Danfoss

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Formulae and units for power transmission engineering

$P=\frac{m\cdot g\cdot v}{\eta\cdot 1000}$	$P=\frac{F_R\cdot v}{1000}$	$P=\frac{M\cdot n}{9550}$
$W=\frac{J\cdot n^2}{182{,}5}$	$M=\frac{9550\cdot P}{n}$	$t_a=\frac{J\cdot n}{9{,}55\cdot M_a}$
$W=m\cdot g\cdot s$	$J=\frac{1}{2}\cdot m\cdot r_a^2$	$J=91{,}2\cdot m\cdot\frac{v^2}{n^2}$

BAUER geared motors

These specifications were compiled and carefully checked on the basis of the latest versions of standards and regulations at the time of going to print. The technical and legal rules and the state of design and manufacture at Danfoss Bauer shall be decisive. No liability shall be accepted for damage resulting from the use of these specifications.

Formulae and units for power transmission engineering

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The International System of Units, identified internationally as SI units (**S**ystème **I**nternational d'Unités) was introduced in 1960 by a resolution of the 11th ”General conference for weights and measures” with the ISO recommendation R 1000 of February 1969. DIN 1301 (current version 1993) was developed on this basis and the law governing units of measurement (in short, the Unit Law), which came into force on 5th July 1970, govern the introduction of the new units in business and official matters. SI units are "coherent", that is to say, all the units are related by equations in which there are no numerical factors other than 1. They are also "absolute", i.e. none of them is dependent on properties such as the value of gravitational acceleration at the surface of the earth. SI units make a firm distinction between mass with kg as its basic unit, measured for instance by weighing, and the forces (force due to weight) of these masses,created by gravitational acceleration, which have the unit N (Newton).
1 N is the force which will accelerate a mass of 1 kg by 1 m/s².
Along with those countries who have always used the metric system, those countries who have made the transition from the imperial to the metric systems also use SI units as the basis for their national standards.

1.1 SI basic units

Size	Unit symbol	Name
Length	m	Metre
Mass	kg	Kilogram
Time	s	Second
Electrical current	A	Ampere
Thermodynamic temperature	K	Kelvin
Luminous intensity	cd	Candela

1.2 Decimal multiples and submultiples of units

Factor	Prefix	Prefix symbol
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{2}	Hecto	h
10	Deka	da
10^{-1}	Deci	d
10^{-2}	Centi	c
10^{-3}	Milli	m
10^{-6}	Micro	µ
10^{-9}	Nano	n
10^{-12}	Pico	p
10^{-15}	Femto	f
10^{-18}	Atto	a

The prefix symbol is sometimes used on its own in front of the unit symbol.
This is incorrect.
For example, 10^{-6} m = 1µm = 1 micrometer should not be written as 1 µ = 1 micron.

49.3 Letter symbols and SI units

Area	Symbol	Meaning	Unit Symbol	Name
Geometry	***A***	Area	m^2	Square metre
	a	Distance	m	Metre
	α, β, γ	Angle	rad °	Radian Degree
	b	Breadth	m	Metre
	d, δ	Thickness	m	Metre
	d	Diameter	m	Metre
	h	Height	m	Metre
	l	Length	m	Metre
	r	Radius	m	Metre
	s	Length of path	m	Metre
	V	Volume	m^3	Cubic metre
Time	***a***	Acceleration	m/s^2	
	α	Angular acceleration	rad/s^2	
	f	Frequency	Hz	Hertz
	g	Acceleration of free fall	m/s^2	
	n	Rotational frquency (speed)	1/s r/min	
	ω	Angular frequency	rad/s	
	T	Time constant	s	Second
	t	Time, time period, duration	s	Second
	v	Linear speed	m/s	
Mechanics	***E***	Modulus of elasticity	Pa	Pascal
	F	Force	N	Newton
	G	Force due to weight	N	Newton
	J	Mass moment of inertia	kgm^2	
	M	Torque	Nm	
	m	Mass	kg	Kilogram
	P	Power	W	Watt
	p	Pressure	Pa	Pascal
	ρ	Density	kg/m^2	
	σ	Tensile stress, compressive stress, bending stress	Pa	Pascal
	W	Work, energy	J	Joule
	η	Efficiency	1	
	μ	Coefficient of friction	1	

