1 Fundamental Physical and Technical Terms

1.1 Units of physical quantities

1.1.1 The International System of Units (SI)

The statutory units of measurement are[1)]

1. the basic units of the International System of Units (SI units) for the basic quantities length, mass, time, electric current, thermodynamic temperature and luminous intensity,
2. the units defined for the atomic quantities of quantity of substance, atomic mass and energy,
3. the derived units obtained as products of powers of the basic units and atomic units through multiplication with a defined numerical factor,
4. the decimal multiples and sub-multiples of the units stated under 1-3.

Table 1-1

Basic SI units

Quantity	Units Symbol	Units Name
Length	m	metre
Mass	kg	kilogramme
Time	s	second
Electric current	A	ampere
Thermodynamic temperature	K	kelvin
Luminous intensity	cd	candela
Atomic units		
Quantity of substance	mol	mole

Table 1-2
Decimals
Multiples and sub-multiples of units

Decimal power	Prefix	Symbol			
10^{12}	Tera	T	10^{-2}	Zenti	c
10^{9}	Giga	G	10^{-3}	Milli	m
10^{6}	Mega	M	10^{-6}	Mikro	μ
10^{3}	Kilo	k	10^{-9}	Nano	n
10^{2}	Hekto	h	10^{-12}	Piko	p
10^{1}	Deka	da	10^{-15}	Femto	f
10^{-1}	Dezi	d	10^{-18}	Atto	a

[1)] DIN 1301

Table 1-3

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1]		Other units		Relationship[1]	Remarks
		Name	Symbol	Name	Symbol		
1	**Length, area, volume**						
1.1	Length	metre	m				see Note to No. 1.1
1.2	Area	square metre	m^2				
				are	a	$1\ a = 10^2\ m^2$	for land measurement only
				hectare	ha	$1\ ha = 10^4\ m^2$	for land measurement only
1.3	Volume	cubic metre	m^3				
				litre	l	$1\ l = 1\ dm^3 = 10^{-3}\ m^3$	
1.4	Reciprocal length	reciprocal metre	1/m				
				dioptre	dpt	$1\ dpt = 1/m$	only for refractive index of optical systems
1.5	Elongation	metre per metre	m/m				Numerical value of elongation often expressed in per cent

[1] See also notes to columns 3 and 4 and to column 7 on page 15.

(*continued*)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
2 Angle							
2.1	Plane angle (angle)	radian	rad				
						1 rad = 1 m/m	
				full angle		1 full angle = 2 π rad	
				right angle	∟	1 ∟ $= \frac{\pi}{2}$ rad	see DIN 1315
				degree	°	1 ° $= \frac{\pi}{180}$ rad	In calculation the unit rad as a factor can be replaced by numerical 1.
				minute	'	1' = 1°/60	
				second	"	1" = 1'/60	
				gon	gon	1 gon $= \frac{\pi}{200}$ rad	
2.2	Solid angle	steradian	sr			1 sr $= 1 m^2/m^2$	see DIN 1315

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

(continued)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1]		Other units		Relationship[1]	Remarks
		Name	Symbol	Name	Symbol		
3	**Mass**						
3.1	Mass	kilogramme	kg				Units of weight used as terms for mass in expressing quantities of goods are the units of mass, see DIN 1305
				gramme	g	1 g $= 10^{-3}$ kg	At the present state of measuring technology the 3-fold standard deviation for the relationship for u given in col. 7 is $\pm 3 \cdot 10^{-32}$ kg.
				tonne	t	1 t $= 10^{3}$ kg	
				atomic mass unit	u	1 u $= 1.66053 \cdot 10^{-27}$ kg	
				metric carat	Kt	1 Kt $= 0.2 \cdot 10^{-3}$ kg	only for gems
3.2	Mass per unit length	kilogramme per metre	kg/m				
				Tex	tex	1 tex $= 10^{-6}$ kg/m $= 1$ g/km	only for textile fibres and yarns, see DIN 60905 Sheet 1

[1] See also notes to columns 3 and 4 and to column 7 on page 15.

(*continued)*

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
3.3	Density	kilogramme per cubic metre	kg/m^3				see DIN 1306
3.4	Specific volume	cubic metre per kilogramme	m^3/kg				see DIN 1306
3.5	Moment of inertia	kilogramme-square metre	$kg\ m^2$				see DIN 5497 and Note to No. 3.5

1) See also notes to columns 3 and 4 and to column 7 on page 15.

(continued)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
4	**Time**						
4.1	Time	second	s	minute hour day year	min h d a	1 min = 60 s 1 h = 60 min 1 d = 24 h	see DIN 1355 In the power industry a year is taken as 8760 hours. See also Note to No. 4.1.
4.2	Frequency	hertz	Hz			1 Hz = 1/s	1 hertz is equal to the frequency of a periodic event having a duration of 1 s.
4.3	Revolutions per second	reciprocal second	1/s	reciprocal minute	1/min	1/min = 1/(60 s)	If it is defined as the reciprocal of the time of revolution, see DIN 1355.

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

(continued)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
4.4	Cyclic frequency	reciprocal second	1/s				
4.5	Velocity	metre per second	m/s				
				kilometre per hour	km/h	1 km/h = $\frac{1}{3.6}$ m/s	
4.6	Acceleration	metre per second squared	m/s^2				
4.7	Angular velocity	radian per second	rad/s				
4.8	Angular acceleration	radian per second squared	rad/s^2				

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

(*continued)*

Table 1-3 (continued)

List of units

1	2	3	4	5	6	7	8
No.	Quantity	SI unit[1]		Other units		Relationship[1]	Remarks
		Name	Symbol	Name	Symbol		
5	**Force, energy, power**						Units of weight as a quantity of force are the units of force, see DIN 1305.
5.1	Force	newton	N			1 N = 1 kg m/s^2	
5.2	Momentum	newton-second	Ns			1 Ns = 1 kg m/s	
5.3	Pressure	pascal	Pa			1 Pa = 1 N/m^2	see Note to columns 3 and 4
				bar	bar	1 bar = 10^5 Pa	see DIN 1314

[1] See also notes to columns 3 and 4 and to column 7 on page 15.

(*continued)*

Table 1-3 (continued)

List of units

1	2	3	4	5	6	7	8
No.	Quantity	SI unit[1]		Other units		Relationship[1]	Remarks
		Name	Symbol	Name	Symbol		
5.4	Mechanical stress	newton per square metre, pascal	N/m^2, Pa			1 Pa = 1 N/m^2	In many technical fields it has been agreed to express mechanical stress and strength in N/mm^2. 1 N/mm^2 = 1 MPa.
5.5	Energy, work, quantity of heat	joule	J			1 J = 1 Nm = 1 Ws = 1 kg m^2/s^2	see DIN 1345
				kilowatt-hour electron volt	kWh eV	1 kWh = 3.6 MJ 1 eV = $1.60219 \cdot 10^{-19}$ J	At the present state of measuring technology the 3-fold standard deviation for the relationship given in col. 7 is $\pm 2 \cdot 10^{-24}$ J.
5.6	Torque	newton-metre	Nm			1 Nm = 1 J = 1 Ws	
5.7	Angular momentum	newton-second-metre	Nsm			1 Nsm = 1 kg m^2/s	

[1] See also notes to columns 3 and 4 and to column 7 on page 15.

(continued)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
5.8	Power energy flow, heat flow	watt	W			1 W = 1 J/s =1 N m/s = 1 VA	The watt is also termed volt-ampere (standard symbol VA) when expressing electrical apparent power, and Var (standard symbol var) when expressing electrical reactive power, see DIN 40110.
6	**Viscometric quantities**						
6.1	Dynamic viscosity	pascal-second	Pas			1 Pas = 1 Ns/m^2 = 1 kg/(sm)	see DIN 1342
6.2	Kinematic viscosity	square metre per second	m^2/s				see DIN 1342

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

(*continued)*

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
7	**Temperature and heat**						
7.1	Temperature	kelvin	K				Thermodynamic temperature; see Note to No. 7.1 and DIN 1345. Kelvin is also the unit for temperature differences and intervals.
				degree Celsius (centigrade)	° C	The degree Celsius is the special name for kelvin when expressing Celsius temperatures.	Expression of Celsius temperatures and Celsius temperature differences, see Note to No 7.1.
7.2	Thermal diffusivity	square metre per second	m^2/s				see DIN 1341
7.3	Entropy, thermal capacity	joule per kelvin	J/K				see DIN 1345
7.4	Thermal conductivity	watt per kelvin-metre	W/(K m)				see DIN 1341

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

(continued)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)] Name	Symbol	Other units Name	Symbol	Relationship[1)]	Remarks
7.5	Heat transfer coefficient	watt per kelvin-square metre	$W/(Km^2)$				see DIN 1341
8	**Electrical and magnetic quantities**						
8.1	Electric current, magnetic potential difference	ampere	A				see DIN 1324 and DIN 1325
8.2	Electric voltage, electric potential difference	volt	V			1 V =1 W/A	see DIN 1323
8 3	Electric conductance	siemens	S			1 S = A/V	see Note to columns 3 and 4 and also DIN 1324
8.4	Electric resistance	ohm	Ω			1 Ω = 1/S	see DIN 1324

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

(continued)

Table 1-3 (continued)

List of units

1	2	3	4	5	6	7	8
No.	Quantity	SI unit[1]		Other units		Relationship[1]	Remarks
		Name	Symbol	Name	Symbol		
8.5	Quantity of electricity, electric charge	coulomb	C	ampere-hour	Ah	1 C = 1 As 1 Ah = 3600 As	see DIN 1324
8.6	Electric capacitance	farad	F			1 F = 1 C/V	see DIN 1357
8.7	Electric flux density	coulomb per square metre	C/m^2				see DIN 1324
8.8	Electric field strength	volt per metre	V/m				see DIN 1324
8.9	Magnetic flux	weber, volt-second	Wb, Vs			1 Wb = 1 Vs	see DIN 1325
8.10	Magnetic flux density, (induction)	tesla	T			1 T = 1 Wb/m^2	see DIN 1325
8.11	Inductance (permeance)	henry	H			1 H = 1 Wb/A	see DIN 1325

[1] See also notes to columns 3 and 4 and to column 7 on page 15.

