top of another in series. This arrangement makes it possible to reach lower temperatures than can be achieved with a single-stage cooler.

Optimum current:- The specific level of electrical current that will produce the greatest heat absorption by the cold side of a thermoelectric cooler. At the optimum current, a thermoelectric cooler will be capable of pumping the maximum quantity of heat; maximum temperature differential (ΔT_{max}) typically occurs at a somewhat lower current level.

Passive heat loads:- The amount of non-active heat (in Watts) being applied on the TE cooler. This includes conductance through wires that extend from the cold side of the TE cooler to the ambient, the convective loads from the surrounding atmosphere (note: convective loads are present in Nitrogen, Argon, and Xenon, but are not present in a vacuum).

Peltier effect:- The phenomenon whereby the passage of an electrical current through a junction consisting of two dissimilar metals results in a cooling effect; when the direction of current flow is reversed heating will occur.

Q_{max}:- The maximum amount of heat (in Watts) that a TE cooler can pump, with the hot-side held at 300K and at I_{max}. This occurs when the ΔT is zero. Only for multi-stage coolers operating near a ΔT_{max} condition.

Seebeck Coefficient:- The Seebeck Coefficient is a measure of the electrical voltage potential that exists in an electrical conductor whose ends are maintained at two different temperatures and current is not flowing. It is an intrinsic property and has units of V/K. Thermocouples used for temperature measurement utilize this principle.

Seebeck effect:- The phenomenon whereby an electrical current will flow in a closed circuit made up of

two dissimilar metals when the junctions of the metals are maintained at two different temperatures. A common thermocouple used for temperature measurement utilizes this principle.

Silicon-germanium:- A high temperature thermoelectric semi-conductor material that exhibits its optimum performance within a temperature range of 500-1000°C. Silicon-Germanium material most often is used for special thermoelectric power generation applications that utilize a radioisotope/nuclear heat source.

Single-stage module:- The most common type of thermoelectric cooling module using a single layer of thermoelectric couples connected electrically in series and thermally in parallel. Single-stage coolers will produce a maximum temperature differential of approximately 70°C under a no-load condition.

Specific Heat:- The amount of thermal energy required to raise the temperature of a particular substance by one temperature degree. Units are J/kg/K.

Thermal coefficient of expansion:- A measure of the dimensional change of a material due to a temperature change. Common measurement units include centimetre per centimetre per °C.

Thermal conductance:- The amount of heat a given object will transmit per unit of temperature. Thermal conductance is independent of the physical dimensions, i.e., cross-sectional area and length of the object. Typical units include watts per degree Celsius.

Thermal conductivity:- The amount of heat a material will transmit per unit of temperature based on the material's cross-sectional area and thickness. Thermal conductance multiplied by length and divided by area.

Thermal grease:- A grease-like material used to enhance heat transfer between two surfaces by filling in the microscopic voids caused by surface roughness. Most thermal greases, also known as Transistor Heat Sink Compound or Thermal Joint Compound, are made from silicone grease loaded with zinc oxide. Non-silicone based compounds are also available which in most cases are superior but more expensive than silicone-based alternatives.

Thermal Interface:- A physical interface between two objects through which heat is conducted. In the case of thermoelectrics, the physical connection the module has with the heat sink/cold sink. Usually, thermal grease is used between the module and heat sink. Alternatively it might be solder or a thermally conductive pad.

Thermal Resistance:- A measure relating a temperature rise per unit of applied heat. All mediums through which heat is conducted have an associated thermal resistance. Common thermal resistances are heat sink resistance and thermal interface resistance. Thermoelectric coolers perform better with heat sinks having a low thermal resistance.

Thermal shock:- Thermal Shock also is referred to as temperature cycling in some MIL specs. In a thermal shock test, the TE cooler (not powered throughout test) is placed in a hot chamber (for example, 85°C) for a set time (for example, 30 minutes). The part is then transferred to the cold chamber (for example, -40°C) for the same time. This cycle is repeated several times depending on the requirement.

Thermoelectric:- A term used to denote not only the products produced but also the basic scientific principle upon which products are designed.

Thermoelectric generator:- A device that directly converts energy into electrical energy based on the Seebeck Effect. Bismuth telluride-based thermoelectric generators have very low efficiencies (generally not exceeding two or three percent) but may provide useful electrical power in certain applications.

Thermoelectric heat pump:- Another name for a thermoelectric module or thermoelectric cooler. The term Heat Pump has been used by some specifically to denote the use of a thermoelectric module in the heating mode, but this usage is uncommon.

Thermoelectric material:- An alloy of materials that produce thermoelectric properties.

Thermoelectric Module:- A semiconductor-based electronic component that functions as a small heat pump. By applying a low voltage DC power source to a TE module, heat will be moved through the module from one side to the other. Therefore, one side will be cooled while the opposite side will be heated. Consequently, a TE module can be used for both heating and cooling.

Thomson Coefficient:- If the ends of an electrical conductor are held at two different temperatures, a voltage potential is created because there will be a tendency for electrons at the hot end of the conductor to drift towards the cold end of the conductor. When an external current is applied, so that electrical carriers flow from cold end to the hot end, the electrical carriers must absorb heat to maintain equilibrium with the temperature. If the external current was applied from hot to cold, the carriers would release heat to maintain temperature equilibrium. The Thomson Coefficient is a measure of the voltage per difference in temperature, and with the application of an external current is a measure of the heat generated or absorbed per unit temperature difference per unit current.

Usually, the Thomson effect is intrinsic to the material. However, the Thomson effect can also be extrinsically applied to a conductor by varying the material properties along the length of the conductor. This can actually improve the cooling performance as compared to the usual isotropic material. The Thomson effect is really more complex than that described above.

Thomson effect:- The phenomena whereby a reversible evolution or absorption of heat occurs at opposite ends of a conductor having a thermal gradient when an electrical current passes through the conductor.

V_{max}:- The optimum voltage the maximum ΔT is produced, with the hot-side held at 300K.

Glossary of Fan Cooling and other Heating and Cooling terminology

A-Coil:- A heat exchanger consisting of two diagonal coils that are joined together in a manner that looks like the letter 'A'.

Absorber:- The blackened surface in a collector that absorbs the solar radiation and converts it to heat energy.

Absorptance:- The ratio of solar energy absorbed by a surface to the solar energy striking it.

Active System:- A solar heating or cooling system that requires external mechanical power to move the collected heat.

Air flow volume:- The amount of air the system circulates, expressed in cubic feet per minute, cfm.

Air Handler/Coil Blower:- The part of an air conditioner or heat pump that moves cooled or heated air throughout the ductwork. An air handler is usually a furnace or a blower coil.

Air System:- Solar domestic hot water systems employing air-type collectors. Hot air generated by these collectors is fan forced through an air-to-liquid heat exchanger with the potable water being pumped through the liquid section of the exchanger. The heated water is then circulated through the storage tank in a similar fashion to the liquid collector system. Air does not need to be protected from freezing or boiling, is non-corrosive, and is free. However, air ducts and air handling units require greater space than piping, and air leaks are difficult to detect.

Air-Type Collector:- A collector that uses air as the heat transfer fluid.

Altitude:- The angular distance from the horizon to the sun.

Ambient Temperature:- The temperature of the surrounding air.

Auxiliary Heat:- The extra heat provided by a conventional heating system for periods of cloudiness or intense cold when a solar heating system cannot provide enough.

Azimuth:- The angular distance between true south and the point on the horizon directly below the sun.

Ball bearing:- The most reliable bearing system in fans. Extremely high temperature load, extremely low starting torque at low temperatures, no loss of lubricant.

Blower:- This frequently refers to large radial and axial fans with dimensions that are usually larger than 120x120mm.

Burn-in:- The running in of fans reduces the otherwise unavoidable early failures and thus increases the reliability of a fan. The burn-in process of fans is integrated in the production process so that errors that may occur, immediately result in "Corrective Action" and do not reach the customer.

BTU:- A British thermal unit is a unit of heat energy. British thermal unit; the amount of heat required to raise or lower the temperature of one pound of water one degree Fahrenheit. The higher the Btu rating, the greater the heating capacity of the system.

BTUh:- British thermal units per hour. 12,000 BTUh equals one ton of cooling.

Calorie:- The quantity of heat needed to raise the temperature of one gram of water one degree Celsius.

Capacity:- The output or producing ability of cooling or heating systems. The ability of a heating or cooling system to heat or cool a given amount of space. For heating, this capacity is usually expressed in British thermal units BTUs. For cooling it is usually given in tons.

CFM:- Abbreviation for cubic feet per minute of air flow, a standard measurement of airflow. This measurement indicates how many cubic feet of air pass by a stationary point in one minute. The higher the number, the more air is being forced through the ductwork by the system.

Check Valve:- A check valve is a mechanical device normally applied to a piping system which allows fluid to flow in only one direction.

Closed Loop:- An underground heat exchanger piping system usually of polyethylene or polybutylene designed to allow the extraction or rejection of heat to the earth by the circulation of fluid within the tubing.

Coefficient of Heat Transmission:- The rate of heat loss in BTU per hour through a square foot interface or other surface when the difference between inner and outer air temperatures is one degree Fahrenheit.

Coefficient of Performance (COP):- Heating capacity divided by electrical energy consumed. (for example,15 kW output / 4.5 kW input = COP of 3.3) The coefficient of performance of a heating system is the electrical ratio of the heat got out divided by the heat put in.

Collector:- A device that collects solar radiation and converts it to heat.

Collector Efficiency:- The ratio of usable heat energy extracted from a collector to the solar energy striking the cover.

Compressor-Watts:- Compressor electricity consumption.

Compressor:- The heart of an air conditioning or heat pump system. It is the part of the unit that pumps refrigerant in order to meet the cooling requirements of the system. It is the refrigeration component which increases the density, temperature and pressure of entering refrigerant through compression and discharges a hot dense gas.

Condensate:- Vapour that liquefies due to the lowering of its temperature to the saturation point.

Condenser:- The heat rejecting mechanism in a heat pump usually in the form of a refrigerant-to-air coil or a refrigerant-to-water coil. Refrigeration heat exchanger where the refrigerant gives up its heat during condensation from a vapour to a liquid.

Condenser coil:- In an air conditioner, the coil dissipates heat from the refrigerant, changing the refrigerant from vapour to liquid. In a heat pump system, the coil absorbs heat from the outdoors.

Condenser fan:- The fan that circulates air over the air-cooled condenser.

Concentrating Collector:- A device which concentrates the sun's rays on an absorber surface which is significantly smaller than the overall collector area

Conductance:- The rate of heat flow (in BTUs per hour) through an object when a 1° F.

Conduction:- The flow of heat due to temperature variations within a material.

Conductivity:- A measure of the ability of a material to permit conduction of heat flow through it.

Convection:- The motion of fluid such as gas or liquid by which heat may be transported.

Cover Plate:- A sheet of glass or transparent plastic placed above the absorber in a flat plate collector.

Cupro-nickel:- 90% copper / 10% nickel alloy which has high corrosion resistance to water containing salt, sulphur, chlorides and other dissolved minerals.