Area	Symbol	Meaning	Unit Symbol	 Name
Heat	α	Temperature coefficient	1/K	
	T	Thermodynamic (Kelvin) temperature	K	Kelvin
	t, ϑ	Celsius temperature	°C	Degree Celsius
	ΔT, $\Delta\vartheta$	Temperature difference, temperature rise	K	Kelvin
Electricity	***C***	Electrical capacitance	F	Farad
	G	Electrical conductivity	S	Siemens
	I	Electrical current	A	Ampere
	J, S, G	Electrical current density	A/m²	
	P	Active power	W	Watt
	Q, P_q	Reactive power	W, var	Var
	R	Equivalent resistance	Ω	Ohm
	S, P_s	Apparent power	W, VA	Volt-ampere
	U	Electrical voltage	V	Volt
	X	Reactance	Ω	Ohm
	Z	Impedance	Ω	Ohm
Magnetism	***B***	Magnetic flux density, induction	T	Tesla
	Φ	Magnetic flux	Wb	Weber
	H	Magnetic field strength	A/m	
	L	Inductance	H	Henry

1.4 Important equations with physical quantities

Translation	Rotation
$v = \frac{s}{t}$	$\omega = 2 \cdot \pi \cdot n$
	$v = \omega \cdot r = 2\pi \cdot n \cdot r$
$s = v \cdot t$	$\varphi = \omega \cdot t = 2\pi \cdot n \cdot t$
$a = \frac{v}{t_a}$	$\alpha = \frac{\omega}{t_a}$
	$M = F \cdot r$
$P = F \cdot v$	$P = M \cdot \omega$
$F = m \cdot a$	$M = J \cdot \alpha$
$W = F \cdot s$	$W = M \cdot \varphi$
$W = \frac{m \cdot v^2}{2}$	$W = \frac{J \cdot \omega^2}{2}$
$W_{pot} = m \cdot g \cdot h$	$J = m \cdot r^2$

1.5 Important definitions

Level of efficiency	$\eta = \frac{P_{ab}}{P_{auf}} = \frac{P_{auf} - V}{P_{auf}} = 1 - \frac{V}{P_{auf}}$	P_{auf} – Power input P_{ab} – Power output V – Losses
Translation	$i = \frac{n_1}{n_2}$	n_1 – Input speed n_2 – Output speed

1.6 Important numerical value equations

The units indicated previously should be used for numerical value equations or tailored equations with physical quantities.
SI units should always refer to a mass in kg.

1.6.1 Power

Lifting motion

$$P = \frac{m \cdot g \cdot v}{\eta \cdot 1000}$$

Translation

$$P = \frac{F_R \cdot v}{1000}$$

$$F_R = \mu \cdot m \cdot g$$

Rotation

$$P = \frac{M \cdot n}{9550}$$

P	–	Power in kW
F_R	–	Frictional resistance in N
m	–	Mass in kg
g	–	Gravitational acceleration (9.81 m/s²)
v	–	Velocity in m/s
η	–	Efficiency as a decimal fraction
μ	–	Coefficient of friction
M	–	Torque in Nm
n	–	Rotational speed in r/min

1.6.2 Torque

$$M = F \cdot r$$

$$M = \frac{9550 \cdot P}{n}$$

M	–	Torque in Nm
F_R	–	Frictional resistance in N
r	–	Lever arm (radius) in m
P	–	Power in kW
n	–	Rotational speed in r/min

1.6.3 Work

$$W = F \cdot s = m \cdot g \cdot s$$

$$W = \frac{J \cdot n^2}{182{,}5}$$

W	–	Work (energy) in Nm = Ws = J
F	–	Force in N
s	–	Path length in m
m	–	Mass in kg
g	–	Gravitational acceleration (9.81 m/s²)
J	–	Mass moment of inertia in kgm²
n	–	Rotational speed in r/min

1.6.4 Acceleration rate or braking time

$$t_a = \frac{J \cdot n}{9{,}55 \cdot M_a}$$

t_a – Acceleration rate or braking time in s

J – Mass moment of inertia in kgm²
n – Rotational speed in r/min
M_a – Acceleration rate/braking torque in Nm

1.6.5 Mass moment of inertia and flywheel effect

The term flywheel effect *GD²* which was previously used on the Technical Measurement System has not been adopted in the SI. The different units and the different definition must therefore be heeded in calculation that use the mass moment of inertia *mr²*.