(*continued*)

Table 1-3 (continued)

List of units

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
No.	Quantity	SI unit[1)]		Other units		Relationship[1)]	Remarks
		Name	Symbol	Name	Symbol		
8.12	Magnetic field intensity	ampere per metre	A/m				see DIN 1325
9	**Photometric quantities**						
9.1	Luminous intensity	candela	cd				see DIN 5031 Part 3. The word candela is stressed on the 2nd syllable.
9.2	Luminance	candela per square metre	cd/m^2				see DIN 5031 Part 3
9.3	Luminous flux	lumen	lm			1 lm = 1 cd · sr	see DIN 5031 Part 3
9.4	Illumination	lux	lx			1 lx = 1 lm/m^2	see DIN 5031 Part 3

[1)] See also notes to columns 3 and 4 and to column 7 on page 15.

Notes to Table 1-3

To column 7:

A number having the last digit in bold type denotes that this number is defined by agreement (see DIN 1333).

To No. 1.1:

The nautical mile is still used for marine navigation (1 nm = 1852 m). For conversion from inches to millimetres see DIN 4890, DIN 4892, DIN 4893.

To No. 3.5:

When converting the so-called "flywheel inertia GD^2" into a mass moment of inertia J, note that the numerical value of GD^2 in kp m^2 is equal to four times the numerical value of the mass moment of inertia J in kg m^2.

To No. 4.1:

Since the year is defined in different ways, the particular year in question should be specified where appropriate.

3 h always denotes a time span (3 hours), but 3^h a moment in time (3 o'clock). When moments in time are stated in mixed form, e.g. $2^h25^m3^s$, the abbreviation min may be shortened to m (see DIN 1355).

To No. 7.1:

The (thermodynamic) temperature *(T)*, also known as "absolute temperature", is the physical quantity on which the laws of thermodynamics are based. For this reason, only this temperature should be used in physical equations. The unit kelvin can also be used to express temperature differences.

Celsius (centigrade) temperature *(t)* is the special difference between a given thermodynamic temperature T and a temperature of $T_0 = 273.15$ K.

Thus,

$$t = T - T_0 = T - 273.15\ \text{K}. \quad (1)$$

When expressing Celsius temperatures, the standard symbol °C is to be used.

The difference Δ t between two Celsius temperatures, e. g. the temperatures $t_1 = T_1 - T_0$ and $t_2 = T_2 - T_0$, is

$$\Delta t = t_1 - t_2 = T_1 - T_2 = \Delta T \quad (2)$$

A temperature difference of this nature is no longer referred to the thermodynamic temperature T_0, and hence is not a Celsius temperature according to the definition of Eq. (1).

However, the difference between two Celsius temperatures may be expressed either in kelvin or in degrees Celsius, in particular when stating a range of temperatures, e. g. (20 ± 2) °C

Thermodynamic temperatures are often expressed as the sum of T_0 and a Celsius temperature t, i. e. following Eq. (1)

$$T = T_0 + t \quad (3)$$

and so the relevant Celsius temperatures can be put in the equation straight away. In this case the kelvin unit should also be used for the Celsius temperature (i. e. for the "special thermodynamic temperature difference"). For a Celsius temperature of 20 °C, therefore, one should write the sum temperature as

$$T = T_0 + t = 273.15\ \text{K} + 20\ \text{K} = 293.15\ \text{K} \quad (4)$$

1.1.2 Other units still in common use; metric, British and US measures

Some of the units listed below may be used for a limited transition period and in certain exceptional cases. The statutory requirements vary from country to country.

ångström	Å	length	1 Å = 0.1 nm = 10^{-10}m
atmosphere physical	atm	pressure	1 atm = 101 325 Pa
atmosphere technical	at, ata	pressure	1 at = 98 066.5 Pa
British thermal unit	Btu	quantity of heat	1 Btu ≈ 1055.056 J
calorie	cal	quantity of heat	1 cal = 4.1868 J
centigon	c	plane angle	1 c = 1 cgon = $5\,\pi \cdot 10^{-5}$ rad
degree	deg, grd	temperature difference	1 deg = 1 K
degree fahrenheit	°F	temperature	$T_K = 273.15 + (5/9) \cdot (t_F - 32)$
dyn	dyn	force	1 dyn = 10^{-5} N
erg	erg	energy	1 erg = 10^{-7} J
foot	ft	length	1 ft = 0.3048 m
gallon (UK)	gal (UK)	volume	1 gal (UK) ≈ $4.54609 \cdot 10^{-3}$ m^3
gallon (US)	gal (US)	liquid volume	1 gal (US) ≈ $3.78541 \cdot 10^{-3}$ m^3
gauss	G.Gs	magnetic flux density	1 G = 10^{-4}T
gilbert	Gb	magnetic potential difference	1 Gb = $(10/4\,\pi)$ A
gon	g	plane angle	1 g = 1 gon = $5\,\pi \cdot 10^{-3}$ rad
horsepower	hp	power	1 hp ≈ 745.700 W
hundredweight (long)	cwt	mass	1 cwt ≈ 50.8023 kg
inch (inches)	in, ″	length	1 in = 25.4 mm = $254 \cdot 10^{-4}$ m
international ampere	A_{int}	electric current	1 A_{int} ≈ 0.99985 A
international farad	F_{int}	electrical capacitance	1 F_{int} = (1/1.00049) F
international henry	H_{int}	inductance	1 H_{int} = 1.00049 H
international ohm	Ω_{int}	electrical resistance	1 Ω_{int} = 1.00049 Ω
international volt	V_{int}	electrical potential	1 V_{int} = 1.00034 V
international watt	W_{int}	power	1 W_{int} ≈ 1.00019 W
kilogramme-force, kilopond	kp, kgf	force	1 kp = 9.80665 N ≈ 10 N

Unit of mass	ME	mass	1 ME = 9.80665 kg
maxwell	M, Mx	magnetic flux	1 M = 10 nWb = 10^{-8} Wb
metre water column	mWS	pressure	1 mWS = 9806.65 PA ≈ 0,1 bar
micron	μ	length	1 μ = 1 μm = 10^{-6} m
millimetres of mercury	mm Hg	pressure	1 mm Hg ≈ 133.322 Pa
milligon	cc	plane angle	1 cc = 0.1 mgon = $5\pi \cdot 10^{-7}$ rad
oersted	Oe	magnetic field strength	10e = $(250/\pi)$ A/m
Pferdestärke, cheval-vapeur	PS, CV	power	1 PS = 735.49875 W
Pfund	Pfd	mass	1 Pfd = 0.5 kg
pieze	pz	pressure	1 pz = 1 mPa = 10^{-3} Pa
poise	P	dynamic viscosity	1 P = 0.1 Pa · s
pond, gram			
-force	p, gf	force	1 p = $9.80665 \cdot 10^{-3}$ N ≈ 10 mN
pound[1)]	lb	mass	1 lb ≈ 0.453592 kg
poundal	pdl	force	1 pdl ≈ 0.138255 N
poundforce	lbf	force	1 lbf ≈ 4.44822 N
sea mile, international	n mile	length (marine)	1 n mile = 1852 m
short hundredweight	sh cwt	mass	1 sh cwt ≈ 45.3592 kg
stokes	St	kinematic viscosity	1 St = 1 cm^2/s = 10^{-4} m^2/s
torr	Torr	pressure	1 Torr ≈ 133.322 Pa
typographical point	p	length (printing)	1 p = (1.00333/2660) m ≈ 0.4 mm
yard	yd	length	1 yd = 0.9144 m
Zentner	z	mass	1 z = 50 kg

1) UK and US pounds avoirdupois differ only after the sixth decimal place.

Table 1-4

Metric, British and US linear measure

Metric units of length					British and US units of length				
Kilometre	Metre	Decimetre	Centimetre	Millimetre	Mile	Yard	Foot	Inch	Mil
km	m	dm	cm	mm	mile	yd	ft	in or "	mil
1	1 000	10 000	100 000	1 000 000	0.6213	1 093.7	3 281	39 370	$3\,937 \cdot 10^{4}$
0.001	1	10	100	1 000	$0.6213 \cdot 10^{-3}$	1.0937	3.281	39.370	39 370
0.0001	0.1	1	10	100	$0.6213 \cdot 10^{-4}$	0.1094	0.3281	3.937	3 937.0
0.00001	0.01	0.1	1	10	$0.6213 \cdot 10^{-5}$	0.01094	0.03281	0.3937	393.70
0.000001	0.001	0.01	0.1	1	$0.6213 \cdot 10^{-6}$	0.001094	0.003281	0.03937	39.37
1.60953	1 609.53	16 095.3	160 953	1 609 528	1	1 760	5 280	63 360	$6\,336 \cdot 10^{4}$
0.000914	0.9143	9.1432	91.432	914.32	$0.5682 \cdot 10^{-3}$	1	3	36	36 000
$0.305 \cdot 10^{-3}$	0.30479	3.0479	30.479	304.79	$0.1894 \cdot 10^{-3}$	0.3333	1	12	12 000
$0.254 \cdot 10^{-4}$	0.02539	0.25399	2.53997	25.3997	$0.158 \cdot 10^{-4}$	0.02777	0.0833	1	1 000
$0.254 \cdot 10^{-7}$	$0.254 \cdot 10^{-4}$	$0.254 \cdot 10^{-3}$	0.00254	0.02539	$0.158 \cdot 10^{-7}$	$0.0277 \cdot 10^{-3}$	$0.0833 \cdot 10^{-3}$	0.001	1

Special measures: 1 metric nautical mile = 1852 m; 1 Brit. or US nautical mile = 1855 m