Damper:- Located in ductwork, this movable plate opens and closes to control and regulate airflow. Dampers can be used to balance airflow in a duct system. They are also used in zoning to regulate airflow to certain regions. Dampers are used to direct air to the areas that need it most.

dB:- A decibel is a unit used to measure the relative intensity of sound.

Degree Day:- The number of degrees that the mean temperature for that day is below 65°F. (for example, mean temperature of 40°F for the day 65-40=25 degree days). A unit that represents a 1°F deviation from some fixed reference point (usually 65°F.) in the mean daily outdoor temperature.

Dehumidifier:- An air cooler that removes moisture from the air.

Delta T:- Difference between LWT and EWT

Desuperheater:- A heat exchanger and pump system which removes a small portion of heat from the compressor discharge gas and typically transfers it to a hot water tank.

Design Heat Load:- The total heat loss from a system under the most severe cold conditions likely to occur.

Design Temperature:- The temperature close to the lowest expected for a location, used to determine the design heat load.

Diffuser:- A grille over an air supply duct having vanes to distribute the discharging air in a specific pattern or direction.

Diffuse Radiation:- Indirect sunlight that is scattered from air molecules, dust and water vapour.

Direct Radiation:- Solar radiation that comes straight from the sun, casting shadows on a clear day.

Downflow:- Air enters at the top or bottom of the unit and is discharged vertically out the bottom.

Downflow furnace:- A furnace that intakes air at its top and discharges air at its bottom.

Drain back system:- The solar heat transfer fluid automatically drains into a tank by gravity. Drain back systems are available in one or two tank configurations. A heat exchanger is necessary, because the tap inlet pressure would prevent draining. The heat transfer fluid in the collector loop may be distilled or tap water if the loop plumbing is copper. If the plumbing is threaded galvanized pipe, inhibitors may be added to prevent corrosion. Most inhibitors are non-potable and require a double wall heat exchanger. The pump used must be sized to overcome a static head.

Drain pan:- This also referred to as a condensate pan. This is a pan used to catch and collect condensate (in residential systems vapour is liquefied on the indoor coil, collected in the drain pan and removed through a drain line).

Dry bulb temperature:- Heat intensity, measured by a dry bulb thermometer.

Dry bulb thermometer:- An instrument that measures air temperature independently of humidity.

DX:- Direct expansion; a system in which heat is transferred by the direct expansion of refrigerant.

Drain down System:- Potable water is circulated from the storage tank through the collector loop. Freeze protection is provided by solenoid valves opening and dumping the water at a preset low temperature.

Collectors and piping are pitched so that the system can drain down, and are assembled to withstand 100 psi tap water line pressures. Pressure reducing valves are recommended when tap water pressure is greater than the working pressure of the system.

Dual Condenser: - A heat pump system which has the capability to switch, usually automatically, between an air and a water heat exchanger. Full capacity hot air or hot water output is available.

Electronic Air Cleaner:- An electronic device that filters out large particles and bioaerosols in the air.

EMC filter grid:- Protective guard with shield, to highly reduce unwanted emission (or influence) of high frequency radiation. The airflow performance is reduced by approximately 10 to 15%. EMC filter and dust protection filters can be combination parts.
Emittance:- A measure of the propensity of a material to emit thermal radiation.
Energy Efficiency Ratio (EER):- Cooling capacity in BTU/hr divided by electrical energy consumed in watts, in steady state.
Eutectic Salts:- A group of materials that melt at low temperatures, absorbing large quantities of heat.
EAT:- Entering air temperature.
EER:- Energy efficiency ratio.
ELT:- Entering liquid temperature.
EWT:- Entering water or fluid temperature.
Evaporator:- The heat absorbing mechanism or heat exchanger in a heat pump. Refrigerant changes phase from a liquid to a gas in this exchanger, absorbing heat energy from the surrounding media in the process.
Evaporator coil:- The half of an air conditioning system located inside. This is a tubing coil in which a volatile liquid evaporates and absorbs heat. This is where the refrigerant evaporates as it absorbs heat from the internal environment air that passes over the coil.
Evaporator Temperature:- The temperature on evaporator side when Freon is converted from a liquid to a vapour (gas).
Fan:- Any device that creates air currents. Electromechanical component for creating airflow that dissipates air heated by thermal loss in a device. In comparison to convection, the heat output is improved by factor 3. Depending on the design, the airflow can be discharged axially (straight through the fan) or radially (discharged at the side).
Fan accessories:- A term for components that are additionally required for a fan: finger guard, filter grid, EMC guard, connecting cable, etc.
Fan Coil:- A unit that includes a cooling and/or heating coil and a fan to move air through the ductwork. Filters for the circulation air and accessories to introduce outside ventilation air may also be included.
Fan-Watts:- Blower motor electricity consumption.
Filter:- Any device that removes impurities through a straining process.
Filter grid:- Protective grid with a replaceable dust filter that protects the fan and the device against dust collecting quickly in an environment that is subject to a high accumulation of dust. The airflow performance is reduced by approx. 25% by a filter guard.
Finger guard:- Safety device of wire or plastic for protecting against injuries to fingers in large fans or for protecting against damage in small fans. The airflow performance is reduced.
Flue:- Any vent or passageway that carries the products of combustion from a furnace.
Flat Plate Collector:- A solar collection device in which sunlight is converted into heat on a plane surface without the aid of reflecting surfaces to concentrate the rays.
Flow IGPM:- Liquid flow.
Forced Convection:- The transfer of heat by the flow of fluids (such as air or water) driven by fans, blowers or pumps.
Freon:- Trade name for a series of synthetic chemicals or refrigerants used in refrigeration systems. Each refrigerant is designed to change phase at specific temperatures and pressures which will produce the desired cooling effect required for a specific application. The refrigerant absorbs energy as it evaporates and releases energy during condensation.
Full Package:- Self contained heat pump which has an integrated blower and compressor.
Full-Condensing Heat Exchanger:- A heat exchanger with enough surface area to condense all the hot refrigerant gas produced by a heat pump to its liquid state thereby transferring all the heat produced by the unit.
Galvanic Corrosion:- A condition caused as a result of a conducting liquid making contact with two different metals which are not properly isolated physically and/or electrically.
Geothermal Energy:- Heat energy stored in the earth's crust by the absorption of solar energy and by conduction with the earth's hot interior.
Getters:- A column or cartridge containing an active metal which will be sacrificed to protect some other metal in the system against galvanic corrosion.
Glaubers Salt:- Sodium sulphate a eutectic salt that melts at 90°F and absorbs about 104 Btu per pound as it does so.
Gravity Convection:- The natural movement of heat that occurs when a warm fluid rises and a cool fluid sinks under the influence of gravity.
Ground Loop:- A series of heat exchange pipes containing an antifreeze solution which are buried either vertically or horizontally in the earth.
Ground Source:- A heat pump which utilizes the earth as its source of energy.
HAB:- Heating mode: heat absorption capacity from the ground or water
Cooling mode: heat absorption capacity from the inside air (total cooling load)
Headers:- The pipe that runs across the edge of an array of solar collectors, gathering or distributing the

heat transfer fluid from, or to the risers in the individual collectors. This insures that equal flow rates and pressure are maintained.
Heat Capacity:- A property of a material denoting its ability to absorb heat.
Heat Exchanger:- A component which transfers heat energy from one medium to another. For example, heat could be transferred, in a geothermal heat pump system, from water-to-air or from water-to-water etc. and vice versa. An area, box or coil where heat flows from the warmer to the colder fluid or surface. The transfer heat from one fluid to another without the fluids coming into direct contact with each other. A device, such as a coiled copper tube immersed in a tank of water, that is used to transfer heat from one fluid to another through a separating wall.
Heat Gain:- Heat added to the conditioned space by infiltration, solar radiation, occupant respiration, lighting, and operating equipment.
Heat Loss:- The rate of heat transfer from a heated space to the external environment.
Heat Pump:- A mechanical-compression cycle refrigeration system that can be reversed to either heat or cool the controlled space. A heat pump is an HVAC unit that heats or cools by moving heat. During the winter, a heat pump draws heat from outdoor air and circulates it through the air ducts. In the summer, it reverses the process and removes heat from the space and releases it outdoors. A mechanical device that transfers heat from one medium to another, thereby cooling the first and warming the second.
Heat sink:- A medium or container to which heat flows. The area or media where heat is deposited.
Heat Source:- A medium or container from which heat flows. The area or media from which heat is removed, for example water, air, etc.
Heat Storage:- A device or medium that absorbs collected solar heat and stores it for use during periods of inclement or cold weather.
Heat Storage Capacity:- The amount of heat which can be stored by a material.
Heating Season:- The period from early fall to late spring (in the northern hemisphere) during which additional heat is needed to maintain an environment.
Hybrid Solar Energy System:- A system that uses both active and passive methods in its operation.
Heat Transfer:- The movement of heat energy from one point to another. The means for such movement are conduction, convection, and radiation.
Humidifier:- A machine that adds water vapour to the air to increase humidity.
Humidity:- The presence of water vapour in the air.
Humidity, absolute:- Weight of water vapour per cubic foot of dry air, expressed as grains of moisture per cubic foot.
Humidity, relative:- The amount of moisture in the air expressed as a percentage of the maximum amount that the air is capable of holding at a specific temperature.
Horizontal Flow:- Air enters at the end or any side of the unit and is discharged horizontally out the other end or any side of the unit.
Humidistat:- An automatic device used to maintain humidity at a fixed or adjustable set point.
Hydrodynamic bearing:- Sintered sleeve bearing systems. The lubrication effect is similar to the typical sintered bearing. Especially treating the shaft and bearing tube can achieve extremely stable lubrication with a lower influence of temperature and wear.
Indirect System:- A solar heating or cooling system in which the solar heat is collected externally and transferred internally using ducts or piping and, usually fans or ducts.
Infrared Radiation:- Electromagnetic radiation from the sun that has wavelengths slightly longer than visible light.
Insolation:- The total amount of solar radiation direct, diffused and reflected-striking a surface exposed to the sky.
Insulation:- A material with high resistance (R-value) to heat flow.
IGPM:- Water flow in Imperial Gallons
kWh - kilowatt hours:- Electrical term - 1 kWh equals the use of 1000 watts for one hour.
kW out:- Heat pump capacity in kW's
Langley:- A measure of solar radiation; equal to one calorie per square centimetre.
Latent:- The load created by moisture in the air, including from outside air infiltration and that from internal sources.
Latent Heat:- A type of heat, which when added to or taken from a substance, does not change the temperature of the substance. Instead, the heat energy enables the substance to change its state.
Liquid Type Collector:- A collector using a liquid as the heat transfer fluid.
Liquid-to-Air Heat Pump:- A heat pump which absorbs heat from a liquid and distributes the energy in the form of hot forced air.
Liquid-to-Liquid heat pump:- A heat pump which absorbs heat from a liquid and distributes the energy in the form of hot water.
LWT:- Leaving water temperature.
LAT:- Leaving air temperature.
LLT:- Leaving liquid temperature.