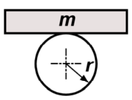
Solid cylinder

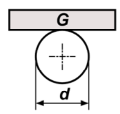
$$J = \frac{1}{2} \cdot m \cdot r_a^{\,2} = \frac{1}{32} \cdot 1000 \cdot \pi \cdot \varsigma \cdot l \cdot d_a^{\,4} = 98 \cdot \varsigma \cdot l \cdot d_a^{\,4}$$

Hollow cylinder

$$J = \frac{1}{2} \cdot m \cdot (r_a^{\,2} + r_i^2) = \frac{1}{32} \cdot 1000 \cdot \pi \cdot \varsigma \cdot l \cdot (d_a^{\,4} - d_i^4) = 98 \cdot \varsigma \cdot l \cdot (d_a^{\,4} - d_i^4)$$

Linear motion as a tangent to the circle





$$J = m \cdot r^2 = m \cdot \left(\frac{d}{2}\right)^2 = \frac{m \cdot d^2}{4}$$

$$GD^2 = G \cdot d^2$$

Since the weight *G* here is seen as a mass in kg, the numerical value of *m* and *G* is the same. The following is used to calculate the flywheel effects in mass moments of inertia:

$$J = \frac{GD^2}{4}$$

That is to say, the numerical value of *GD²* (in kpm²) is to be divided by 4 to give the numerical value of *J* (in kgm²).

Conversion of a mass action from translation to rotation

$$J = 91{,}2 \cdot m \cdot \frac{v^2}{n^2}$$

J	–	Mass moment of inertia in kgm²	r_i	–	Inside radius in m
m	–	Mass in kg	l	–	Length in m
r	–	Radius in m	ς	–	Density in kg/dm³
d_a	–	External diameter in m	v	–	Velocity in m/s
d_i	–	Inside diameter in m	n	–	Rotational speed in r/min
r_a	–	Outside radius in m			

Factor of inertia

The *inertia factor FI* (Factor of Inertia) is the relationship between all masses driven by the motor, including the motor rotor's inertia torque, converted to the motor speed, to the motor rotor's inertia torque, thus

$$FI = \frac{J_{total}}{J_{rotor}} = \frac{J_{extern1} + J_{rotor}}{J_{rotor}}$$

1.6.6 Electrical characteristic values of the drive motor

Input

$$P_{auf} = \frac{\sqrt{3} \cdot U \cdot I \cdot \cos\varphi}{1000}$$

Output

$$P_{ab} = \frac{\sqrt{3} \cdot U \cdot I \cdot \cos\varphi \cdot \eta}{1000}$$

Temperature rise

$$\Delta T = \frac{R_w \text{-} R_k}{R_k} \cdot (235 + \vartheta_k)$$

P	–	Power in kW
U	–	Main conductor voltage in V
I	–	Main conductor current in A
$\cos\varphi$	–	Power factor as a decimal fraction
η	–	Motor efficiency as a decimal fraction
ΔT	–	Temperature rise of the winding in K
ϑ	–	Temperature of the winding in °C

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auf	–	Input
ab	–	Output
k	–	when cold
w	–	when warm

2 Conversion factors

Since specific units are required for the numerical value equations as well as for the inputs and for the result, the conversion factors must be used.
This also applies to the characteristics of the imperial system which is still commonly used in North America.

2.1 Length

		m	dm	cm	mm	yd	ft	in	mil
1 m	=	1	10	100	1000	1.094	3.281	39.370	39.4×10^{3}
1 dm	=	0.1	1	10	100	0.1094	0.3281	3.937	3937
1 cm	=	0.01	0.1	1	10	10.9×10^{-3}	32.8×10^{-3}	0.3937	393.7
1 mm	=	0.001	0.01	0.1	1	1.09×10^{-3}	3.28×10^{-3}	39.4×10^{-3}	39.37
1 yd	=	0.9144	9.144	91.44	914.4	1	3	36	36×10^{3}
1 ft	=	0.3048	3.048	30.48	304.8	0.3333	1	12	12×10^{3}
1 in	=	25.4×10^{-3}	0.2540	2.540	25.40	27.8×10^{-3}	83.3×10^{-3}	1	1000
1 mil	=	25.4×10^{-6}	254×10^{-6}	2.54×10^{-3}	25.4×10^{-3}	27.8×10^{-6}	83.3×10^{-6}	1×10^{-3}	1