1 metric land mile = 7500 m; 1 micron (μ) = 1/1000 mm = 10 000 Å

Table 1-5

Metric, British and US square measure

Metric units of area					British and US units of area				
Square kilometres	Square metre	Square decim.	Square centim.	Square millim.	Square mile	Square yard	Square foot	Square inch	Circular mils
km^2	m^2	dm^2	cm^2	mm^2	sq.mile	sq.yd	sq.ft	sq.in	cir.mils
1	$1 \cdot 10^{6}$	$100 \cdot 10^{6}$	$100 \cdot 10^{8}$	$100 \cdot 10^{10}$	0.386013	$1\,196 \cdot 10^{3}$	$1076 \cdot 10^{4}$	$1\,550 \cdot 10^{6}$	$197.3 \cdot 10^{13}$
$1 \cdot 10^{-6}$	1	100	10 000	1 000 000	$0.386 \cdot 10^{-6}$	1.1959	10.764	1 550	$197.3 \cdot 10^{7}$
$1 \cdot 10^{-8}$	$1 \cdot 10^{-2}$	1	100	10 000	$0.386 \cdot 10^{-8}$	0.01196	0.10764	15.50	$197.3 \cdot 10^{5}$
$1 \cdot 10^{-10}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-2}$	1	100	$0.386 \cdot 10^{-10}$	$0.1196 \cdot 10^{-3}$	$0.1076 \cdot 10^{-2}$	0.1550	$197.3 \cdot 10^{3}$
$1 \cdot 10^{-12}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-4}$	$1 \cdot 10^{-2}$	1	$0.386 \cdot 10^{-12}$	$0.1196 \cdot 10^{-5}$	$0.1076 \cdot 10^{-4}$	0.00155	1 973
2.58999	2 589 999	$259 \cdot 10^{6}$	$259 \cdot 10^{8}$	$259 \cdot 10^{10}$	1	$30\,976 \cdot 10^{2}$	$27\,878 \cdot 10^{3}$	$40\,145 \cdot 10^{5}$	$5\,098 \cdot 10^{12}$
$0.8361 \cdot 10^{-6}$	0.836130	83.6130	8 361.307	836 130.7	$0.3228 \cdot 10^{-6}$	1	9	1296	$1\,646 \cdot 10^{6}$
$9.290 \cdot 10^{-8}$	$9.290 \cdot 10^{-2}$	9.29034	929.034	92 903.4	$0.0358 \cdot 10^{-6}$	0.11111	1	144	$183 \cdot 10^{6}$
$6.452 \cdot 10^{-10}$	$6.452 \cdot 10^{-4}$	$6.452 \cdot 10^{-2}$	6.45162	645.162	$0.2396 \cdot 10^{-9}$	$0.7716 \cdot 10^{-3}$	0.006940	1	$1.27 \cdot 10^{6}$
$506.7 \cdot 10^{-18}$	$506.7 \cdot 10^{-12}$	$506.7 \cdot 10^{-10}$	$506.7 \cdot 10^{-8}$	$506.7 \cdot 10^{-6}$	$0.196 \cdot 10^{-15}$	$0.607 \cdot 10^{-9}$	$0.00547 \cdot 10^{-6}$	$0.785 \cdot 10^{-6}$	1

Special measures:

1 hectare (ha) = 100 are (a)
1 are (a) = 100 m^2
1 Bad. morgen = 56 a = 1.38 acre
1 Prussian morgen = 25.53 a = 0.63 acre
1 Württemberg morgen = 31.52 a = 0.78 acre
1 Hesse morgen = 25.0 a = 0.62 acre
1 Tagwerk (Bavaria) = 34.07 a = 0.84 acre
1 sheet of paper = 86 x 61 cm
gives 8 pieces size A4 or 16 pieces A5
or 32 pieces A6

USA:
1 section (sq.mile) = 64 acres = 2,589 km^2
1 acre = 4840 sq.yds = 40.468 a
1 sq. pole = 30.25 sq.yds = 25.29 m^2

Brit.:
1 acre = 160 sq.poles = 4840 sq.yds = 40.468 a
1 yard of land = 30 acres = 1214.05 a
1 mile of land = 640 acres = 2.589 km^2

Table 1-6

Metric, British and US cubic measures

Metric units of volume				British and US units of volume			US liquid measure		
Cubic metre	Cubic decimetre	Cubic centimetre	Cubic millimetre	Cubic yard	Cubic foot	Cubic inch	Gallon	Quart	Pint
m^3	dm^3	cm^3	mm^3	cu.yd	cu.ft	cu.in	gal	quart	pint
1	1 000	$1\,000 \cdot 10^3$	$1\,000 \cdot 10^6$	1.3079	35.32	$61 \cdot 10^3$	264.2	1 056.8	2 113.6
$1 \cdot 10^{-3}$	1	1 000	$1\,000 \cdot 10^3$	$1.3079 \cdot 10^{-3}$	0.03532	61.023	0.2642	1.0568	2.1136
$1 \cdot 10^{-6}$	$1 \cdot 10^{-3}$	1	1 000	$1.3079 \cdot 10^{-6}$	$0.3532 \cdot 10^{-4}$	0.061023	$0.2642 \cdot 10^{-3}$	$1.0568 \cdot 10^{-3}$	$2.1136 \cdot 10^{-3}$
$1 \cdot 10^{-9}$	$1 \cdot 10^{-6}$	$1 \cdot 10^{-3}$	1	$1.3079 \cdot 10^{-9}$	$0.3532 \cdot 10^{-7}$	$0.610 \cdot 10^{-4}$	$0.2642 \cdot 10^{-6}$	$1.0568 \cdot 10^{-6}$	$2.1136 \cdot 10^{-6}$
0.764573	764.573	764 573	$764\,573 \cdot 10^3$	1	27	46 656	202	808	1 616
0.0283170	28.31701	28 317.01	28 317 013	0.037037	1	1 728	7.48224	29.92896	59.85792
$0.1638 \cdot 10^{-4}$	0.0163871	16.38716	16387.16	$0.2143 \cdot 10^{-4}$	$0.5787 \cdot 10^{-3}$	1	0.00433	0.01732	0.03464
$3.785 \cdot 10^{-3}$	3.785442	3 785.442	3 785 442	0.0049457	0.1336797	231	1	4	8
$0.9463 \cdot 10^{-3}$	0.9463605	946.3605	946 360.5	0.0012364	0.0334199	57.75	0.250	1	2
$0.4732 \cdot 10^{-3}$	0.4731802	473.1802	473 180.2	0.0006182	0.0167099	28.875	0.125	0.500	1

Table 1-7

Conversion tables

Millimetres to inches, formula: mm x 0.03937 = inch

mm	0	1	2	3	4	5	6	7	8	9
0		0.03937	0.07874	0.11811	0.15748	0.19685	0.23622	0.27559	0.31496	0.35433
10	0.39370	0.43307	0.47244	0.51181	0.55118	0.59055	0.62992	0.66929	0.70866	0.74803
20	0.78740	0.82677	0.86614	0.90551	0.94488	0.98425	1.02362	1.06299	1.10236	1.14173
30	1.18110	1.22047	1.25984	1.29921	1.33858	1.37795	1.41732	1.45669	1.49606	1.53543
40	1.57480	1.61417	1.65354	1.69291	1.73228	1.77165	1.81102	1.85039	1.88976	1.92913
50	1.96850	2.00787	2.04724	2.08661	2.12598	2.16535	2.20472	2.24409	2.28346	2.32283

Inches to millimetres, formula: inches x 25.4 = mm

inch	0	1	2	3	4	5	6	7	8	9
0		25.4	50.8	76.2	101.6	127.0	152.4	177.8	203.2	228.6
10	254.0	279.4	304.8	330.2	355.6	381.0	406.4	431.8	457.2	482.6
20	508.0	533.4	558.8	584.2	609.6	635.0	660.4	685.8	711.2	736.6
30	762.0	787.4	812.8	838.2	863.6	889.0	914.4	939.8	965.2	990.8
40	1 016.0	1 041.4	1 066.8	1 092.2	1 117.6	1 143.0	1 168.4	1 193.8	1 219.2	1 244.6
50	1 270.0	1 295.4	1 320.8	1 246.2	1 371.6	1 397.0	1 422.4	1 447.8	1 473.2	1 498.6

Fractions of inch to millimetres

inch	mm	inch	mm	inch	mm	inch	mm	inch	mm
1/64	0.397	7/32	5.556	27/64	10.716	5/8	15.875	53/64	21.034
1/32	0.794	15/64	5.953	7/16	11.112	41/64	16.272	27/32	21.431
3/64	1.191	1/4	6.350	29/64	11.509	21/32	16.669	55/64	21.828
1/16	1.587	17/64	6.747	15/32	11.906	43/64	17.066	7/8	22.225
5/64	1.984	9/32	7.144	31/64	12.303	11/16	17.462	57/64	22.622
3/32	2.381	19/64	7.541	1/2	12.700	45/64	17.859	29/32	23.019
7/64	2.778	5/6	7.937	33/64	13.097	23/32	18.256	59/64	23.416
1/8	3.175	21/64	8.334	17/32	13.494	47/64	18.653	15/16	23.812
9/64	3.572	11/32	8.731	35/64	13.891	3/4	19.050	61/64	24.209
5/32	3.969	23/64	9.128	9/16	14.287	49/64	19.447	31/32	24.606
11/64	4.366	3/8	9.525	37/64	14.684	25/32	19.844	63/64	25.003
3/16	4.762	25/64	9.922	19/32	15.081	51/64	20.241	1	25.400
13/64	5.159	13/32	10.319	39/64	15.478	13/16	20.637	2	50.800

1.1.3 Fundamental physical constants

General gas constant: $R = 8.3166\ J\ K^{-1}\ mol^{-1}$
is the work done by one mole of an ideal gas under constant pressure (1013 hPa) when its temperature rises from 0 °C to 1 °C.

Avogadro's constant: N_A (Loschmidt's number N_L): $N_A = 6.0225 \cdot 10^{23}\ mol^{-1}$
number of molecules of an ideal gas in one mole.
When $V_m = 2.2414 \cdot 10^4\ cm^3 \cdot mol^{-1}$: $N_A/V_m = 2.686\ 10^{19}\ cm^{-3}$.

Atomic weight of the carbon atom: $^{12}C = 12.0000$
is the reference quantity for the relative atomic weights of fundamental substances.

Base of natural logarithms: $e = 2.718282$

Bohr's radius: $r_1 = 0.529 \cdot 10^{-8}$ cm
radius of the innermost electron orbit in Bohr's atomic model

Boltzmann's constant: $k = \frac{R}{N_A} = 1.38 \cdot 10^{-23}\ J \cdot K^{-1}$

is the mean energy gain of a molecule or atom when heated by 1 K.

Elementary charge: $e_o = F/N_A = 1.602 \cdot 10^{-19}$ As
is the smallest possible charge a charge carrier (e.g. electron or proton) can have.

Electron-volt: $eV = 1.602 \cdot 10^{-19}$ J

Energy mass equivalent: $8.987 \cdot 10^{13}\ J \cdot g^{-1} = 1.78 \cdot 10^{-27}\ g\ (MeV)^{-1}$
according to Einstein, following $E = m \cdot c^2$, the mathematical basis for all observed transformation processes in sub-atomic ranges.