Mechanical Cooling:- Conventional cooling provided by a compressor operated refrigeration device. Term can be interchanged with ‘active cooling’.
Natural Convection:- See Gravity Convection.
Nocturnal Cooling:- The cooling of a building or heat storage device by the radiation of excess heat into the night sky.
One-Tank Closed-Loop System:- A conventional DHW tank, usually electrically heated, is converted to a solar DHW storage tank by installing an external heat exchanger coil. The lower electrical element is removed, leaving the uppermost of the usual two elements to provide auxiliary water heating and to achieve good stratification (layering of hotter water over progressively colder water).
Open System:- Some part of the System is open to the atmosphere, or system contains fresh or changeable water or air.
Open Loop:- A system where water is pumped from a water source for use in a heat pump.
Output:- Heat pump capacity in Btu/Ton.
Oversized Evaporator:- A technique of employing a larger than normal evaporator (heat absorption device) in a geothermal heat pump in order to obtain greater heat exchange and thus better performance from the unit.
PSI:- Pounds per square inch.
PSIA:- Pounds per square inch, absolute.
PSIG:- Pounds per square inch gauge.
Package Heat Pump:- A heat pump which has all components (compressor, blower and heat exchangers etc.) in one cabinet.
Passive System:- A solar heating or cooling system that uses no external mechanical power to move the collected solar heat.
Percentage of Possible Sunshine:- The percentage of daytime hours during which there is enough direct solar radiation to cast a shadow.
Photosynthesis:- The conversion of solar energy to chemical energy, by the action of chlorophyll in plants and algae.
Photovoltaic Cells:- Semiconductor devices that convert solar energy into electricity.
Pyranometer:- An instrument for measuring solar radiation.
Radial Fan:- Special shape of a fan where the air is suctioned in axially, turned 90°, radially, and thus discharged vertical to the axis. Also known as a Turbofan. The distinguishing features of radial fans are their extremely high compression rigidity, which renders them especially suitable for ventilation of heat sinks and general cooling applications where space is limited.
Radiation:- The flow of energy through open space via electromagnetic waves, such as visible light.
Radiant Panels:- Panels with integral passages for the flow of warm fluids, either air or liquids. Heat from the fluid is conducted through the metal and transferred to the environment by thermal radiation.
Passive Cooling:- A process whereby cold water (less than 10ºC) is pumped directly to a finned air coil (much like the radiator of a vehicle) so that when the heat pump fan is operated, cooling and dehumidification are provided without the operation of a compressor driven refrigeration system.
Radiant Floor Heating:- Process of embedding tubing (cross-linked polyethylene, polybutylene, etc.) directly in a concrete floor so that hot water can be pumped through the tubing for the purpose of heating the building via the flooring.
Reflected Radiation:- Sunlight that is reflected from the surrounding environment onto a surface exposed to the sky.
Refrigerant:- A chemical that produces a cooling effect while expanding or vaporizing. Most air conditioning systems contain R-22 refrigerant, which is scheduled to be in production until the year 2020. Its used in approximately 95 percent of air conditioning equipment. A liquid such as Freon is use in cooling devices to absorb heat from surrounding air or liquids as it evaporates. A naturally occurring or man made liquid which absorbs and releases heat energy in a refrigeration device by changing phase from a liquid to a gas and vice versa in response to the influence of a refrigeration compressor.
Refrigerant Charge:- The required amount of refrigerant in a system.
R-410A Refrigerant:- A chlorine-free refrigerant that meets environmental guidelines.
Resistance, or R Value:- The tendency of a material to retard the flow of heat.
Retrofitting:- The application of a solar heating or cooling system to an existing site.
Reversing Heat Pump:- A heat pump in which the condenser and evaporator coils of the unit reverse roles in response to a reverse in the direction of the flow of refrigerant in the machine.
Risers:- The flow channels or pipes that distribute the heat transfer liquid across the face of an absorber.
Scroll Compressor:- A specially designed compressor that works in a circular motion, as opposed to a reciprocating up-and-down piston action.
Seasonal Coefficient of Performance (SCoP):- Is the average CoP over the entire heating period.
Seasonal Efficiency:- The ratio, over an entire heating period, of solar energy collected and used to the solar energy striking the collector.
Seasonal Energy Efficiency Ratio (SEER):-The average cooling efficiency over an entire cooling period.

Self-contained System:- A refrigerating system that can be moved without disconnecting any refrigerant lines; also know as a package unit.
Selective Surface:- A surface that absorbs radiation of one wavelength (fe.g., sunlight) but emits little radiation of another wavelength (for example, infrared); used as a coating for absorber plates.
Sensible:- The internal heat gain due to heat conduction, convection, and radiation from the external into the internal, and from appliances.
Sensible Heat:- That heat which, when added to or taken away from a substance, causes a temperature rise or fall.
Sensor:- Any device that reacts to a change in the conditions being measured, permitting the condition to be monitored and controlled.
SEPA:- Acronym for the terms, Silent, Economic, Powerful, Advanced
Setpoint:- The temperature or pressure at which a controller is set with the expectation that this will be a nominal value depending on the range of the controller.
Shading Coefficient:- The ratio of the solar heat gain through a specific glazing system to the total solar heat gain through a single layer of clear double-strength glass.
Simple Payback Factor (heating):- Subtract the installation cost of the least expensive (less efficient) system from the installation cost of the more expensive (more efficient) heating system. This value is the increased cost of installing the more efficient system. Calculate the yearly energy savings by installing the more efficient system. Take the increased cost to install divided by the yearly energy savings and the result is the number of years required for the more efficient system to pay for itself.
Sink Temperature:- This is the temperature of the media (water or air) into which the heat pump must reject its heat.
Sleeve bearing:- Sleeve bearings of porous, sintered iron or bronze alloys are used in fans. The liquid lubricant is stored in the sintered pores and is discharged when the shaft rotates. Due to the hydrodynamic effect, a lubricant cycle is created that only functions freely in a relatively tight temperature range (approximately 0 to 60°C). Due to surface errors, micro-contamination and natural wear during running the fan in and running down, reliability is considerably lower than with ball bearings. Sleeve bearings are frequently used due to their favourable price.
Silencer System:- Carrier Silencer System ensures quite operation inside and out, typically achieved using quiet motor mounts, a compressor sound blanket, forward swept fan blades, a laminated sound elimination compressor mounting plate, and integrated silencer airflow baffles.
Split System:- Split heat pumps are two part refrigeration systems which have separate evaporator / air handler and compressor / condenser sections. Commonly employed in air-to-air systems where the condenser section is located externally while the evaporator / air handler is located inside the conditioned structure.
Spine Fin Coil:- All-aluminium outdoor coil with a spine fin design which provides greater heat exchanging capabilities (meaning higher efficiencies) and is more resistant to corrosion than traditional copper/aluminium.
Solar Constant:- The average intensity of solar radiation reaching the earth outside the atmosphere; amounting to 1395 W/m².
Solar Radiation (Solar Energy):- Electromagnetic radiation emitted by the sun.
Source Temperature:- This is the temperature of the media (water or air) from which the heat pump extracts its heat.
Specific Heat:- The quantity of heat, in BTU, needed to raise the temperature of one pound of a material 1°F.
Standby Heat Loss:- Heat lost though the storage tank and piping walls.
Sun Path Diagram:- A circular projection of the sky vault, similar to a map, that is used to determine solar positions and to calculate shading.
Thermal Capacity:- The quantity of heat needed to warm a collector to its operating temperature.
Thermal Mass or Thermal Inertia:- The tendency of a structure with large quantities of heavy materials to remain at the same temperature or to fluctuate only slowly; also the overall heat storage capacity of the building.
Thermal Radiation:- Electromagnetic radiation emitted by a warm body.
Thermostat:- A thermostat consists of a series of sensors and relays that monitor and control the functions of a heating and cooling system.
Thermidistat:- Monitors temperature and humidity and adjusts heating or cooling system to maintain the desired levels.
Thermistor:- Sensing device which changes its electrical resistance according to temperature. Used in the control system to generate input data on collector and storage temperatures.
Thermosyphoning:- The process that makes water circulate automatically between a warm collector and a cooler storage tank above it. (See Gravity Convection).
Tilt Angle:- The angle that a flat plate collector surface forms with the horizontal plane.
Ton (of refrigeration):- The amount of energy it takes to convert 2000 lbs. of water at 32º F to ice at 32º F during a 24 hour period. Calculation: 2000 lbs.H_2O x 144 Btu/lb. = 288,000 Btu's in 24 Hrs.

Divide by 24 hrs = 12,000 BTU/hr. Therefore a 'ton' of cooling is a measure of heat energy which is roughly equivalent to 12,000 BTU's.

Temperature difference.:- Difference between ELT and a LLT.

Trickle Type Collector:- A collector in which the heat transfer liquid flows through metal tubes which are fastened to the absorber plate by solder, clamps or other means. (See Collector).

Tube-in-Plate-Absorber:- A metal absorber plate in which the heat transfer fluid flows through passages formed in the plate itself.

Two-stage heating / Two-stage cooling:- Two-stage heating and cooling is considered to be more efficient, because it operates at low speed most of the time. However, when more heating or air conditioning is required, it switches to the next stage for maximum performance.

TX Valve:- A temperature and pressure controlled device for metering refrigerant in a heat pump or other refrigeration device.

U-Factor:- The factor representing resistance to heat flow of various materials.

Ultraviolet Radiation:- Electromagnetic radiation with wavelengths slightly shorter than visible light.

Upflow:- Air enters at the bottom of the unit and is discharged vertically out the top.

Upflow Furnace:- A furnace in which air is drawn in through the sides or bottom and discharged out the top.

Vacuum:- A pressure below atmospheric pressure. A perfect vacuum is 30 inches Mercury (elemental symbol 'Hg').

Ventilator:- A system that exchanges old, recirculated indoor air with fresh, filtered outside air.

Water-to-Water:- A heat pump which extracts heat from water in one area and transfers the heat usually at a higher temperature to another body of water. For example, extracting heat from a 10°C. source and using it to heat domestic hot water at 50°C.

Glossary of Magnetic terminology

Absolute Permeability:- The permeability of a magnetic material expressed in actual physical units, not relative to permeability of free space. The permeability of magnetic materials is rarely expressed in terms of absolute permeability. The usual mode is in terms of relative permeability.

Aging:- Change in magnetic properties, especially B_r, with time.

Air gap:- A low permeability gap in the flux path of a magnetic circuit. A non-magnetic discontinuity in a ferro-magnetic circuit. Often air, but inclusive of other materials such as paint, aluminium, etc.

Air gap volume V_g:- The useful volume of air or nonmagnetic material between magnetic poles; measured in cubic centimetres.

Amorphous:- Refers to magnetic materials that are metallurgically non-crystalline in nature.

Anisotropic magnet:- A magnet having a preferred direction of magnetic orientation, so that the magnetic characteristics are optimum in one preferred direction.

In manufacturing process, the molecules of magnetic material are aligned by an external magnetic field, a process is also called anisotropy or orientation, to obtain a higher magnetic value in the direction of anisotropic axis. An AlNiCo magnet is oriented in the heat treatment process, all other magnets get anisotropy in the moulding process. Magnetizing direction on an anisotropic magnet can only be along the anisotropic axis. An anisotropic magnet will create a stronger flux and remanence than an isotropic magnet.