1 mile (statute or British mile) = 1760 yd = 5280 ft = 1609.344 m
1 n mile (nautical mile) = 6080 ft = 1.853 km
1 km = 39370 in = 3281 ft = 1093.6 yd = 0.6214 mile = 0.5396 n mile
1 fathom = 6 ft = 1.8288 m

2.2 Area

		m²	dm²	cm²	mm²	yd²	ft²	in²	CM
1 m²	=	1	100	10×10^{3}	1×10^{6}	1.196	10.764	1550	–
1 dm²	=	0.01	1	100	10×10^{3}	12×10^{-3}	0.1076	15.50	–
1 cm²	=	0.1×10^{-3}	0.01	1	100	0.12×10^{-3}	1.08×10^{-3}	0.1550	197×10^{3}
1 mm²	=	1×10^{-6}	0.1×10^{-3}	0.01	1	1.2×10^{-6}	10.8×10^{-6}	1.55×10^{-3}	1.97×10^{3}
1 yd²	=	0.8361	83.61	8361	836×10^{3}	1	9	1296	–
1 ft²	=	92.9×10^{-3}	9.290	929.03	92.9×10^{3}	0.1111	1	144	183×10^{6}
1 in²	=	0.645×10^{-3}	64.5×10^{-3}	6.4516	645.16	772×10^{-6}	6.94×10^{-3}	1	1.27×10^{6}
1 CM	=	–	–	5.07×10^{-6}	0.507×10^{-3}	–	5.45×10^{-9}	0.785×10^{-6}	1

CM – circular mil – imperial unit for small areas

1 square mile = 640 acres = 2.590 km² = 259 ha
1 acre = 4840 yd² = 0.405 ha = 4047 m²
1 km² = 0.386 sq. mile = 100 ha = 10 000 a
1 ha = 100 a = 2.471 acres = 11959.6 yd²
1 a = 100 m² = 119.6 yd² = 1076.4 ft²

2.3 Volume

		m³	dm³	cm³	yd³	ft³	in³	gal (UK)	gal (US)
1 m³	=	1	1000	1 x 10^{6}	1.3079	35.32	61.02 x 10^{3}	220	264.2
1 dm³	=	1 x 10^{-3}	1	1000	1.3 x 10^{-3}	35.3 x 10^{-3}	61.02	0.22	0.2642
1 cm³	=	1 x 10^{-6}	1 x 10^{-3}	1	1.3 x 10^{-6}	35.3 x 10^{-6}	61 x 10^{-3}	0.22 x 10^{-3}	0.26 x 10^{-3}
1 yd³	=	0.765	764.6	765 x 10^{3}	1	27	46.7 x 10^{3}	168.2	202
1 ft³	=	28.3 x 10^{-3}	28.32	28.3 x 10^{3}	37 x 10^{-3}	1	1728	6.229	7.481
1 in³	=	16.4 x 10^{-6}	16.4 x 10^{-3}	16.39	21.4 x 10^{-6}	579 x 10^{-6}	1	3.6 x 10^{-3}	4.3 x 10^{-3}
1 gal (UK)	=	4.55 x 10^{-3}	4.546	4546	5.95 x 10^{-3}	0.1605	277	1	1.201
1 gal (US)	=	3.79 x 10^{-3}	3.785	3785	4.95 x 10^{-3}	0.1337	231	0.8327	1

1 bushel (UK)	= 8 gal (UK)	= 64 pt (UK) = 36.37 l
1 bushel (US)	= 0.969 bu (UK)	= 35.24 l
1 pint (UK)	= 1/8 gal (UK)	= 0.5682 l
1 liqu. pt (US)	= 1/8 gal (US)	= 0.4732 l
1 l	= 1.76 pt (UK)	= 2.113 liqu. pt (US)