Faraday's constant: $F = 96\,480\ As \cdot mol^{-1}$
is the quantity of current transported by one mole of univalent ions.

Field constant, electrical: $\varepsilon_o = 0.885419 \cdot 10^{-11}\ F \cdot m^{-1}$.
a proportionality factor relating charge density to electric field strength.

Field constant, magnetic: $\mu_0 = 4 \cdot \pi \cdot 10^{-7}\ H \cdot m^{-1}$
a proportionality factor relating magnetic flux density to magnetic field strength.

Gravitational constant: $\gamma = 6.670 \cdot 10^{-11}\ m^4 \cdot N^{-1} \cdot s^{-4}$
is the attractive force in N acting between two masses each of 1 kg weight separated by a distance of 1 m.

Velocity of light in vacuo: $c = 2.99792 \cdot 10^8\ m \cdot s^{-1}$
maximum possible velocity. Speed of propagation of electro-magnetic waves.

Mole volume: $V_m = 22\,414\ cm^3 \cdot mol^{-1}$
the volume occupied by one mole of an ideal gas at 0 °C and 1013 mbar. A mole is that quantity (mass) of a substance which is numerically equal in grammes to the molecular weight (1 mol H_2 = 2 g H_2)

Planck's constant: $h = 6.625 \cdot 10^{-34}\ J \cdot s$
a proportionality factor relating energy and frequency of a light quantum (photon).

Stefan Boltzmann's radiation constant: $\delta = 5.6697 \cdot 10^{-8}\ W \cdot m^{-2}\ K^{-4}$ relates radiant energy to the temperature of a radiant body. Radiation coefficient of a black body.

Temperature of absolute zero: $T_0 = -273.16$ °C = 0 K.

Wave impedance of space: $\Gamma_0 = 376.73\ \Omega$
coefficient for the H/E distribution with electromagnetic wave propagation.

$$\Gamma_0 = \sqrt{\mu_0/\varepsilon_0} = \mu_0 \cdot c = 1/(\varepsilon_0 \cdot c)$$

Weston standard cadmium cell: $E_0 = 1.0186$ V at 20 °C.

Wien's displacement constant: $A = 0.28978\ cm \cdot K$
enables the temperature of a light source to be calculated from its spectrum.

1.2 Physical, chemical and technical values

1.2.1 Electrochemical series

If different metals are joined together in a manner permitting conduction, and both are wetted by a liquid such as water, acids, etc., an electrolytic cell is formed which gives rise to corrosion. The amount of corrosion increases with the differences in potential. If such conducting joints cannot be avoided, the two metals must be insulated from each other by protective coatings or by constructional means. In outdoor installations, therefore, aluminium/copper connectors or washers of copper-plated aluminium sheet are used to join aluminium and copper, while in dry indoor installations aluminium and copper may be joined without the need for special protective measures.

Table 1-8

Electrochemical series, normal potentials against hydrogen, in volts.

1. Lithium	approx. – 3.02	10. Zinc	approx. – 0.77	19. Hydrogen	approx. 0.0
2. Potassium	approx. – 2.95	11. Chromium	approx. – 0.56	20. Antimony	approx. + 0.2
3. Barium	approx. – 2.8	12. Iron	approx. – 0.43	21. Bismuth	approx. + 0.2
4. Sodium	approx. – 2.72	13. Cadmium	approx. – 0.42	22. Arsenic	approx. + 0.3
5. Strontium	approx. – 2.7	14. Thallium	approx. – 0.34	23. Copper	approx. + 0.35
6. Calcium	approx. – 2.5	15. Cobalt	approx. – 0.26	24. Silver	approx. + 0.80
7. Magnesium	approx. – 1.8	16. Nickel	approx. – 0.20	25. Mercury	approx. + 0.86
8. Aluminium	approx. – 1.45	17. Tin	approx. – 0.146	26. Platinum	approx. + 0.87
9. Manganese	approx. – 1.1	18. Lead	approx. – 0.132	27. Gold	approx. + 1.5

If two metals included in this table come into contact, the metal mentioned first will corrode.

The less noble metal becomes the anode and the more noble acts as the cathode. As a result, the less noble metal corrodes and the more noble metal is protected.

Metallic oxides are always less strongly electronegative, i. e. nobler in the electrolytic sense, than the pure metals. Electrolytic potential differences can therefore also occur between metal surfaces which to the engineer appear very little different. Even though the potential differences for cast iron and steel, for example, with clean and rusty surfaces are small, as shown in Table 1-9, under suitable circumstances these small differences can nevertheless give rise to significant direct currents, and hence corrosive attack.

Table 1-9

Standard potentials of different types of iron against hydrogen, in volts

SM steel, clean surface	approx. – 0.40	cast iron, rusty	approx. – 0.30
cast iron, clean surface	approx. – 0.38	SM steel, rusty	approx. – 0.25

1.2.2 Faraday's law

1. The amount m (mass) of the substances deposited or converted at an electrode is proportional to the quantity of electricity $Q = I \cdot t$.
   $m \sim I \cdot t$

2. The amounts m (masses) of the substances converted from different electrolytes by equal quantities of electricity $Q = I \cdot t$ behave as their electrochemical equivalent masses M^*. The equivalent mass M^* is the molar mass M divided by the electrochemical valency n (a number). The quantities M and M^* can be stated in g/mol.

$$m = \frac{M^*}{F} I \cdot t$$

If during electroysis the current I is not constant, the product $I \cdot$ t must be represented by the integral $\int_{t_1}^{t_2} I\,dt$.

The quantity of electricity per mole necessary to deposit or convert the equivalent mass of 1 g/mol of a substance (both by oxidation at the anode and by reduction at the cathode) is equal in magnitude to Faraday's constant (F = 96480 As/mol).

Table 1-10

Electrochemical equivalents[1)]

	Valency n	Equivalent mass[2)] g/mol	Quantity precipitated, theoretical g/Ah	Approximate optimum current efficiency %
Aluminium	3	8.9935	0.33558	85 … 98
Cadmium	2	56.20	2.0970	95 … 95
Caustic potash	1	56.10937	2.0036	95
Caustic soda	1	30.09717	1.49243	95
Chlorine	1	35.453	1.32287	95
Chromium	3	17.332	0.64672	—
Chromium	6	8.666	0.32336	10 … 18
Copper	1	63.54	2.37090	65 … 98
Copper	2	31.77	1.18545	97 … 100
Gold	3	65.6376	2.44884	—
Hydrogen	1	1.00797	0.037610	100
Iron	2	27.9235	1.04190	95 … 100
Iron	3	18.6156	0.69461	—
Lead	2	103.595	3.80543	95 … 100
Magnesium	2	12.156	0.45358	—
Nickel	2	29.355	1.09534	95 … 98
Nickel	3	19.57	0.73022	—
Oxygen	2	7.9997	0.29850	100
Silver	1	107.870	4.02500	98 … 100
Tin	2	59.345	2.21437	70 … 95
Tin	4	29.6725	1.10718	70 … 95
Zinc	2	32.685	1.21959	85 … 93

1) Relative to the carbon-12 isotope = 12.000.

2) Chemical equivalent mass is molar mass/valency in g/mol.

Example:

Copper and iron earthing electrodes connected to each other by way of the neutral conductor form a galvanic cell with a potential difference of about 0.7 V (see Table 1-8). These cells are short-circuited via the neutral conductor. Their internal resistance is determined by the earth resistance of the two earth electrodes. Let us say the sum of all these resistances is 10 Ω. Thus, if the drop in "short-circuit emf" relative to the "open-circuit emf" is estimated to be 50 % approximately, a continuous corrosion current of 35 mA will flow, causing the iron electrode to decompose. In a year this will give an electrolytically active quantity of electricity of

$$35 \text{ mA} \cdot 8760 \frac{\text{h}}{\text{a}} = 306 \frac{\text{Ah}}{\text{a}} .$$

Since the equivalent mass of bivalent iron is 27.93 g/mol, the annual loss of weight from the iron electrode will be

$$m = \frac{27.93 \text{ g/mol}}{96480 \text{ As/mol}} \cdot 306 \text{ Ah/a} \cdot \frac{3600 \text{ s}}{\text{h}} = 320 \text{ g/a}.$$

1.2.3 Thermoelectric series

If two wires of two different metals or semiconductors are joined together at their ends and the two junctions are exposed to different temperatures, a thermoelectric current flows in the wire loop (Seebeck effect, thermocouple). Conversely, a temperature difference between the two junctions occurs if an electric current is passed through the wire loop (Peltier effect).

The thermoelectric voltage is the difference between the values, in millivolts, stated in Table 1-11. These relate to a reference wire of platinum and a temperature difference of 100 K.

Table 1-11

Thermoelectric series, values in mV, for platinum as reference and temperature difference of 100 K

Bismut ll axis	−7.7	Rhodium	0.65
Bismut ⊥ axis	−5.2	Silver	0.67 … 0.79
Constantan	−3.37 … −3.4	Copper	0.72 … 0.77
Cobalt	−1.99 … −1.52	Steel (V2A)	0.77
Nickel	−1.94 … −1.2	Zinc	0.6 … 0.79
Mercury	−0.07 … +0.04	Manganin	0.57 … 0.82
Platinum	± 0	Irdium	0.65 … 0.68
Graphite	0.22	Gold	0.56 … 0.8
Carbon	0.25 … 0.30	Cadmium	0.85 … 0.92
Tantalum	0.34 … 0.51	Molybdenum	1.16 … 1.31
Tin	0.4 … 0.44	Iron	1.87 … 1.89
Lead	0.41 … 0.46	Chrome nickel	2.2
Magnesium	0.4 … 0.43	Antimony	4.7 … 4.86
Aluminium	0.37 … 0.41	Silicon	44.8
Tungsten	0.65 … 0.9	Tellurium	50
Common thermocouples			
Copper/constantan (Cu/const)	up to 500 °C	Nickel chromium/nickel (NiCr/Ni)	up to 1 000 °C
Iron/constantan (Fe/const)	up to 700 °C	Platinum rhodium/ platinum	up to 1 600 °C
Nickel chromium/ constantan	up to 800 °C	Platinum rhodium/ platinum rhodium	up to 1 800 °C

1.2.4 pH value

The pH value is a measure of the “acidity” of aqueous solutions. It is defined as the logarithm to base 10 of the reciprocal of the hydrogen ion concentration CH_3O[1].

$$pH \equiv -\log CH_3O.$$

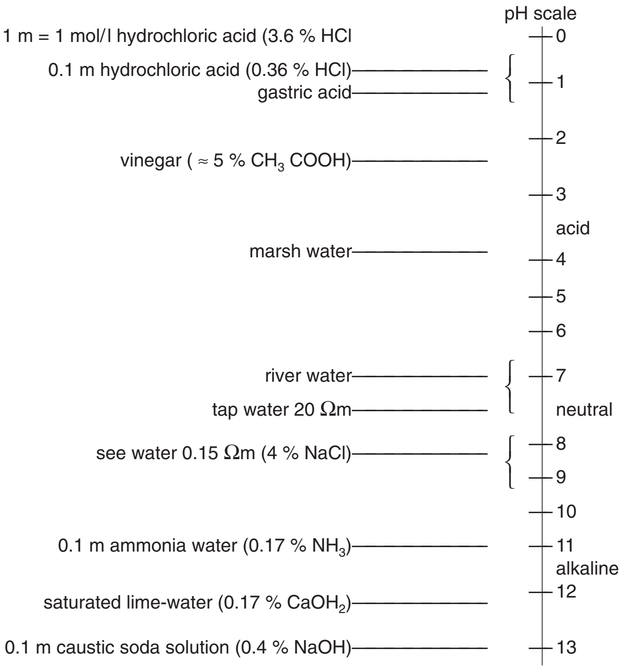


Fig. 1-1

pH value of some solutions

[1] CH_3O = Hydrogen ion concentration in mol/l.