Anisotropy:- Having different properties depending on the inspected direction. Magnets which are anisotropic, or have an easy axis of magnetization, have their anisotropy developed by two methods: Shape and Magnetocrystalline.

Material that have a preferred magnetization direction. These materials are typically manufactured in the influence of strong magnetic fields, and can only be magnetized through the preferred axis.

Anneal:- A high-temperature conditioning of magnetic material to relieve the stresses introduced when the material was formed. To prevent oxidation, the anneal is usually performed in a vacuum or inert-gas atmosphere.

Antiferromagnetic:- Materials in which the internal magnetic moments line up antiparallel, resulting in permeabilities slightly greater than unity; unlike paramagnetic substances, these materials exhibit hysteresis and have a Curie Temperature. Examples include manganese oxide, nickel oxide and ferrous sulphide.

Area of the air gap, A_s:- or the cross sectional area of the air gap perpendicular to the flux path, is the average cross sectional area of that portion of the air gap within which the application interaction occurs. Area is measured in sq. cm. in a plane normal to the central flux line of the air gap.

Area of the magnet, A_m:- The cross sectional area of the magnet perpendicular to the central flux line, measured in sq. cm. at any point along its length. In design, A_m is usually considered the area at the neutral section of the magnet.

Barkhausen Effect:- The series of irregular changes in magnetization that occur when a magnetic material is subjected to a change in magnetizing force.

Bonded Magnets:- Consisting of powdered permanent magnet material, usually isotropic ceramic ferrite or neodymium iron-boron, and a polymer binder, typically rubber or epoxy. This magnet material can be moulded into complex shapes.

B_d / $\mu_o H_d$:- Slope of the operating line, is the ratio of the remnant induction, B_d, to a demagnetizing force, H_d. It is also referred to as the permeance coefficient, shear line, load line and unit permeance.

$B_d H_d$:- Energy product, indicates the energy that a magnetic material can supply to an external magnetic circuit when operating at any point on its demagnetization curve; measured in kiloJoules per cubic meter (kJ/m^3).

BH_{max} Maximum energy product:- The maximum product of $B_d H_d$ which can be obtained on the demagnetization (normal) curve, that is, in the second (fourth) quadrant of the hysteresis loop.

BH Curve:- See Demagnetization Curve.

BH Loop:- A hysteresis loop across four quadrants.

B_g, Magnetic induction in the air gap:- The average value of magnetic induction over the area of the air gap, A_g. Also defined as the magnetic induction measured at a specific point within the air gap; measured Tesla.

B_i (or J), Intrinsic induction:- The contribution of the magnetic material to the total magnetic induction, *B*. It is the vector difference between magnetic induction in the material and magnetic induction that would exist in a vacuum under the same field, *H*.

B_m:- Maximum induction.

B_r, Residual induction:- The magnetic induction which corresponds to zero applied field (magnetizing force) in a magnetic material after saturation in a closed circuit; measured in Tesla.

Carbonyl Iron:- A relatively expensive iron powder used in low-permeability, high frequency powdered iron cores.

Ceramic Ferrite:- A relatively inexpensive permanent magnet material with moderate coercivity and low energy product that is composed of strontium or barium oxide and iron oxide.

Closed Circuit:- This exists when the flux path external to a permanent magnet is confined within high permeability materials that compose the magnet circuit.

Closed circuit condition: A condition that exists when the external flux path of a permanent magnet is confined with high permeability material.

Closed Magnetic Path Cores:- Also known as shielded cores, these core geometries are designed to contain all of the magnetic flux generated from an excited winding within the core. Theoretically, leakage flux outside the structure is zero. The most commonly used closed magnetic path geometries are E- cores, toroidal cores, and pot cores.

Coercive Force, H_c:- The demagnetizing force, measured in At/m, necessary to reduce observed induction, *B*, to zero after the magnet has previously been brought to saturation. It is expressed in At/m.

Coercive force, H_k:- The value of H_{ci} at 0.9B_r. This value gives an indication of the squareness of the intrinsic curve. The more square the intrinsic curve, the closer the material is to being ideal. H_k values that approach the H_{ci} values are considered extremely good materials.

Coercive force of a material, H_c:- Equal to the demagnetizing force required to reduce residual induction, B_k to zero in a magnetic field after magnetizing to saturation; measured in At/m.

The material characteristic of coercivity is taken as the maximum coercivity - that value of *H* required to reduce the residual induction to zero after the material has been saturated (fully magnetized).

Coercivity, H_{ci} or iH_c:- The resistance of a magnetic material to demagnetization. It is equal to the value of *H* where the intrinsic curve intersects the H axis in the second quadrant of the hysteresis loop. It is expressed in At/m.

Core Loss:- Power lost in a magnetic material when flux density changes. Also called iron losses or excitation losses, mainly consisting of hysteresis and eddy current losses. This loss is proportional to excitation frequency and flux density swing. In bipolar excitation applications, the core loss is proportional to the peak-to-peak flux density. In unipolar excitation applications, the core loss is proportional to the peak flux density.

Core Saturation:- The ability for an inductive element to store energy is limited. Beyond this limit, the permeability of the core drops which causes a drop in inductance. It is standard to identify core saturation when the inductance has dropped 10% from its zero bias inductance level.

Copper Loss:- Magnetics dissipate power and this power loss is due to both copper and core losses. Copper loss is a term that describes both the AC and DC losses in a magnetic winding and is solely due to the resistive properties of the winding. Refer to the winding table in the reference section for specific ohmic values of different wire gauges.

Curie Temperature, *T_c*:- The transition temperature above which the alloy loses its magnetic properties. It is not the maximum serviceable temperature, which is usually much lower. The temperature at which the parallel alignment of elementary magnetic moments completely disappears, and the material is no longer able to hold magnetization. Most references state that the ferromagnetic material becomes paramagnetic (weakly magnetic).

Current Density:- The amps per unit of cross-section in the conductor.

DC Bias:- Direct Current (DC) applied to the winding of a core in addition to any time-varying current. Inductance with DC bias is a common specification for powder cores. The inductance decreases or rolls-off gradually and predictably with increasing DC bias.

DC Stress:- Annealing a magnetic material in the presence of a DC magnetic field to enhance magnetic properties.

Demagnetization curve:- The second (or fourth) quadrant of a major hysteresis loop generally describing the behaviour of magnetic characteristics in actual use. Also known as the *B-H* Curve. That portion of the hysteresis loop which lies between the residual induction point, B_r, and the coercive force point, H_c (normal curve) or H_{ci} (intrinsic curve). Points on this curve are designated by the coordinates B_d and H_d.

Demagnetized:- A material condition where a ringing AC field has reduced the remanent induction to or near zero. A ringing AC field is a continually decreasing sinusoidal field. A pulsed DC field can be used to achieve gross demagnetization, but with much effort and with residual local magnetization.

Dimension ratio h:D:- Dimension ratio is the ratio of a magnet's length to its diameter, or the diameter of a disk of equivalent cross sectional area. For simple geometries, such as bars and rods, the dimension ratio is related to the slope of the magnet's operating line. If the magnet is thin but long or has a large outside diameter and is in a closed magnetic circuit, then magnet losses attraction force faster when the temperature is increased.

Diamagnetic Material:- A material with magnetization directed opposite to the magnetizing field, so that the relative permeability is less than one; metallic bismuth is an example.

Dipole (Magnetic):- An arrangement of one or more magnets to form a magnet system that produces a magnetic field with one pair of opposite poles.

Direction of magnetization:- Refers to the 'easy axis' or the axis of choice for the direction of alignment. Most rings are aligned axially so the direction of magnetization is through the axis (or thickness). Other possibilities for rings would include 'across the diameter' and 'radial'.

Distributed Air Gap:- Major feature of powder cores. It is the cumulative effect of many small gaps distributed evenly throughout the core. In a typical MPP core, the number of separate air gaps results from the use of powder to construct the core and numbers in the millions. The result is minimal fringing flux density compared to a core with one or two air gaps in the magnetic path. (Flux that passes around a discrete air gap and through the sides of a core is fringing. Fringing flux enters the surrounding winding and causes a substantial amount of eddy current loss.)

Domains:- Areas in a magnetic alloy which have the same orientation. The magnetic domains are regions where the atomic moments of atoms cooperate and allow for a common magnetic moment. It is the domains which are rotated and manipulated by an external magnetizing field to create a useful magnet which has a net magnetic moment. In un-magnetized material the domains are un-oriented and cancel each other out. In this condition there is no net external field.

Eddy currents:- Circulating electrical currents that are induced in electrically conductive elements when exposed to changing magnetic fields, creating an opposing force to the magnetic flux. Eddy currents can be harnessed to perform useful work (such as dampening of movement), or may be unwanted consequences of certain designs, which should be accounted for of minimized.

Eddy Current Loss:- Electric fields in close proximity to magnetic flux lines cause currents to flow both in magnetic cores, which are electrically conductive, and in windings. Core loss associated with the electrical resistivity of the magnetic material and induced voltages within the material. Eddy currents are inversely proportional to material resistivity and proportional to rate of change of flux density. Eddy current and hysteresis losses are the two major core loss factors. Eddy current loss becomes dominant in powder cores as the frequency increases.

Electrical Resistivity:- The electrical resistance to current flow in ohms per unit length of the material being evaluated.

Electromagnet:- A magnet, consisting of solenoid with a permeable material such as iron core, which has a magnetic field existing only during the time of current flow through the coil.

Energy Product:- Indicates the energy that a magnetic material can supply to an external magnetic circuit when operating at any point on its demagnetization curve. Calculated as $B_d \times H_d$, and measured in kiloJoules per cubic meter (kJ/m^3).

Epoxy Impregnated:- Cut cores are impregnated with an epoxy to make the core rigid. No insulative purpose is intended.

Epstein Test:- A standardized method of evaluating unprocessed thin-gauge alloy for core loss and permeability.

Excitation Current:- The current which produces magnetic energy (or flux) in an inductor.

Ferrimagnetic Material:- An antiparallel alignment of adjacent atomic moments is present as in antiferromagnetic materials, but the moments are not equal. The response to an external magnetic field is therefore large, although smaller than that for a ferromagnetic material. Ferrites are the most important example of this class of material.

Ferrites:- A soft ferrite material that has lower permeability with very low eddy current loss. The common ferrites are nickel-zinc, manganese-zinc and magnesium-zinc ferrite.

Ferromagnetic material:- A material whose permeability is very much larger than 1 (from 60 to several thousands times 1), and which exhibits hysteresis phenomena. A material in which internal magnetic moments spontaneously line up parallel to each other to form domains, resulting in relative permeabilities considerably higher than unity (in practice, 1.1 or more); examples include iron, nickel and cobalt.

Ferromagnetism:- Ferromagnetic materials have atomic fields that align themselves parallel with externally applied fields creating a total magnetic field much greater than the applied field. Ferromagnetic materials have permeabilities much greater than 1. Above the Curie temperature, the ferromagnetic materials become paramagnetic.