2.4 Force

		N	kgf	p	dyn	tonf (UK)	lbf	ozf
1 N	=	1	0.1020	102.0	1 x 10^{5}	100.4 x 10^{-6}	0.2248	3.597
1 kgf	=	9.807	1	1000	981 x 10^{3}	0.984 x 10^{-3}	2.205	35.27
1 p	=	9.81 x 10^{-3}	1 x 10^{-3}	1	980.7	0.984 x 10^{-6}	2.2 x 10^{-3}	35.3 x 10^{-3}
1 dyn	=	1 x 10^{-5}	1.02 x 10^{-6}	1.02 x 10^{-3}	1	1 x 10^{-9}	2.25 x 10^{-6}	36 x 10^{-6}
1 tonf (UK)	=	9964	1016	1.02 x 10^{6}	996 x 10^{6}	1	2240	35.8 x 10^{3}
1 lbf	=	4.448	0.4536	453.6	445 x 10^{3}	446 x 10^{-6}	1	16
1 ozf	=	0.278	28.4 x 10^{-3}	28.35	27.8 x 10^{3}	27.9 x 10^{-6}	62.5 x 10^{-3}	1

1 (long) ton (UK)	= 160 stones	= 2240 lb	= 1.016 t
1 (short) ton (US)	= 142.9 stones	= 2000 lb	= 0.907 t
1 stone	= 14 lb	= 224 oz	= 6.35 kg
1 ton	= 20 cwt		
1 cwt (UK)	= 4 quarters	= 8 stones	= 112 lb
1 cwt (US)	= 100 lb	= 45.36 kg	
1 t	= 1000 kg	= 0.984 ton (UK)	= 1.101 ton (US)

2.5 Velocity

		km/h	m/min	m/s	mile/h	ft/min	f t/s	in/s
1 km/h	=	1	16.667	0.2778	0.6214	54.68	0.9113	10.936
1 m/min	=	0.06	1	16.7×10^{-3}	37.3×10^{-3}	3.281	54.7×10^{-3}	0.656
1 m/s	=	3.6	60	1	2.237	196.85	3.281	39.37
1 mile/h	=	1.609	26.82	0.4470	1	88	1.467	17.6
1 ft/min	=	18.3×10^{-3}	0.3048	5.08×10^{-3}	11.4×10^{-3}	1	16.7×10^{-3}	0.2
1 ft/s	=	1.097	18.288	0.3048	0.6818	60	1	12
1 in/s	=	91×10^{-3}	1.524	25.4×10^{-3}	56.8×10^{-3}	5	83.3×10^{-3}	1

2.6 Torque

		Nm	cNm	kgfm	cpm	lbf x ft	lbf x in	ozf x in
1 Nm	=	1	100	0.10197	10.2×10^{3}	0.73756	8.8507	141.61
1 cNm	=	0.01	1	1.02×10^{-3}	101.97	7.376×10^{-3}	88.5×10^{-3}	1.4161
1 kgfm	=	9.8067	980.67	1	100×10^{3}	7.233	86.796	1389
1 cpm	=	98.1×10^{-6}	9.81×10^{-3}	10×10^{-6}	1	72.3×10^{-6}	868×10^{-6}	13.9×10^{-3}
1 lbf x ft	=	1.356	135.6	0.1383	13.8×10^{3}	1	12	192
1 lbf x in	=	0.1129	11.29	11.5×10^{-3}	1152	83.3×10^{-3}	1	16
1 ozf x in	=	7.062×10^{-3}	0.7062	0.72×10^{-3}	72.01	5.21×10^{-3}	62.5×10^{-3}	1

2.7 Power

		kW	mhp	hp	kgfm/s	ft x lbf/s	kcal/s	Btu/s
1 kW	=	1	1.360	1.341	102.0	737.6	0.2388	0.9478
1 mhp	=	0.7355	1	0.9863	75	542.5	0.1757	0.6971
1 hp	=	0.7457	1.014	1	76.04	550	0.1781	0.7068
1 kgfm/s	=	9.81×10^{-3}	13.33×10^{-3}	13.15×10^{-3}	1	7.233	2.342×10^{-3}	9.295×10^{-3}
1 ft x lbf/s	=	1.36×10^{-3}	1.84×10^{-3}	1.82×10^{-3}	0.1383	1	0.324×10^{-3}	1.285×10^{-3}
1 kcal/s	=	4.1868	5.692	5.615	426.9	3088	1	3.968
1 Btu/s	=	1.055	1.435	1.415	107.6	778.2	0.2520	1