1.2.5 Heat transfer

Heat content (enthalpy) of a body: $Q = V \cdot \rho \cdot c \cdot \Delta\vartheta$
V volume, ρ density, c specific heat, $\Delta\vartheta$ temperature difference

Heat flow is equal to enthalpy per unit time:

$$\Phi = Q/t$$

Heat flow is therefore measured in watts (1 W = 1 J/s).

Specific heat (specific thermal capacity) of a substance is the quantity of heat required to raise the temperature of 1 kg of this substance by 1 °C. Mean specific heat relates to a temperature range, which must be stated. For values of c and λ, see Section 1.2.7.

Thermal conductivity is the quantity of heat flowing per unit time through a wall 1 m^2 in area and 1 m thick when the temperatures of the two surfaces differ by 1 °C. With many materials it increases with rising temperature, with magnetic materials (iron, nickel) it first falls to the Curie point, and only then rises (Curie point = temperature at which a ferro-magnetic material becomes non-magnetic, e. g. about 800 °C for Alnico). With solids, thermal conductivity generally does not vary much (invariable only with pure metals); in the case of liquids and gases, on the other hand, it is often strongly influenced by temperature.

Heat can be transferred from a place of higher temperature to a place of lower temperature by

- conduction (heat transmission between touching particles in solid, liquid or gaseous bodies).
- convection (circulation of warm and cool liquid or gas particles).
- radiation (heat transmission by electromagnetic waves, even if there is no matter between the bodies).

The three forms of heat transfer usually occur together.

Heat flow with conduction through a wall:

$$\Phi = \frac{\lambda}{s} \cdot A \cdot \Delta\vartheta$$

A transfer area, λ thermal conductivity, s wall thickness, $\Delta\vartheta$ temperature difference.

Heat flow in the case of transfer by convection between a solid wall and a flowing medium:

$$\Phi = \alpha \cdot A \cdot \Delta\vartheta$$

α heat transfer coefficient, A transfer area, $\Delta\vartheta$ temperature difference.

Heat flow between two flowing media of constant temperature separated by a solid wall:

$$\Phi = k \cdot A \cdot \Delta\vartheta$$

k thermal conductance, A transfer area, $\Delta\vartheta$ temperature difference.

In the case of plane layered walls perpendicular to the heat flow, the thermal conductance coefficient k is obtained from the equation

$$\frac{1}{k} = \frac{1}{\alpha_1} + \sum \frac{s_n}{\lambda_n} + \frac{1}{\alpha_2}$$

Here, α_1 and α_2 are the heat transfer coefficients at either side of a wall consisting of n layers of thicknesses s_n and thermal conductivities λ_n.

For two parallel black surfaces of equal size the heat flow exchanged by radiation is

$$\Phi_{12} = \sigma \cdot A(T_1^4 - T_2^4)$$

With grey radiating surfaces having emissivities of ε_1 and ε_2, it is

$$\Phi_{12} = C_{12} \cdot A\,(T_1^4 - T_2^4)$$

$\sigma = 5.6697 \cdot 10^{-8}\ \mathrm{W \cdot m^{-2} \cdot K^{-4}}$ radiation coefficient of a black body (Stefan Boltzmann's constant), A radiating area, T absolute temperature.

Index 1 refers to the radiating surface, Index 2 to the radiated surface.

C_{12} is the effective radiation transfer coefficient. It is determined by the geometry and emissivity ε of the surface.

Special cases: $A_1 \ll A_2$ $\qquad C_{12} = \sigma \cdot \varepsilon_1$

$A_1 \approx A_2$ $\qquad C_{12} = \dfrac{\sigma}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$

A_2 includes A_1 $\qquad C_{12} = \dfrac{\sigma}{\dfrac{1}{\varepsilon_1} + \dfrac{A_1}{A_2} \cdot \left(\dfrac{1}{\varepsilon_2} - 1\right)}$

Table 1-12

Emissivity ε (average values ϑ < 200 °C)

Black body	1	Oil	0.82
Aluminium, bright	0.04	Paper	0.85
Aluminium, oxidized	0.5	Porcelain, glazed	0.92
Copper, bright	0.05	Ice	0.96
Copper, oxidized	0.6	Wood (beech)	0.92
Brass, bright	0.05	Roofing felt	0.93
Brass, dull	0.22	Paints	0.8-0.95
Steel, dull, oxidized	0.8	Red lead oxide	0.9
Steel, polished	0.06	Soot	0.94

Table 1-13

Heat transfer coefficients α in W/(m^2 · K) (average values)		
Natural air movement in a closed space		
Wall surfaces		10
Floors, ceilings:	in upward direction	7
	in downward direction	5
Force-circulated air		
Mean air velocity w = 2 m/s		20
Mean air velocity w > 5 m/s		$6.4 \cdot w^{0.75}$

1.2.6 Acoustics, noise measurement, noise abatement

Perceived sound comprises the mechanical oscillations and waves of an elastic medium in the frequency range of the human ear of between 16 Hz and 20 000 Hz. Oscillations below 16 Hz are termed infrasound and above 20 000 Hz ultrasound. Sound waves can occur not only in air but also in liquids (water-borne sound) and in solid bodies (solid-borne sound). Solid-borne sound is partly converted into audible air-borne sound at the bounding surfaces of the oscillating body. The frequency of oscillation determines the pitch of the sound. The sound generally propagates spherically from the sound source, as longitudinal waves in gases and liquids and as longitudinal and transverse waves in solids.

Sound propagation gives rise to an alternating pressure, the root-mean-square value of which is termed the sound pressure p. It decreases approximately as the square of the distance from the sound source. The sound power P is the sound energy flowing through an area in unit time. Its unit of measurement is the watt.

Since the sensitivity of the human ear is proportional to the logarithm of the sound pressure, a logarithmic scale is used to represent the sound pressure level as loudness.

The *sound pressure level* L is measured with a sound level metre as the logarithm of the ratio of sound pressure to the reference pressure p_o, see DIN 35 632

$$L = 20 \lg \frac{p}{p_o} \text{ in dB.}$$

Here: p_o reference pressure, roughly the audible threshold at 1000 Hz.

$p_o = 2 \cdot 10^{-5}$ N/m^2 $= 2 \cdot 10^{-4}$ µbar

p = the root-mean-square sound pressure

Example:

$p = 2 \cdot 10^{-3}$ N/m^2 measured with a sound level metre, then

$$\text{sound level } L = 20 \lg \frac{2 \cdot 10^{-3}}{2 \cdot 10^{-5}} = 40 \text{ dB.}$$

The *loudness* of a sound can be measured as DIN loudness (DIN 5045) or as the weighted sound pressure level. DIN loudness (λ DIN) is expressed in units of DIN phon.

The weighted sound pressure levels L_A, L_B, L_C, which are obtained by switching in defined weighting networks A, B, C in the sound level metre, are stated in the unit dB (decibel). The letters A, B and C must be added to the units in order to distinguish the different values, e. g. dB (A). According to an ISO proposal, the weighted sound pressure L_A in dB (A) is recommended for expressing the loudness of machinery noise. DIN loudness and the weighted sound pressure level, e.g. as recommended in IEC publication 123, are related as follows: for all numerical values above 60 the DIN loudness in DIN phon corresponds to the sound pressure level LB in dB (B), for all numerical values between 30 and 60 to the sound pressure level LA in dB (A). All noise level values are referred to a sound pressure of $2 \cdot 10^{-5}$ N/m^2.

According to VDI guideline 2058, the acceptable loudness of noises must on average not exceed the following values at the point of origin:

Area	Daytime (6–22 hrs) dB (A)	Night-time (22–6 hrs) dB (A)
Industrial	70	70
Commercial	65	50
Composite	60	45
Generally residential	55	40
Purely residential	50	35
Therapy (hospitals, etc.)	45	35

Short-lived, isolated noise peaks can be disregarded.

Disturbing noise is propagated as air- and solid-borne sound. When these sound waves strike a wall, some is thrown back by reflection and some is absorbed by the wall. Air-borne noise striking a wall causes it to vibrate and so the sound is transmitted into the adjacent space. Solid-borne sound is converted into audible air-borne sound by radiation from the bounding surfaces. Ducts, air-shafts, piping systems and the like can transmit sound waves to other rooms. Special attention must therefore be paid to this at the design stage.

There is a logarithmic relationship between the sound pressure of several sound sources and their total loudness.

Total loudness of several sound sources:

A doubling of equally loud sound sources raises the sound level by 3 dB (example: 3 sound sources of 85 dB produce 88 dB together). Several sound sources of different loudness produce together roughly the loudness of the loudest sound source. (Example: 2 sound sources of 80 and 86 dB have a total loudness of 87 dB). In consequence: with 2 equally loud sound sources attenuate both of them, with sound sources of different loudness attentuate only the louder.

An increase in level of 10 dB signifies a doubling, a reduction of 10 dB a halving of the perceived loudness.