Flux:- The condition existing in a medium subjected to a magnetizing force. This quantity is characterized by the fact that an electromotive force is induced in a conductor surrounding the flux at any time the flux changes in magnitude. The MKS unit of flux is the Weber.

Flux Density:- *Magnetic, B* - The conceptual fundamental magnetic force field. Flux means to flow (around a current carrying conductor, for example) and 'density' refers to its use with an enclosed area and Faraday's Law to determine induced voltage. Also called the 'induction field.' From Faraday's Law, the MKSA unit of flux density is a volt-second per square meter per turn or Tesla.

Flux loss:- Refers to the change (loss) in magnetic strength of a magnet, which occurs as a result of temperature stabilization. Also known as irreversible loss. Once it occurs, the only way to regain the flux loss is to re-magnetize the magnet. Under normal circumstances, flux loss is limited to a few percent.

Flux meter:- An instrument that measures the change of flux linkage with a search coil or Helmholtz coil. A flux meter is basically a voltage integrator, which is an integrating device totalizing the voltage output with respect to time.

Fringing fields:- Leakage flux particularly associated with edge effects in a magnetic circuit. The field(s) associated with the divergence of the flux from the shortest path between poles in a magnetic circuit. Where flux passes from a high permeability into a lower permeability material, the flux redistributes.

Gauss:- Lines of magnetic flux per square centimetre, cgs unit of flux density, equivalent to lines per square inch in the English system, and Webers per square meter or Tesla in the SI system. One Tesla is equal to one Weber per square centimetre (metre).

Gauss meter:- An instrument that measures the instantaneous value of magnetic induction, *B*. Its principle of operation is usually based on one of the following: the Hall effect, nuclear magnetic resonance (NMR), or the rotating coil principle.

Gilbert:- The unit of magneto motive force, *F*, in the cgs electromagnetic system. MKS equivalent is ampturns, At

Grain Oriented:- Silicon steel or other granular magnetic material that has a preferred direction of magnetization.

Hall Effect Transducer:- A device which produces a voltage output dependent upon an applied DC voltage and an incident magnetic field. The magnitude of the output is a function of the field strength and the angle of incidence with the Hall device.

Hard Ferrite:- Same as ceramic ferrite.

Hard Magnetic Material:- A permanent magnet material that has an intrinsic coercivity greater than or equal to about 24 kA/m. A ferromagnetic material that retains its magnetization when the magnetizing field is removed; a magnetic material with significant coercivity.

H_c, Coercive Force, or Coercivity:- Is equal to the demagnetizing field required to reduce the B field in the magnet to zero after the magnet has been fully saturated; measured A/m.

H_{ci}, Intrinsic Coercive Force, or Intrinsic Coercivity:- That value of *H* corresponding to the remnant induction, B_d; on the demagnetization curve, measured in At/m. Represents the ability of the magnetic materials to resist demagnetization. It is equal to the demagnetizing field that reduces the B field in the magnet to zero (from saturation).

H_d, B_d:- Operating point on demagnetisation curve.

Henry:- A unit of inductance.

H_{mv}, H_m:- That value of H corresponding to the recoil induction, B_m,; measured in At/m. Common symbol for maximum applied magnetizing force.

H_o:- The magnetic field strength at the point of the maximum energy product BH_{max}; measured in At/m.

H_s:- Net effective magnetizing force, is the minimum magnetizing force required in the material, to magnetize to saturation measured in At/m.

Hysteresis and Hysteresis Loss:- Hysteresis is the tendency of a magnetic material to retain its magnetization. Hysteresis causes the graph of magnetic flux density versus magnetizing force to form a loop rather than a line. The area of the loop represents the difference between energy stored and energy released per unit volume of material per cycle. This difference is called hysteresis loss. It is one of two major loss mechanisms in inductor cores; the other is eddy current loss. Hysteresis loss is measured at low frequency to distinguish it from eddy current loss.

Hysteresis loop:- A closed curve obtained for a material by plotting (usually to rectangular coordinates) corresponding values of magnetic induction, *B*, for ordinates and magnetizing force, *H*, for abscissa when the material is passing through a complete cycle between definite limits of either magnetizing force, *H*, or magnetic induction, *B*. If the material is not driven to saturation, it is said to be on a minor loop.

Hysteresis Loop, Major:- Of a material is the closed loop obtained when the material is cycled between positive and negative saturation.

Hysteresis, Magnetic:- The property of a magnetic material by virtue of which the magnetic induction for a given magnetizing force depends upon the previous conditions of magnetization.

Induction, B:- The magnetic flux per unit area of a section normal to the direction of flux. Unit - Tesla.

Induced Flux Density:- The flux density generated in a core (or soft magnetic material) by the applied MMF.

Inductance:- Inductance is the ratio of voltage to time rate of change of current. By definition, it has dimensions of volt-seconds per ampere. A volt-second per ampere is called a Henry.

Inductance Factor A_L:- Core constant used to calculate inductance based on the number of winding turns squared. Value is given in millihenries per 1000 turns squared, which is the same as nanohenries per turn squared.

$$L = A_L N^2 \text{ nanohenries}$$

Induction, B:- Magnetic induction, B, is the magnetic field induced by an applied field, *H*. It is measured as the flux per unit area normal to the direction of the magnetic path.

Induction Curve, Normal:- A graph depicting the relation between normal induction B and magnetizing force H, where B corresponds to the sum of the externally applied field, H, and the magnetic flux from the magnetic material, B_i.

Inductor:- A coil that has significant self inductance, typically many turns of wire and with a permeable core. It is a device that stores and releases electromagnetic energy.

Initial Permeability:- The relative permeability of a magnetic material at a very low flux level.

Insulator, Insulation:- Opposite of conductor, that is, does not conduct an electrical current. In soft magnetic cores, refers to electrical insulation between adjacent laminations, layers of thin gauge tape, or powder particles. Also associated with some of the finishes, which have dielectric capacity, applied to cores.

Intrinsic Coercive Force, H_{ci}, iH_c :- Measured in At/m, this is a measure of the materials inherent ability to resist demagnetization. It is the demagnetization force corresponding to zero intrinsic induction in the magnetic material after saturation. Practical consequences of high H_{ci} values are seen in greater temperature stability for a given class of material, and greater stability in dynamic operating conditions.

Intrinsic coercive force of a material, H_{ci}:- Indicates its resistance to demagnetization. It is equal to the demagnetizing force which reduces the intrinsic induction, B_i, in the material to zero after magnetizing to saturation; measured in At/m. This quantity is used to gage the field required to magnetize a material and its ability to resist demagnetization.

Intrinsic Coercivity:- Same as H_{ci}. Indicates a material's resistance to demagnetization. It is equal to the demagnetizing force which reduces the intrinsic induction, B_i, in the material to zero; measured in At/m. As for coercivity, the maximum value of intrinsic coercivity is obtained after the material has been saturated (fully magnetized).

Intrinsic Demagnetization Curve:- The hysteresis loop corresponding to *B* versus *H* where *B* is the magnetization resulting from only the magnetic material. For the Normal Curve, B corresponds to the sum of the externally applied field and the field of the magnetic material. The second quadrant portion of the hysteresis loop generated when intrinsic induction B_i is plotted against applied field *H*, which is mathematically related to the normal curve; most often used to determine the effects of demagnetizing (or magnetizing) fields. Also known as the intrinsic B versus H curve.

Intrinsic induction, B_i (or J):- The contribution of the magnetic material to the total magnetic induction, *B*. It is the vector difference between the magnetic induction in the material and the magnetic induction that would exist in a vacuum under the same field strength, *H*. This relation is expressed by the equation: $B_i = B - H_{em}$ where: B_i = intrinsic induction in Tesla; *B* = magnetic induction in Tesla; H_{em} = field strength in kA/m.

Irreversible (flux) loss:- Defined as partial demagnetization of the magnet, caused by exposure to high or low temperatures external fields or other factors, such as mechanical shock. Irreversible loss is not definite and is influenced by magnet material, geometric dimension, operating point and its working magnetic circuit. These losses are recoverable by remagnetisation. Magnets can be stabilized against irreversible losses by partial demagnetization induced by temperature cycles or by external magnetic fields. Stabilization results in the loss prior to placing the magnet in the application and the application is designed around the output of the stabilized magnet.
Irreversible losses are not recoverable by re-magnetization if due to metallurgical changes if the magnet is exposed to very high temperatures.

Isotropic:- A magnetic material that has the same magnetic properties in all directions. Such a material may be magnetized in any direction since it does not have a preferred alignment direction. Also known as unoriented material. Most magnetic materials are anisotropic as cast or powdered: each crystallite has a preferred direction of magnetic orientation. If the particles are not physically oriented during manufacture of the magnet, this results in a random arrangement of the particles and magnetic domains and produces isotropic magnet properties. Conversely, orienting the material during processing results in an anisotropic magnet.

Isotropic Magnet:- A magnet material whose magnetic properties are the same in any direction, and which can therefore be magnetized in any direction without loss of magnetic characteristics.

J:- see B_i Intrinsic induction.

J_s:- see B_{is}, Saturation intrinsic induction.

Keeper:- A piece (or pieces) of soft iron that is placed on or between the pole faces of a permanent magnet to decrease the reluctance of the air gap and thereby reduce the flux leakage from the magnet. It also makes the magnet less susceptible to demagnetizing influences.

Keepers:- A keeper is a high permeability material, typically mild steel, which is installed on a magnet or magnetic assembly to reduce the reluctance of the magnetic circuit. This reduces the overall leakage fields generated by the magnet or magnetic assembly. Keepers are typically installed to help the magnet or magnetic assembly resist demagnetization during handling, transportation, or storage. Keepers are typically found on Alnico magnets and Alnico magnetic assemblies.

Knee (of the demagnetization curve):- The point at which the *B-H* curve ceases to be linear. All magnet materials, even if their second quadrant curves are straight line at room temperature, develop a knee at some temperature. Alnico 5 exhibits a knee at room temperature. If the operating point of a magnet falls below the knee, small changes in *H* produce large changes in *B*, and the magnet will not be able to recover its original flux output without re-magnetization.

Leakage factor, k_ℓ:- Accounts for flux leakage from the magnetic circuit. It is the ratio between the magnetic flux at the magnet neutral section and the average flux present in the air gap. $k_\ell = (B_m A_m)/(B_g A_g)$

Leakage flux:- The flux, ø, whose path is outside the useful or intended magnetic circuit; measured in Weber. That portion of the magnetic flux that is lost through leakage in the magnetic circuit due to saturation or air-gaps, and is therefore unable to be used.

Leakage Inductance:- The inductance associated with the leakage flux of a core coil.

Legg's Equation:- An expression for total core loss at low flux densities. The sum of hysteresis loss, residual loss and eddy current loss. The equation is:

$$R_{ac} / \mu L = a B_{max} f + cf + ef^2$$

where

R_{ac} = effective resistance due to core losses
μ = permeability of the core
L = inductance in henries
a = hysteresis loss coefficient
B_{max} = maximum flux density in Tesla
f = frequency
c = residual loss coefficient
e = eddy current loss coefficient

Length of the air gap, ℓ_g:- The length of the path of the central flux line of the air gap; measured in centimetres. It is important to distinguish between the magnetic length of the gap and the physical length; for magnetic circuit calculations, any nonmagnetic material in the flux path is equivalent to air and contributes to the (magnetic) gap.