2.8 Mass moment of inertia and flywheel effect

	kgm^2 (*mr*^{2})	kgfm^2 (*GD*^{2})	lbf x ft^2 (*WK*^{2})	kpms^2	ft x lbf s^2
1 kgm^2 (mr^2)	= 1	4	23.73	0.102	0.7376
1 kgfm^2 (GD^2)	= 0.25	1	5.933	25.5 x 10^{-3}	0.1844
1 lbf x ft^2 (WK^2)	= 42.1 x 10^{-3}	0.1686	1	4.30 x 10^{-3}	31.1 x 10^{-3}
1 kpms^2	= 9.807	39.23	232.7	1	7.233
1 ft x lbf s^2	= 1.356	5.423	32.17	0.1383	1

2.9 Pressure

		Pa (N/m²)	bar	kgf/m²	kgf/cm²	kgf/mm²	lbf/yd²
1 Pa	=	1	1 x 10^{-5}	0.102	10.2 x 10^{-6}	0.102 x 10^{-6}	0.188
1 bar	=	1 x 10^{5}	1	10.2 x 10^{3}	1.02	10.2 x 10^{-3}	18.8 x 10^{3}
1 kgf/m²	=	9.81	98.1 x 10^{-6}	1	0.1 x 10^{-3}	1 x 10^{-6}	1.843
1 kgf/cm²	=	98.1 x 10^{3}	0.981	10 x 10^{3}	1	0.01	18.4 x 10^{3}
1 kgf/mm²	=	9.81 x 10^{6}	98.1	1 x 10^{6}	100	1	1.84 x 10^{6}
1 lbf/yd²	=	5.32	53.2 x 10^{-6}	0.543	54 x 10^{-6}	0.54 x 10^{-6}	1
1 lbf/ft²	=	47.88	479 x 10^{-6}	4.882	0.488 x 10^{-3}	4.88 x 10^{-6}	9
1 lbf/in²	=	6.89 x 10^{3}	68.9 x 10^{-3}	703	70.3 x 10^{-3}	0.703 x 10^{-3}	1296
1 tonf/in²	=	15.4 x 10^{6}	154	1.58 x 10^{6}	157.5	1.575	2.9 x 10^{6}

		lbf/ft²	lbf/in²	tonf/in²
1 Pa	=	20.88 x 10^{-3}	145 x 10^{-6}	64.75 x 10^{-9}
1 bar	=	2.088 x 10^{3}	14.5	6.475 x 10^{-3}
1 kgf/m²	=	0.2048	1.42 x 10^{-3}	0.64 x 10^{-6}
1 kgf/cm²	=	2.05 x 10^{3}	14.223	6.4 x 10^{-3}
1 kgf/mm²	=	205 x 10^{3}	1.422 x 10^{3}	0.6349
1 lbf/yd²	=	0.1111	772 x 10^{-6}	0.345 x 10^{-6}
1 lbf/ft²	=	1	6.94 x 10^{-3}	3.1 x 10^{-6}
1 lbf/in²	=	144	1	0.446 x 10^{-3}
1 tonf/in²	=	0.323 x 10^{6}	2240	1

1 N/m² = 1 Pa (Pascal)
1 mbar = 1 hPa (Hectopascal)

2.10 Temperature

	°F	°C	K	°Réau	°R
v °F =	*v*	5/9 (*v* – 32)	5/9 (*v* – 32) + 273	4/9 (*v* – 32)	*v* + 460
w °C =	9/5 *w* + 32	*w*	*w* + 273	4/5 *w*	9/5 *w* + 492
x K =	9/5 *x* – 460	*x* – 273	x	4/5 (*x* – 273)	9/5 *x*
y °Réau =	9/4 *y* + 32	5/4 *y*	5/4 *y* + 273	*y*	9/4 *y* + 492
z °R =	*z* – 460	5/9 *z* – 273	5/9 *z*	4/9 *z* – 219	*z*

Reference points of temperature:

Boiling point of water:
212 °F 100 °C 373.15 K 80 °Réau 671.67 °R

Freezing point of water:
32 °F 0 °C 273.15 K 0 °Réau 491.67 °R

Absolute zero:
– 459.67 °F – 273.15 °C 0 K – 0 °R