In general, noises must be kept as low as possible at their point of origin. This can often be achieved by enclosing the noise sources.

Sound can be reduced by natural means. The most commonly used sound-absorbent materials are porous substances, plastics, cork, glass fibre and mineral wool, etc. The main aim should be to reduce the higher-frequency noise components. This is also generally easier to achieve than eliminating the lower-frequency noise.

When testing walls and ceilings for their behaviour regarding air-borne sound, one determines the difference "D" in sound level "L" for the frequency range from 100 Hz to 3200 Hz.

$$D = L1 - L2 \text{ in dB where } L = 20 \lg \frac{p}{p_o} \text{ dB}$$

L_1 = sound level in room containing sound source

L_2 = sound level in room receiving the sound

Table 1-14

Attenuation figures for some building materials in the range 100 to 3200 Hz

Structural component	Attenuation dB	Structural component	Attenuation dB
Brickwork rendered, 12 cm thick	45	Single door without extra sealing	to 20
Brickwork rendered, 25 cm thick	50	Single door with good seal	30
Concrete wall, 10 cm thick	42	Double door without seal	30
Concrete wall, 20 cm thick	48	Double door with extra sealing	40
Wood wool mat, 8 cm thick	50	Single window without sealing	15
Straw mat, 5 cm thick	38	Spaced double window with seal	30

The reduction in level ΔL obtainable in a room by means of sound-absorbing materials or structures is:

$$\Delta L = 10 \lg \frac{A_2}{A_1} = 10 \lg \frac{T_1}{T_2} \text{ dB}$$

In the formula:

$$A = 0.163 \frac{V}{T} \text{ in } m^2$$

V = volume of room in m^3

T = reverberation time in s in which the sound level L falls by 60 dB after sound emission ceases.

Index 1 relates to the state of the untreated room, Index 2 to a room treated with noise-reduction measures.

1.2.7 Technical values of solids, liquids and gases

Table 1-15

Technical values of solids

Material	Density ρ kg/dm³	Melting or freezing point °C	Boiling point °C	Linear thermal expansion α mm/K x 10^{-6} 1)	Thermal conductivity λ at 20 °C W/(m · K)	Mean spec. heat c at 0 . . 100 °C J/(kg · K)	Specific electrical resistance ρ at 20 °C Ω mm²/m	Temperature coefficient α of electrical resistance at 20 °C 1/K
E-aluminium F9	2.70	658	2270	23.8	220	920	0.02874	0.0042
Alu alloy AlMgSi 1 F20	2.70	≈ 645		23	190	920	0.0407	0.0036
Lead	11.34	327	1 730	28	34	130	0.21	0.0043
Bronze CuSnPb	8.6 . . 9	≈ 900		≈ 17.5	42	360	≈ 0.027	0.004
Cadmium	8.64	321	767	31.6	92	234	0.762	0.0042
Chromium	6.92	1 800	2 400	8.5		452	0.028	
Iron, pure	7.88	1 530	2 500	12.3	71	464	0.10	0.0058
Iron, steel	≈ 7.8	≈ 1 350		≈ 11.5	46	485	0.25 . . 0.10	≈ 0.005
Iron, cast	≈ 7.25	≈ 1 200		≈ 11	46	540	0.6 . . 1	0.0045
Gold	19.29	1 063	2 700	14.2	309	130	0.022	0 0038
Constantan Cu + Ni	8 . . 8.9	1 600		16.8	22	410	0.48 . . 0.50	≈ 0.00005
Carbon diamond	3.51	≈ 3 600	4 200	1.3		502		
Carbon graphite	2.25			7.86	5	711		
E-copper F30	8.92	1 083	2 330	16.5	385	393	0.01786	0.00392
E-copper F20	8.92	1 083	2 330	16.5	385	393	0.01754	0.00392
Magnesium	1.74	650	1110	25.0	167	1034	0.0455	0.004

1) between 0 °C and 100 °C

(continued)

Table 1-15 (continued)

Technical values of solids

Material	Density ρ kg/dm^3	Melting or freezing point °C	Boiling point °C	Linear thermal expansion α mm/K x 10^{-6} [1]	Thermal conductivity λ at 20 °C W/(m · K)	Mean spec. heat c at 0 . . 100 °C J/(kg · K)	Specific electrical resistance ρ at 20 °C Ω mm^2/m	Temperature coefficient α of electrical resistance at 20 °C 1/K
Brass (Ms 58)	8.5	912		17	110	397	≈ 0.0555	0.0024
Nickel	8.9	1 455	3 000	13	83	452	≈ 0.12	0.0046
Platinum	21.45	1 773	3 800	8.99	71	134	≈ 0.11	0.0039
Mercury	13.546	38.83	357	61	8.3	139	0.698	0.0008
Sulphur (rhombic)	2.07	113	445	90	0.2	720		
Selenium (metallic)	4.26	220	688	66		351		
Silver	10.50	960	1 950	19.5	421	233	0.0165	0.0036
Tungsten	19.3	3 380	6 000	4.50	167	134	0.06	0.0046
Zinc	7.23	419	907	16.50	121	387	0.0645	0.0037
Tin	7.28	232	2 300	26.7	67	230	0.119	0.004

[1] between 0 °C and 100 °C

Table 1-16

Technical values of liquids

Material	Chemical formula	Density ρ kg/dm³	Melting or freezing point °C	Boiling point at 760 Torr °C	Expansion coefficient x 10^{-3} at 18 °C	Thermal conductivity λ at 20 °C W/(m · K)	Specific heat c_p at 0 °C J/(kg · K)	Relative dielectric constant ε_r at 180 °C
Acetone	C_3H_6O	0.791	— 95	56.3	1.43		2 160	21.5
Ethyl alcohol	C_2H_6O	0.789	—114	78.0	1.10	0.2	2 554	25.8
Ethyl ether	$C_4H_{10}O$	0.713	—124	35.0	1.62	0.14	2 328	4.3
Ammonia	NH_3	0.771	— 77.8	— 33.5		0.022	4 187	14.9
Aniline	C_6H_7N	1.022	— 6.2	184.4	0.84		2 064	7.0
Benzole	C_6H_6	0.879	+ 5.5	80.1	1.16	0.14	1 758	2.24
Acetic acid	$C_2H_4O_2$	1.049	+ 16.65	117.8	1.07		2 030	6.29
Glycerine	$C_3H_8O_3$	1.26	— 20	290	0.50	0.29	2 428	56.2
Linseed oil		0.94	— 20	316		0.15		2.2
Methyl alcohol	CH_4O	0.793	— 97.1	64.7	1.19	0.21	2 595	31.2
Petroleum		0.80			0.99	0.16	2 093	2.1
Castor oil		0.97			0.69		1 926	4.6
Sulphuric acid	H_2SO_4	1.834	— 10.5	338	0.57	0.46	1 385	> 84
Turpentine	$C_{10}H_{16}$	0.855	— 10	161	9.7	0.1	1 800	2.3
Water	H_2O	1.00[1]	0	106	0.18	0.58	4 187	88

[1] at 4 °C

Table 1- 17

Technical values of gases

Material	Chemical formula	Density ρ[1] kg/m³	Melting point °C	Boiling point °C	Thermal conductivity λ 10^{-2} W/(m · K)	Specific heat c_p at 0 °C J/(kg · K)	Relative[1] dielectric constant ε_r
Ammonia	NH_3	0.771	— 77.7	— 33.4	2.17	2 060	1.0072
Ethylene	C_2H_4	1.260	— 169.4	— 103.5	1.67	1 611	1.001456
Argon	Ar	1.784	— 189.3	— 185.9	1.75	523	1.00056
Acetylene	C_2H_2	1.171	— 81	— 83.6	1.84	1 511	
Butane	C_4H_{10}	2.703	— 135	— 0.5	0.15		
Chlorine	Cl_2	3.220	— 109	— 35.0	0.08	502	1.97
Helium	He	0.178	— 272	— 268.9	1.51	5 233	1.000074
Carbon monoxide	CO	1.250	— 205	— 191.5	0.22	1 042	1.0007
Carbon dioxide	CO_2	1.977	— 56	— 78.5	1.42	819	1.00095
Krypton	Kr	3.743	— 157.2	— 153.2	0.88		
Air	CO_2 free	1.293		— 194.0	2.41	1 004	1.000576
Methane	CH_4	0.717	— 182.5	— 161.7	3.3	2 160	1.000953
Neon	Ne	0.8999	— 248.6	— 246.1	4.6		
Ozone	O_3	2.22	— 252	— 112			
Propane	C_2H_8	2.019	— 189.9	— 42.6			
Oxygen	O_2	1.429	— 218.83	— 192.97	2.46	1 038	1.000547
Sulphur hexafluoride	SF_6	6.07[2]	— 50.8[3]	— 63	1.28[2]	670	1.0021[2]
Nitrogen	N_2	1.250	— 210	— 195.81	2.38	1042	1.000606
Hydrogen	H_2	0.0898	— 259.2	— 252.78	17.54	14 235	1.000264

1) at 0 °C and 1013 mbar
2) at 20 °C and 1013 mbar
3) at 2.26 bar

1.3 Strength of materials

1.3.1 Fundamentals and definitions

External forces F acting on a cross-section A of a structural element can give rise to tensile stresses (σ_z), compressive stresses (σ_d), bending stresses (σ_b), shear stresses (τ_s) or torsional stresses (τ_t). If a number of stresses are applied simultaneously to a component, i. e. compound stresses, this component must be designed according to the formulae for compound strength. In this case the following rule must be observed:

Normal stresses σ_z. σ_d. σ_b,
Tangential stresses (shear and torsional stresses) τ_s, τ_t.

are to be added arithmetically;

Normal stresses σ_b with shear stresses τ_s,
Normal stresses σ_b with torsional stresses τ_t,

are to be added geometrically.

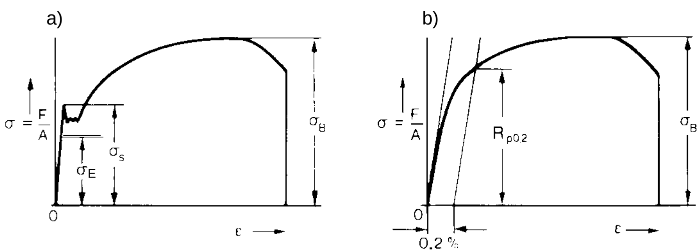


Fig. 1-2

Stress-strain diagram, a) Tensile test with pronounced yield point, material = structural steel; b) Tensile test without pronounced yield point, material = Cu/Al, ε Elongation, σ Tensile stress, σ_s Stress at yield point, σ_E Stress at proportionality limit, R_{p02} Stress with permanent elongation less than 0.2 %, σ_B Breaking stress.