Length of the magnet, ℓ_m:-The total length of magnet material traversed in one complete revolution of the centreline of the magnetic circuit; measured in centimetres. The distance between the magnetic poles. (Measured in centimetres when using the cgs system for calculations).

Litz Wire:- A special type of wire that consists of many strands (sometimes hundreds) of magnet wire woven together to form a single conductor. This type of wire offers advantages over single strand at high frequency.

L_m / D Dimension ratio:- The ratio of the length of a magnet to its diameter, or the diameter of a circle of equivalent cross-sectional area. For simple geometries, such as bars and rods, the dimension ratio is related to the slope of the operating line of the magnet, B_d/H_a.

Load line:- Graphically, a line drawn from the origin of the demagnetization curve with a slope of *B/H*, the intersection of which with the second quadrant *B-H* curve represents the operating (working) point, H_d, B_d, of the magnet. Graphic representation of permeance. Also see permeance coefficient.

Mag amp (Magnetic Amplifier):- A device that utilizes a square loop core material to provide a series impedance. The impedance is switched off at a predetermined time during a voltage pulse.

Magnet:- Any object that can sustain an external magnetic field.

Magnetic Bias:- A constant magnetic field on which is superimposed a variable, often sinusoidal, perturbation magnetic field in devices like magnetic bearings (Tesla (T)).

Magnet Wire:- Copper or aluminium wire with electrical insulating material applied to the surface to prevent continuity between adjacent turns in a winding.

Magnetic Assemblies:- A combination of materials, magnetic and non-magnetic, which form a particular solution. Incorporates a permanent magnet as the flux generator and usually relies on mild steel to conduct the flux to the workface. Allows for better means of mounting-tapped holes, threads, press fits, etc.

Magnetic circuit:- An assembly consisting of some or all of the following: permanent magnets, ferromagnetic conduction elements, air gaps through or around which the magnetic flux path passes.

Magnetic Energy:- The product of the flux density B in a magnetic circuit and the (de)magnetizing force H required to reach that flux density. See Energy Product.

Magnetic field strength, H:- (magnetizing or demagnetizing force), The measure of the vector magnetic quantity that determines the ability of an electric current, or a magnetic body, to induce a magnetic field at a given point; measured in At/m.

Magnetic Flux, ø:- A contrived but measurable concept that has evolved in an attempt to describe the flow of a magnetic field. The total magnetic induction over a given area. When the magnetic induction, B, is uniformly distributed over an area A, Magnetic Flux = BA. Is a contrived but measurable concept that has evolved in an attempt to describe the flow of a magnetic field. Mathematically, it is the surface integral of the normal component of the magnetic induction, B, over an area, A.

$$\o = \iint B \cdot dA$$

where:

$\o$ = magnetic flux, in Weber
B = magnetic induction, in Tesla
dA = an element of area, in square centimetres

When the magnetic induction, B, is uniformly distributed and is normal to the area, A, the flux, $\o = BA$.

Magnetic Flux Density, B: A vector quantifying a magnetic field, so that a particle carrying unit charge experiences unit force when travelling with unit velocity in a direction perpendicular to the magnetic field characterized by unit magnetic flux density (Tesla (T)).

Magnetizing Force:- The driving force that pushes flux around a magnetic circuit and is given the symbol H. This force is sometimes referred to as mmf, or magneto motive force.

Magnetic induction, B_o:- Magnetic induction at the point of the maximum energy product BH_{max}; measured in Tesla.

Magnetic Induction in the Air Gap, B_g:- The average value of magnetic induction over the area of the air gap, A_g; or it is the magnetic induction measured at a specific point within the air gap; measured in Tesla.

Magnetic induction, B:- The magnetic field induced by a field strength, H, at a given point. It is the vector sum, at each point within the substance, of the magnetic field strength and resultant intrinsic induction. Magnetic induction is the flux per unit area normal to the direction of the magnetic path. The flux density within a magnetic material when driven by an external applied field or by its self demagnetizing field, which is the vector sum of the applied field and the intrinsic induction (Tesla (T)).

Magnetic Length:- The effective distance between the north and south poles within a magnet, which varies from 0.7 (Alnico) to 1.0 (NdFeB, SmCo, hard ferrite) times the physical length of the magnet.

Magnetic (path) Length:- The physical length of the magnet dimension which corresponds to the direction the magnet is magnetized. This may or may not be the magnet's orientation direction. The length of the closed path that magnetic flux follows around a magnetic circuit. Ampere's Law determines it.

Magnetic Line of Force:- An imaginary line representing a magnetic field, which at every point has the direction of the magnetic flux at that point. Flux is a vector quantity having both magnitude and direction.

Magnetic Losses:- The loss of flux in a magnetic circuit, primarily due to leakage and fringing.

Magnetic Orientation:- The preferred direction of magnetization for an anisotropic magnetic material.

Magnetic saturation:- Of a material exists when an increase in magnetizing force, H, does not cause an increase in the intrinsic magnetic induction, B, of the material.

Magnetic Stabilization:- The act of purposely demagnetizing a magnet with reverse fields or a change in

temperature so that no irreversible losses are experienced when the magnet operates under similar conditions in the field.

Magnetic Susceptibility:- The ratio of the magnetization to the applied external field; an indicator of how easily a material is magnetized.

Magnetizing field (H):- An applied magnetic field used to drive another material to a condition of being magnetized. It may be applied by current through a coil of wire or by using permanent magnets to generate the applied field.

Magnetizing Force, H:- The magnetomotive force per unit length at any point in a magnetic circuit. An applied magnetic field used to drive another material to a condition of being magnetized. It may be applied by current through a coil of wire or by using permanent magnets to generate the applied field. Measured in At/m.

Magnetomotive Force, F:- (magnetic potential difference), Analogous to voltage in electrical circuits, this is the magnetic potential difference between any two points. Most commonly produced by a current flowing through a coil of wire where its magnitude is proportional to the current, and to the number of turns.

$$F = NI$$

where I is in amperes and N is the number of turns

The line integral of the field strength, H, between any two points, p_1 and p_2.

$$F = \int_{p_1}^{p_2} H\, dl$$

F = magneto motive force in At
H = field strength in At/m
dl = an element of length between the two points, in centimetres.
The rationalized unit is the ampere-turn (*ni*).
Magnetomotive force may also result from a magnetized body.

Magnetostriction:- The expansion and contraction of a magnetic material with changing magnetic flux density. The saturation magnetostriction coefficient has the symbol □s. It is change of length divided by original length (a dimensionless number) and is measured at the saturation flux density. Magnetostriction causes audible noise if the magnetostriction is sufficiently large and the applied field is AC and in the audible frequency range, e.g., 50 or 60 Hz.

Major hysteresis loop:- Material closed loop obtained when the material is cycled between positive and negative saturation. For a magnetic material, the loop generated as intrinsic or magnetic induction (B_i or B) is plotted with respect to applied field H when the material is driven from positive saturation to negative saturation and back, showing the lag of induction with respect to applied field.

Manganese-Zinc Ferrites:- A soft magnetic material used in powder cores and characterized by very low eddy current loss. Used for transformer and inductor cores. Compared to nickel-zinc ferrites, they have higher saturation flux density but with greater loss with high frequency current.

Maximum Energy Product, BH_{max}:- The point on the Demagnetization Curve where the product of B and H is a maximum and the required volume of magnet material required to project a given energy into its surroundings is a minimum. Measured in kiloJoules per cubic meter (kJ/m^3).

Maximum Operating Temperature, T_{max}:- The maximum operating temperature, also known as maximum service or working temperature, is the temperature at which the magnet may be exposed to continuously with no significant long-term instability or structural changes. A proposed magnetic definition is that the hysteresis normal curve is substantially a straight line in the second quadrant up to the T_{max} temperature and becomes curved above T_{max}. Note that this temperature is a function of the operating point of the magnet, and not an absolute value.

Maxwell:- The unit of magnetic flux in the cgs electromagnetic system. One Maxwell is one line of magnetic flux. MKS equivalent is Weber.

Mean Length Turn:- The average length of a single turn in the winding of the device.

Minor Hysteresis Loop:- A hysteresis loop generated within the major hysteresis loop when a magnetic material is not driven to full positive or negative saturation.

MMF:- Magneto-motive force.

MMF Drops:- The portions of a magnetic circuit that "consume" the applied MMF. Analogous to voltage drop in an electrical circuit.

Mu-metal:- A nickel-iron alloy typically containing more than 65% nickel used for shielding magnetic flux. The name of the material refers to the Greek letter, μ (mu), which is the symbol for magnetic permeability. Mu-metal has a high value of magnetic permeability.

Multifilar Winding:- A winding technique where a single turn consists of two or more stands of magnet wire operating in parallel. This reduces some of the second order effects associated with a single strand of wire. Typical would be a bifilar, trifilar, etc.

Neodymium-Iron-Boron (NdFeB):- A high energy magnetic material composed of the three nominal elements and other additives, characterized by a high residual induction and high coercivity.

NdFeB has a high magnetic temperature coefficient, which is undesirable for high temperature use.

Net permeability:- The permeability of a magnetic circuit when all materials, air gaps, and applied mmf's are taken into account; it is the same as effective permeability.

Neutral section:- part of a permanent magnet defined by a plane passing through the magnet perpendicular to its central flux line at the point of maximum flux.

Nickel-Zinc Ferrites:- A soft ferrite material that has lower permeability with very low eddy current loss. The other common ferrites are manganese-zinc and magnesium-zinc.

Normal Demagnetization Curve:- The second quadrant portion of the hysteresis loop generated when magnetic induction *B* is plotted against applied field *H*, which is mathematically related to the intrinsic curve; used to determine the performance of a magnet in a magnetic circuit. Also known as the normal *B* versus *H* curve.

North pole:- is the pole of a magnet which, when freely suspended, would point to the north magnetic pole of the earth. The definition of polarity can be a confusing issue, and it is often the best to clarify by using "north seeking pole" instead of "north pole" in specifications.

Oersted:- The unit of magnetic field strength, H, in the cgs electromagnetic system. One Oersted equals a magneto motive force of one gilbert per centimetre of flux path. A cgs unit of measure used to describe magnetizing force. The SI systems is Ampere turns per meter, (At/m).

Open circuit condition:- Exists when a magnetized magnet is by itself with no external flux path of high permeability material.

Operating (load) line:- For a given permanent magnet circuit it is a straight line passing through the origin of the demagnetization curve with a slope of negative B_d / H_d. Although the slope is negative, by convention the values are usually referred to in the absolute value of the slope. (Also known as permeance coefficient line.)

Operating point:- That point on a demagnetization curve of a permanent magnet defined by the coordinates H_d, B_d or that point within the demagnetization curve defined by the coordinates B_m H_m.

Orientation direction:- The direction in which an anisotropic magnet should be magnetized in order to achieve optimum magnetic properties. Also known as the axis, easy axis, or angle of inclination.

Oriented (anisotropic) material:- One that has better magnetic properties in a given direction. Material with a preferred direction of magnetization. This type of material should be magnetized only through this preferred direction. Trying to magnetize through the other directions will result in substantial losses in magnetic properties, and the data provided will not be valid.

Paramagnetic material:- A material having a permeability slightly greater than 1. Sodium, Potassium, Oxygen and the rare earth elements are examples.

Permalloy:- 4-79 Molybdenum Permalloy. A high permeability alloy of 4% molybdenum, 79% nickel, 17% iron used to make tape-wound and laminated cores and other components in a magnetic circuit. See Mu-Metal.

Permanent Magnet Material:- Shaped piece of ferromagnetic material, which once having been magnetized, shows definite resistance to external demagnetizing forces, that is, requires a high demagnetizing force to remove the residual magnetism. Varies with temperature, flux density, and frequency of excitation.

Permeability, μ:- The general term used to express various relationships between magnetic induction, *B*, and the field strength, *H*. The ratio of flux density β to field intensity H. The ratio of the ability of a material to carry magnetic flux in comparison to air or a vacuum, the permeability of which is, by definition, one.

Permeability, Incremental:- The ratio of change in magnetic flux density to change in magnetic field (magnetizing force).

$\mu = (1/\mu_o)\Delta B/\Delta H$ in MKSA units

$\mu = \Delta B/\Delta H$ in CGS units

The magnetic field variations are small or incremental and can be in addition to a steady (DC) bias field. For magnetic powder core data, permeability is incremental permeability unless otherwise noted. Because of the distributed air gap in powder cores, the initial permeability and incremental permeability, without bias, are essentially the same.

Permeability, Initial:- The limit of incremental permeability as a changing unbiased magnetizing force approaches zero. Because of the distributed gap in powder cores, the initial permeability and incremental permeability without bias are essentially the same.

Permeability, Normal, *μ*:- The ratio of the normal induction to the corresponding magnetizing force.

In the cgs system, the flux density in a vacuum is numerically equal to the magnetizing force and, consequently, the magnetic permeability is numerically equal to the ratio of the flux density to the magnetizing force. Thus:

$\mu = B/H$

In a non-isotropic (anisotropic) medium the permeability is a function of the orientation of the medium, since, in general, the magnetizing force and the magnetic flux are not parallel.

Permeability of Free Space μ_o:- The permeability of a volume occupied by a vacuum. Sometimes called the magnetic constant. Free space permeability is an arbitrary constant used with relative permeability to define the magnetic field (magnetizing force), *H*, and account for the contribution of a magnetic material to total flux density. In the MKSA system, it has a magnitude of $4\pi \times 10^{-7}$ and dimensions of Henries per meter. In the CGS System, free space permeability has a magnitude of 1 and no dimensions. The MKSA free space permeability was chosen so that the practical units for electrical measurements match the ones used for relating magnetic quantities to voltage and current.

Permeability, Recoil:- The ratio of change in flux density as a function of incremental change in applied field (H) in the vicinity of *H*=0. It has no dimensions.

$\mu_o\mu_R = B/H$ in MKS units.

$\mu_r = B/H$ in CGS units.

Permeameter:- An instrument that can measure, and often record, the magnetic characteristics of a specimen.

Permeance, P:- The reciprocal of the reluctance, *R*, measured in weber/At. analogous to conductance in electrical circuits. Indicates the ease with which magnetic flux will follow a certain path, which can be approximated by calculations based purely on magnetic circuit geometry.

Permeance Coefficient, P_c:- Ratio of the magnetic induction, B_d, to its self demagnetizing force, H_d. $P_c = B_d / \mu_o H_d$. This is also known as the 'load line', 'slope of the operating line', 'shear line', or operating point of the magnet, and is useful in estimating the flux output of the magnet in various conditions. As a first order approximation, $B_d / H_d = L_m / L_g$, where L_m is the length of the magnet, and L_g is the length of an air gap that the magnet is subjected to. P_c is therefore a function of the geometry of the magnetic circuit.

Polarity:- The characteristic of a particular pole at a particular location of a permanent magnet. Differentiates the North from the South Pole.

Poles, North and South Magnetic:- The north pole of a magnet, or compass, is attracted toward the north geographic pole of the earth (which is actually, by definition, a magnetic south pole), and the south pole of a magnet is attracted toward the south geographic pole of the earth. The north-seeking pole of a compass or of a magnet is designated by the letter "N", and the other pole by the letter "S". The N (north) pole of the magnet will attract the S (south) pole of another magnet: unlike poles attract.

Pole pieces:- Ferromagnetic materials placed on magnetic poles used to shape and alter the effect of lines of flux.

Polymer bonded magnets:- Magnet powder is mixed with a polymer such as epoxy to form a carrier matrix. The magnets are moulded by compression, extrusion, or injection into a certain shape. Solidification occurs by curing instead of sintering.

Proximity Effect:- When conductors are close together, particularly in low voltage equipment, a distortion of current density results from the interaction of the magnetic fields of other conductors.

Quenching:- A rapid cooling process which follows sintering or solid solutioning.

Rare Earths:- A family of elements in the periodic table having an atomic number from 57 to 71, and including 21 and 39. They are also known as the lanthanide series, which includes lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium, scandium, and yttrium.

Rare-Earth Magnet:- A magnet that has any of the rare-earth elements in its composition; typically stronger than other magnet materials, these include neodymium iron boron and samarium cobalt.

Recoil induction, B_m:- The magnetic induction that remains in a magnetic material after magnetizing and conditioning for final use; measured in Tesla.

Recoil induction B_{ri}, is the magnetic induction that remains in a magnetic material after magnetizing and conditioning for final use; measured in Tesla.

Recoil permeability, μ_R:- $\mu_R = \chi+1$, or permanent permeability, is the average slope of the recoil hysteresis loop, also known as the minor loop. Of a permanent magnet is defined by a plane passing through the magnet perpendicular to its central flux line at the point of maximum flux.

Relative Permeability:- The ratio of permeability of a medium to that of a vacuum. In the cgs system, the permeability is equal to 1 in a vacuum by definition. The permeability of air is also for all practical purposes equal to 1 in the cgs system.

Rectangularity Ratio:- See squareness ratio.

Reluctance factor, f:- Accounts for the apparent magnetic circuit reluctance. This factor is required due to the treatment of *H*, and *H*, as constants.

Relative Permeability:- The permeability of a material compared with the permeability of free space. This is what normally is specified as material permeability.

Reluctance:- Analogous to electrical resistance, it is the quantity that determines the magnetic flux, ø, resulting from a given magnetomotive force, F.

$R = F / ø$

where: *R* = reluctance, in At/Weber

F = magnetomotive force, in At

$\o$ = flux, in webers

Remnant or *residual*:- The flux density that remains in a magnetic material after an applied magnetic field (magnetizing force) is removed.

Remnant induction, B_d:- Any magnetic induction that remains in a magnetic material after removal of an applied saturating magnetic field, H_s. (B_d is the magnetic induction at any point on the demagnetization curve: measured in Tesla.)

Remanence, B_d:- The magnetic induction that remains in a magnetic circuit after the removal of an applied magnetizing force. If there is an air gap in the circuit, the remanence will be less than the residual induction, B_r.

Residual Flux:- The flux that remains in a core when the applied MMF is returned to a value of zero.

Residual induction (or flux density), B_r:- The magnetic induction corresponding to zero magnetizing force in a magnetic material after saturation in a closed circuit; measured in Tesla. The point at which the hysteresis loop crosses the *B* axis at zero magnetizing force, and represents the maximum flux output from the given magnet material. By definition, this point occurs at zero air gap, and therefore cannot be seen in practical use of magnet materials.

Return path:- Conduction elements in a magnetic circuit, which provide a low reluctance path for the magnetic flux. Soft magnetic material such as iron or various steels are used to carry or channel the magnetic flux to the gap or working region for interaction with other components. This conductor of magnetic flux is referred to as the return path. It is usually designed to minimize fringing and leakage flux.

Reversible Loss:- A decrease in magnetic induction B of a permanent magnet when subjected to thermal or magnetic demagnetization that is fully recovered (without remagnetisation) when the detrimental conditions are removed. Partial demagnetization of the magnet, caused by exposure to high or low temperatures, can be recovered when the magnet returns to its original temperature. (Tesla (T)).

Reversible temperature coefficient:- A measure of the reversible changes in magnetic property, flux, caused by temperature variations. These are spontaneously regained when the temperature is returned to its original point. Magnetic saturation of a material exists when an increase in magnetizing force produces no increase in intrinsic induction. The temperature coefficient is a factor which describes the reversible change in a magnetic property with a change in temperature. The magnetic property spontaneously returns when the temperature is cycled to its original point. Most materials exhibit a non-linear response with temperature. It usually is expressed as the percentage change per unit of temperature.

Samarium Cobalt:- A brittle, high energy magnetic material that is best known for its performance at high temperatures. It comes in two compositions: $SmCo_5$ and a higher energy Sm_2Co_{17}.

Saturation - This is the flux density of maximum material magnetization. Magnetization M is the contribution of a magnetic material to the total flux density.

$B = \mu_o (H+M)$ in MKSA units.

$B = H+4\pi M$ in CGS units.

Saturation magnetization is the maximum value of magnetization. Also, the term saturation is sometimes used as a reference to the decrease of permeability with increasing magnetizing force. In an inductor, this corresponds to a decrease of inductance with current.

Saturation:- A condition where the increase in applied external field yields no increase in induction. When this condition is met, all of the elementary magnetic moments have the same alignment. This condition is important in permanent magnet alloys and in Ferromagnetic alloys. Magnet alloys must always be magnetized to saturation. The magnet may not be used at this level, but before conditioning and stabilization the magnet must always first be magnetized to saturation. Usually saturation should not be exceeded in Ferromagnetic alloys which comprise the yoke or return path elements of a magnetic circuit. If ferromagnetic elements are saturated there will be flux leakage in the system and a redesign should be considered.

The condition under which all elementary magnetic moments have become oriented in one direction. A ferromagnetic material is saturated when an increase in the applied magnetizing force produces no increase in induction. Saturation flux densities for steels are in the range of 1.6 to 2 Tesla.

Saturation Flux Density, B_{sat}:- The flux density at which a material saturates.

search coil:- A coiled conductor, usually of known area and number of turns, that is used with a flux meter to measure the change of flux linkage with the coil.

Saturation intrinsic induction, B_{is}, (or *J*):- The maximum intrinsic induction possible in a material.

Second quadrant curve:- The second quadrant curve is the demagnetization portion of the hysteresis loop created with a permeameter. In a permeameter, magnets are magnetized to saturation in the first quadrant and then demagnetized to plot the second quadrant curve. The second quadrant curve is the intrinsic curve starting at B_r and ending at H_{ci}. From this intrinsic curve, the extrinsic (normal) curve is calculated to derive the line which extends from B_r to H_c.

Self Demagnetizing Field:- A field inside a permanent magnet that is opposed to its own magnetization,

which is due to the internal coupling of its poles following the introduction of an air gap in the magnetic circuit (Tesla (T)).

Sintered:- A sintered magnet is comprised of a compacted powder which is then subjected to a heat treat operation where the full density and magnetic orientation is achieved. Sintering occurs at elevated temperatures, typically between 1100 and 1200°C.