Elongation $\varepsilon = \Delta\, l/l_0$ (or compression in the case of the compression test) is found from the measured length l_0 of a bar test specimen and its change in length $\Delta\, l = l - l_0$ in relation to the tensile stress σ_z, applied by an external force F. With stresses below the proportionality limit σ_E elongation increases in direct proportion to the stress σ (Hooke's law).

The ratio $\dfrac{\text{Stress } \sigma}{\text{Elongation } \varepsilon} = \dfrac{\sigma_E}{\varepsilon_E} = E$ is termed the elasticity modulus.

E is an imagined stress serving as a measure of the resistance of a material to deformation due to tensile or compressive stresses; it is valid only for the elastic region.

According to DIN 1602/2 and DIN 50143, *E* is determined in terms of the load $\sigma_{0.01}$, i.e. the stress at which the permanent elongation is 0.01 % of the measured length of the test specimen.

If the stresses exceed the yield point σ_s, materials such as steel undergo permanent elongation. The ultimate strength, or breaking stress, is denoted by σ_B, although a bar does not break until the stress is again being reduced. Breaking stress σ_B is related to the elongation on fracture δ of a test bar. Materials having no marked proportional limit or elastic limit, such as copper and aluminium, are defined in terms of the so-called $R_{p0.2}$-limit, which is that stress at which the permanent elongation is 0.2 % after the external force has been withdrawn, cf. DIN 50144.

For reasons of safety, the maximum permissible stresses, σ_{max} or τ_{max} in the material must be below the proportional limit so that no permanent deformation, such as elongation or deflection, persists in the structural component after the external force ceases to be applied.

Table 1-18

Material	Elasticity modulus *E* N/mm² [1)]
Structural steel in general, spring steel (unhardened), cast steel	210 000
Grey cast iron	100 000
Electro copper, Al bronze with 5 % Al, rolled	110 000
Red brass	90 000
E-AlMgSi 0.5	75 000
E-Al	65 000
Magnesium alloy	45 000
Wood	10 000

[1)] Typical values.

Fatigue strength (endurance limit) is present when the maximum variation of a stress oscillating about a mean stress is applied “infinitely often” to a loaded material (at least 10^7 load reversals in the case of steel) without giving rise to excessive deformation or fracture.

Cyclic stresses can occur in the form of a stress varying between positive and negative values of equal amplitude, or as a stress varying between zero and a certain maximum value. Cyclic loading of the latter kind can occur only in compression or only in tension.

Depending on the manner of loading, fatigue strength can be considered as bending fatigue strength, tension-compression fatigue strength or torsional fatigue strength. Structural elements which have to withstand only a limited number of load reversals can be subjected to correspondingly higher loads. The resulting stress is termed the fatigue limit.

One speaks of creep strength when a steady load with uniform stress is applied, usually at elevated temperatures.

1.3.2 Tensile and compressive strength

If the line of application of a force *F* coincides with the centroidal axis of a prismatic bar of cross section *A* (Fig.1-3), the normal stress uniformly distributed over the cross-section area and acting perpendicular to it is

$$\sigma = \frac{F}{A}\ .$$

With the maximum permissible stress σ_{max} for a given material and a given loading, the required cross section or the maximum permissible force, is therefore:

$$A = \frac{F}{\sigma_{max}} \text{ or } F = \sigma_{max} \cdot A.$$

Example:

A drawbar is to be stressed with a steady load of $F = 180\,000$ N.

The chosen material is structural steel St 37 with $\sigma_{max} = 120$ N/mm².

Required cross section of bar:

$$A = \frac{E}{\sigma_{max}} = \frac{180\,000\ N}{120\ N/mm^2} = 1500\ mm^2.$$

Round bar of d = 45 mm *chosen.*

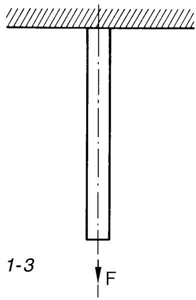


Fig. 1-3

1.3.3 Bending strength

The greatest bending action of an external force, or its greatest bending moment *M,* occurs at the point of fixing *a* in the case of a simple cantilever, and at point *c* in the case of a centrally loaded beam on two supports.

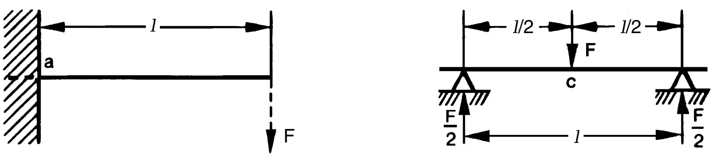


Fig. 1-4

Maximum bending moment at a: M = Fl; at c: M = Fl/4

In position *a* and *c*, assuming the beams to be of constant cross section, the bending stresses σ_b are greatest in the filaments furthermost from the neutral axis. *M* may be greater, the greater is σ_{max} and the "more resistant" is the cross-section. The following cross sections have moments of resistance *W* in cm, if *a, b, h* and *d* are stated in cm.

The maximum permissible bending moment is $M = W \cdot \sigma_{max}$ and the required moment of resistance

$$W = \frac{M}{\sigma_{max}}.$$

Example:

A mild-steel stud $\left(\sigma_{max} = 70 \text{ N/mm}^2\right)$ with an unsupported length of $l = 60$ mm is to be loaded in the middle with a force $F = 30\,000$ N. Required moment of resistance is:

$$W = \frac{M}{\sigma_{max}} = \frac{F \cdot l}{4 \cdot \sigma_{max}} = \frac{30\,000 \text{ N} \cdot 60 \text{ mm}}{4 \cdot 70 \text{ N/mm}^2} = 6.4 \cdot 10^3 \text{ mm}^3.$$

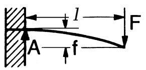
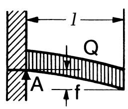
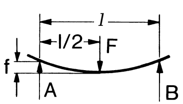
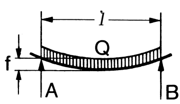
According to Table 1-22, the moment of resistance W with bending is $W \approx 0.1 \cdot d^3$.

The diameter of the stud will be: $d = \sqrt[3]{10\,W}$, $\quad d = \sqrt[3]{64\,000} = \sqrt[3]{64} \cdot 10 = 40$ mm.

1.3.4 Loadings on beams

Table 1-19

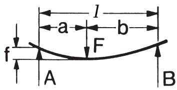
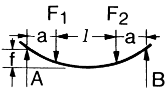
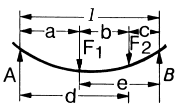
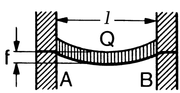
Bending load

Case	Reaction force Bending moment	Required moment of resistance, max. permissible load	Deflection
	$A = F$ $M_{max} = F\,l$	$W = \dfrac{F\,l}{\sigma_{max}}$ $F = \dfrac{\sigma_{max}\,W}{l}$	$f = \dfrac{F\,l^3}{3\,E\,J}$
	$A = Q$ $M_{max} = \dfrac{Q\,l}{2}$	$W = \dfrac{Q\,l}{2\,\sigma_{max}}$ $Q = \dfrac{2\,\sigma_{max}\,W}{l}$	$f = \dfrac{Q\,l^3}{8\,E\,J}$
	$A = B = \dfrac{F}{2}$ $M_{max} = \dfrac{F\,l}{4}$	$W = \dfrac{F\,l}{4\,\sigma_{max}}$ $F = \dfrac{4\,\sigma_{max}\,W}{l}$	$f = \dfrac{F\,l^3}{48\,E\,J}$
	$A = B = \dfrac{Q}{2}$ $M_{max} = \dfrac{Q\,l}{8}$	$W = \dfrac{Q\,l}{8\,\sigma_{max}}$ $Q = \dfrac{8\,\sigma_{max}\,W}{l}$	$f = \dfrac{5}{384} \cdot \dfrac{Q\,l^3}{E\,J}$

(continued)

Table 1-19 (continued)

Bending load

Case	Reaction force Bending moment	Required moment of resistance, max. permissible load	Deflection
	$A = \frac{F\,b}{l}$ $B = \frac{F\,a}{l}$ $M_{max} = A\,a = B\,b$	$W = \frac{F\,a\,b}{l\,\sigma_{max}}$ $F = \frac{\sigma_{max}\,W\,l}{a\,b}$	$f = \frac{F\,a^2\,b^2}{3\,E\,J\,l}$
	for $F_1 = F_2 = F$ [1)] $A = B = F$ $M_{max} = F\,a$	$W = \frac{F\,a}{\sigma_{max}}$ $F = \frac{\sigma_{max}\,W}{a}$	$f = \frac{F\,a}{24\,E\,J}$ $[3\,(l + 2\,a)^2 - 4\,a^2]$
	$A = \frac{F_1\,e + F_2\,c}{l}$ $B = \frac{F_1\,a + F_2\,d}{l}$	$W_1 = \frac{A\,a}{\sigma_{max}}$ $W_2 = \frac{B\,c}{\sigma_{max}}$ Determine beam for greatest *"W"*	$f = \frac{F_1\,a^2\,e^2 + F_2 l^2\,d^2}{3\,E\,J\,l}$
	$A = B = \frac{Q}{l}$ $M_{max} = \frac{Q\,l}{12}$	$W = \frac{Q\,l}{12\,\sigma_{zul}}$ $Q = \frac{12\,\sigma_{zul}\,W}{l}$	$f = \frac{Q}{E\,J} \cdot \frac{l^3}{384}$

A and *B* = Section at risk.

F = Single point load, *Q* = Uniformly distributed load.

1) If F_1 und F_2 are not equal, calculate with the third diagram.

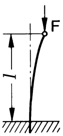
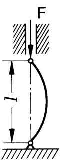
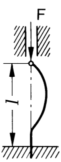
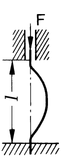
1.3.5 Buckling strength

Thin bars loaded in compression are liable to buckle. Such bars must be checked both for compression and for buckling strength, cf. DIN 4114.

Buckling strength is calculated with Euler's formula, a distinction being drawn between four cases.