Sintered Iron:- Powdered iron that has been pressed and sintered into a structural form. This type of material occasionally is used in a magnetic
application, but they normally exhibit excessive core losses.

Sintered Magnets:- Magnets that are made from powdered materials that are pressed together, and then heated in an oven to produce desired shapes and magnetic properties.

Skewing Of The Loop:- When air gap is added to the magnetic path, the hysteresis loop is made to lean over (permeability is reduced); it is said to be skewed or sheared.

Skin Effect:- An isolated conductor carrying current will generate a concentric magnetic field. With alternating currents, a magnetizing force will exist, generating eddy currents in the conductor. The direction of these eddy currents is such as to add to the current at the surface of the conductor and subtract from the current in the centre. The effect is to encourage the current to flow near the surface of the conductor. The majority of the current will flow in an equivalent surface skin thickness or penetration depth. At one skin depth in a conductor the current density will have decreased by 1/e, or 36.8%.

Soft Magnetic Material:- Shaped piece of ferromagnetic material that once having been magnetized is easily demagnetized, i.e. requires a slight coercive force to remove the resultant magnetism. A material with low coercivity and high permeability. Generally accepted as having a coercivity of less than 24 kA/m though most soft materials used in inductors have coercivity of under 0.8 kA/m.

Square Loop:- Refers to a hysteresis loop where the difference between B_m and B_r of a material is quite small, resulting in a rectangular appearance of the intrinsic curve.

Stabilization:- Exposure of a magnet to demagnetizing influences expected to be encountered in use in order to prevent irreversible losses during actual operation. Demagnetizing influences can be caused by high or low temperatures, or by external magnetic fields.

Temperature Coefficient of B_r:- A factor, which describes the reversible change in a magnetic property with change in temperature. Expressed as percent change per unit of temperature.

The magnetic property spontaneously returns when the temperature is cycled to its original point so long as a limit condition is not exceeded – see note below. It usually is expressed as the percentage change per unit of temperature over a specified temperature range.

Above (or below) a critical temperature, dependent upon the material and its magnetic characteristics and magnetic circuit, an irreversible loss may take place which is recovered when the magnet is re-saturated.

Temperature Stabilization:- After manufacture, many types of hard and soft magnetic materials can be thermally cycled to make them less sensitive to subsequent temperature extremes.

Tesla:- MKSA (SI) unit for magnetic flux density, defined by Faraday's Law. A Tesla represents a volt-second per square meter per turn. One Tesla is equal to one Weber per square metre. One Tesla equals 10,000 Gauss

T_{max}, T_m, or Maximum service temperature:- The maximum temperature to which the magnet may be exposed with no significant long-range instability or structural changes. A proposed magnetic definition is that the normal hysteresis curve is a straight line in the second quadrant up to the T_{max} temperature; the line begins to show curvature (a 'knee') once T_{max} is exceeded.

Unoriented (isotropic) material:- Material with equal magnetic properties in all directions.

Volume Resistivity:- Volume resistivity is a measure of a magnetic cores ability to impede the flow of current through the material or on its surface. When a core comes in contact with one or more of its terminals, a low core volume resistivity can present some problems. Typically, the higher the cores permeability, the lower the cores volume resistivity.

Weber:- The practical unit of magnetic flux. It is the amount of magnetic flux which, when linked at a uniform rate with a single-turn electric current during an interval of 1 second, will induce in this circuit an electromotive of force of 1 volt. 1 Weber = 10^8 Maxwells.

Glossary of FACTS Terminology

Flexibility of electric power transmission:- The ability to accommodate changes in the electric transmission system or operating conditions while maintaining steady-state and transient margins.

Flexible ac transmission system (FACTS):- Alternating-current transmission systems incorporating power electronic based and other static controllers to enhance controllability and increase power transfer capability.

FACTS controller:- A power electronic based system and static equipment that provide control of one or more ac transmission system parameters.
Battery-energy-storage system (BESS):- A chemical-based energy-storage system using shunt-connected switching converters to supply or absorb energy to or from an ac system which can be adjusted rapidly.
Interphase power controller (IPC):- A series-connected controller of active and reactive power consisting, in each phase, of inductive and capacitive branches subjected to separately phase-shifted voltages. The active and reactive power can be set independently by adjusting the phase shift and/or the branch impedance using mechanical or electronic switches. In the particular case where the inductive and capacitive impedances form a conjugate pair, each terminal of the IPC is a passive current source dependent on the voltage at the other terminal.
Static condenser (STATCON):- Preferred terminology is static synchronous compensator (SSC or STATCOM).
Static synchronous compensator (SSC or STATCOM):- A static synchronous generator operated as a shunt-connected static VAr compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.
Static synchronous generator (SSG):- A static, self-commutated switching power converter supplied from an appropriate electric energy source and operated to produce a set of adjustable multiphase output voltages, which may be coupled to an ac power system for the purpose of exchanging independently controllable real and reactive power.
Static synchronous series compensator (SSSC or S3C): A static synchronous generator operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted electric power. The S3C may include transiently rated energy-storage or energy-absorbing devices to enhance the dynamic behaviour of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall real (resistive) voltage drop across the line.
Static VAr compensator (SVC):- A shunt-connected static VAr generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage).
Static VAr generator or absorber (SVG):- A static electrical device, equipment, or system that is capable of drawing controlled capacitive and/or inductive current from an electrical power system and thereby generating or absorbing reactive power. Generally considered to consist of shunt-connected, thyristor-controlled reactor(s) and/or thyristor-switched capacitors.
Static VAr system (SVS):- A combination of different static and mechanically switched VAr compensators whose outputs are coordinated.
Superconducting magnetic energy storage (SMES):- A superconducting electromagnetic-based energy-storage system using shunt-connected switching converters to rapidly exchange energy with an ac system.
Thyristor-controlled braking resistor (TCBR):- A shunt-connected, thyristor switched resistor, which is controlled to aid stabilization of a power system or to minimize power acceleration of a generating unit during a disturbance.
Thyristor-controlled phase-shifting transformer (TCPST):- A phase-shifting transformer, adjusted by thyristor switches to provide a rapidly variable phase angle.
Thyristor-controlled reactor (TCR):- A shunt-connected, thyristor-controlled inductor whose effective reactance is varied in a continuous manner by partial-conduction control of the thyristor valve.
Thyristor-controlled series capacitor (TCSC):- A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide smoothly variable series capacitive reactance.
Thyristor-controlled series compensation:- An inductive reactance compensator which consists of a series reactor shunted by a thyristor-controlled reactor in order to provide a smoothly variable series inductive reactance.
Thyristor-controlled voltage limiter (TCVL):- A thyristor-switched metal oxide varistor (MOV) used to limit the voltage across its terminals during transient conditions.
Thyristor-switched capacitor (TSC):- A shunt-connected, thyristor-switched capacitor whose effective reactance is varied stepwise by full- or zero-conduction operation of the thyristor valve.
Thyristor-switched reactor (TSR):- A shunt-connected, thyristor-switched inductor whose effective reactance is varied stepwise by full- or zero-conduction operation of the thyristor valve.
Thyristor-switched series capacitor (TSSC):- A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor switched reactor to provide a stepwise control of series capacitive reactance.
Thyristor-switched series compensation A impedance compensator which is applied in series on an ac transmission system to provide a stepwise control of series reactance.
Thyristor-switched series reactor (TSSR):- An inductive reactance compensator which consists of a series reactor shunted by a thyristor-switched reactor in order to provide a stepwise control of series inductive reactance.

Unified power-flow controller (UPFC):- A combination of a static synchronous compensator (STATCOM) and a static synchronous series compensator (S3C) which are coupled via a common de link, to allow bidirectional flow of real power between the series output terminals of the S3C and the shunt output terminals of the STATCOM, and are controlled to provide concurrent real and reactive series line compensation without an external electric energy source. The UPFC, by means of angularly unconstrained series voltage injection, is able to control, concurrently or selectively, the transmission line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt-reactive compensation.
VAr compensating system (VCS):- A combination of different static and rotating VAr compensators whose outputs are coordinated.

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Physical Constants

Angstrom	Å	10^{-10} m = 10^{-1} nm = 10^{-4} µm		
Avogadro's number	N	6.022×10^{23}	atom per mole	/mol
Bohr radius	a_o	0.529177	Angstrom	
		52.9177		pm
Boltzmann's constant	k	1.38×10^{-23}	Joule per Kelvin J/K	
Electronic charge, *eV*	q	1.602×10^{-19}	Coulomb	C
Free electron rest mass	m_e	9.11×10^{-31}	kilogram	kg
Acceleration – gravity	g	9.80665		m/s^2
Permeability of free space	μ_o	$4\pi\times10^{-7}$	Henry per metre	H/m
Permittivity of free space	ε_o	8.854×10^{-12}	Farad per metre	$1/\mu_o c^2$
Planck's constant	h	6.626×10^{-34}	Joule second	J s
Proton rest mass	M_p	1.67×10^{-27}	kilogram	kg
Speed of light in vacuum	c	2.998×10^{8}	metre per second	m/s
Standard Atmospheric Pressure		1.01325×10^5 Pa		Pa or N/m^2
Stefan-Boltzmann constant	σ	5.671		$W/(m^2K^4)$
Thermal voltage @ 300K	V_t	0.02586	kT/q	V
Wavelength of 1 eV quantum	λ	1.23977 µm		µm

Silicon Material parameters

Bandgap @ 300K	E_g	1.12		eV
Breakdown field	E_{br}	3×10^{7}		V/m
Density	ρ	2.33		g/cm^3
Intrinsic concentration @ 300K	n_i	1.0×10^{10}		cm^{-3}
Electron affinity	X	4.05		V
Mobility @ 300K	μ_n	1400	electrons	cm^2/V-s
	μ_p	450	holes	
Relative dielectric constant	$\varepsilon_s/\varepsilon_o$	11.9		
Thermal conductivity @ 300K	χ	1.5		W/cmK

Metal	resistivity @ 20ºC ρ µΩ m	temperature co-efficient /K
Copper	0.01724	0.0039
Silver	0.0159	0.0041
Aluminium	0.0280	0.0043
Nichrome	1.080	0.0001
Tin	0.120	0.00046
Tantalum	0.1245	0.0038
Tungsten	0.0565	0.0045
Brass	0.062 – 0.078	

Derived electromagnetic units

Energy	joule	J	kg m^2/s^2
Charge	coulomb	C	A s
Voltage	volt	V	J/C = kg $m^2/(A\ s^3)$
Magnetic flux	weber	Wb	V s = kg $m^2/(A\ s^2)$
Magnetic flux density	tesla	T	V s/m^2 = kg/(A s^2)
Magnetic field intensity	amp-turn/metre	A/m	A/m
Resistance	ohm	Ω	V/A = kg $m^2/(A^2\ s^3)$
Inductance	henry	H	Vs/A = kg $m^2/(A^2\ s^2)$
Capacitance	farad	F	C/V = A^2s^4/(kg m^2)
Power	watt	W	VA = J/s = kg m^2/s^3

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