Table 1-20

Buckling

	Case I One end fixed, other end free	$F = \frac{10\,E\,J}{4\,s\,l^2}$ $J = \frac{4\,s\,F\,l^2}{10\,E}$
	Case II Both ends free to move along bar axis	$F = \frac{10\,E\,J}{s\,l^2}$ $J = \frac{s\,F\,l^2}{10\,E}$
	Case III One end fixed, other end free to move along bar axis	$F = \frac{20\,E\,J}{s\,l^2}$ $J = \frac{s\,F\,l^2}{20\,E}$
	Case IV Both ends fixed, movement along bar axis	$F = \frac{40\,E\,J}{s\,l^2}$ $J = \frac{s\,F\,l^2}{40\,E}$

E = Elasticity modulus of material
J = Minimum axial moment of inertia
F = Maximum permissible force
l = Length of bar

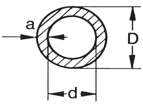
s = Factor of safety:
for cast iron = 8,
for mild carbon steel = 5,
for wood = 10.

1.3.6 Maximum permissible buckling and tensile stress for tubular rods

Threaded steel tube (gas pipe) DIN 2440, Table 1[1)]
or seamless steel tube DIN 2448[2)].

$$F_{buck} = \frac{10\,E}{s\,l^2} \cdot J = \frac{10\,E}{s\,l^2} \cdot \frac{D^4 - d^4}{20} \quad \text{where } J \approx \frac{D^4 - d^4}{20} \text{ from Table 1-22}$$

$$F_{ten} = A \cdot \sigma_{max}$$



in which
F Force
E Elasticity modulus = 210 000 N/mm²
J Moment of inertia in cm⁴
s Factor of safety = 5
σ_{max} Max. permissible stress
A Cross-section area
D Outside diameter
d Inside diameter
l Length

Fig. 1-5

Table 1-21

Nominal diameter	Dimensions D inch	D mm	a mm	Cross-sections A mm²	Moment of inertia J cm⁴	Weight of tube kg/m	F_{buck} for tube length $l \approx$ 0.5 m N	1 m N	1.5 m N	2 m N	2.5 m N	3 m N	F_{ten} N
10	⅜	17.2	2.35	109.6	0.32	0.85	5400	1350	600	340	220	150	6600
15	½	21.3	2.65	155.3	0.70	1.22	11800	2950	1310	740	470	330	9300
20	¾	26.9	2.65	201.9	1.53	1.58	25700	6420	2850	1610	1030	710	12100
25	1	33.7	3.25	310.9	3.71	2.44	62300	15600	6920	3900	2490	1730	18650
	0.8	25	2	144.5	0.98	1.13	16500	4100	1830	1030	660	460	17350
	0.104	31.8	2.6	238.5	2.61	1.88	43900	11000	4880	2740	1760	1220	28600

1) No test values specified for steel ST 00.
2) σ_{max} = 350 N/mm² for steel ST 35 DIN 1629 seamless steel tube, cf. max. permissible buckling stress for structural steel, DIN 1050 Table 3.

1.3.7 Shear strength[1)]

Two equal and opposite forces F acting perpendicular to the axis of a bar stress this section of the bar in shear. The stress is

$$\tau_s = \frac{F}{A} \text{ or for given values of } F \text{ and } \tau_{s\,max}\text{, the required cross section is}$$

$$A = \frac{F}{\tau_{s\,max}}$$

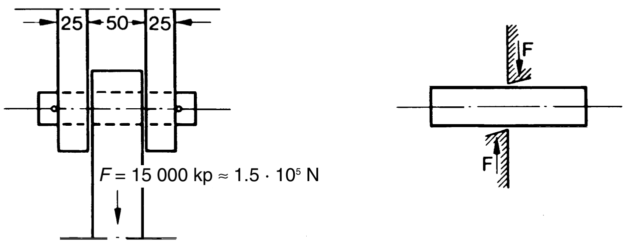


Fig. 1-6

Pull-rod coupling

Stresses in shear are always combined with a bending stress, and therefore the bending stress σ_b has to be calculated subsequently in accordance with the following example.

Rivets, short bolts and the like need only be calculated for shear stress.

Example:

Calculate the cross section of a shackle pin of structural steel ST 50-1[2)], with $R_{p\,0.2\,min}$ = 300 N/mm² and $\tau_{s\,max}$ = 0.8 $R_{p\,0.2\,min}$, for the pull-rod coupling shown in Fig. 1-6.

1. Calculation for shear force:

$$A = \frac{F}{2\,\tau_{s\,max}} = \frac{150\,000\text{ N}}{2 \cdot (0.8 \cdot 300)\text{ N/mm}^2} = 312\text{ mm}^2$$

yields a pin diameter of $d \approx$ 20 mm, with W = $0.8 \cdot 10^3$ mm³ (from $W \approx 0.1 \cdot d^3$, see Table 1-22).

1) For maximum permissible stresses on steel structural components of transmission towers and structures for outdoor switchgear installations, see VDE 0210.

2) Yield point of steel ST 50-1 $\sigma_{0.2\,min}$ = 300 N/mm², DIN 17100 Table 1 (Fe 50-1).

2. Verification of bending stress:

The bending moment for the pin if $F\,l/4$ with a singlepoint load, and $F\,l/8$ for a uniformly distributed load. The average value is

$$M_b = \frac{\frac{F\,l}{4} + \frac{F\,l}{8}}{2} = \frac{3}{16}\,F\,l$$

when F $= 1.5 \cdot 10^5$ N, $l = 75$ mm becomes:

$$M_b = \frac{3}{16} \cdot 1.5 \cdot 10^5 \text{ N} \cdot 75 \text{ mm} \approx 21 \cdot 10^5 \text{ N} \cdot \text{mm};$$

$$\sigma_B = \frac{M_b}{W} = \frac{21 \cdot 10^5 \text{ N} \cdot \text{mm}}{0.8 \cdot 10^3 \text{ mm}^3} \approx 262 \cdot 10^3 \frac{\text{N}}{\text{mm}^2} = 2.6 \cdot 10^5 \frac{\text{N}}{\text{mm}^2}$$

i. e. a pin calculated in terms of shear with $d = 20$ mm will be too weak. The required pin diameter d calculated in terms of bending is

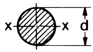
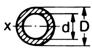
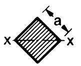
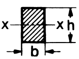
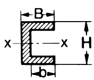
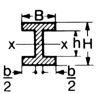
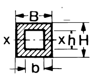
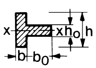
$$W = \frac{M_b}{\sigma_{max}} = \frac{21 \cdot 10^5 \text{ N} \cdot \text{mm}}{300 \text{ N/mm}^2} = 7 \cdot 10^3 \text{ mm}^2 = 0.7 \text{ cm}^3$$

$$d \approx \sqrt[3]{10 \cdot W} = \sqrt[3]{10 \cdot 7 \cdot 10^3 \text{ mm}^3} = \sqrt[3]{70} = 41.4 \text{ mm} \approx 42 \text{ mm}.$$

i. e. in view of the bending stress, the pin must have a diameter of 42 mm instead of 20 mm.

1.3.8 Moments of resistance and moments of inertia

Table 1-22

Cross-section	Moment of resistance torsion W[4)] cm³	bending[1)] W[4)] cm³	Moment of inertia polar[1)] J_p cm⁴	axial[2)] J cm⁴
	$0.196\, d^3$ $\approx 0.2\, d^3$	$0.098\, d^3$ $\approx 0.1\, d^3$	$0.098\, d^4$ $\approx 0.1\, d^4$	$0.049\, d^4$ $\approx 0.05\, d^4$
	$0.196\ \dfrac{D^4 - d^4}{D}$	$0.098\ \dfrac{D^4 - d^4}{D}$	$0.098\,(D^4 - d^4)$	$0.049\,(D^4 - d^4) \approx \dfrac{D^4 - d^4}{20}$
	$0.208\, a^3$	$0.018\, a^3$	$0.167\, a^4$	$0.083\, a^4$
	$0.208\, k\, b^2\, h$ [3)]	$\dfrac{b\, h^2}{6} = 0.167\, b\, h^2$	$\dfrac{b\, h}{12}\,(b^2 + h^2)$	$\dfrac{b\, h^3}{12} = 0.083\, b\, h^3$
		$\dfrac{B\, H^3 - b\, h^3}{6\, H}$		$\dfrac{B\, H^3 - b\, h^3}{12}$
		$\dfrac{B\, H^3 - b\, h^3}{6\, H}$		$\dfrac{B\, H^3 - b\, h^3}{12}$
		$\dfrac{B\, H^3 - b\, h^3}{6\, H}$		$\dfrac{B\, H^3 - b\, h^3}{12}$
		$\dfrac{b\, h^3 + b_o\, h_o^3}{6\, h}$		$\dfrac{b\, h^3 + b_o\, h_o^3}{12}$

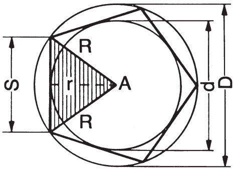
1) Referred to CG of area.
2) Referred to plotted axis.
3) Values for *k:*

if $h : b$ =	1	1.5	2	3	4
then k =	1	1.11	1.18	1.27	1.36

4) Symbol Z is also applicable, see DIN VDE 0103

1.4 Geometry, calculation of areas and solid bodies

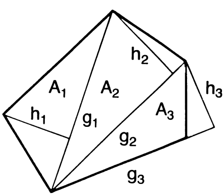
1.4.1 Area of polygons



Regular polygons (n angles)
The area A, length of sides S and radii of the outer and inner circles can be taken from Table 1-23 below.

Table 1-23

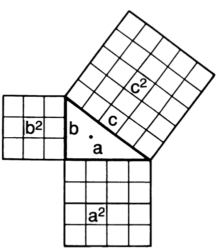
Number of sides	Area A			Side S		Outer radius		Inner radius	
						R		r	
n	$S^2 \times$	$R^2 \times$	$r^2 \times$	$R \times$	$r \times$	$S \times$	$r \times$	$R \times$	$S \times$
3	0.4330	1.2990	5.1962	1.7321	3.4641	0.5774	2.0000	0.5000	0.2887
4	1.0000	2.0000	4.0000	1.4142	2.0000	0.7071	1.4142	0.7071	0.5000
5	1.7205	2.3776	3.6327	1.1756	1.4531	0.8507	1.2361	0.8090	0.6882
6	2.5981	2.5981	3.4641	1.0000	1.1547	1.0000	1.1547	0.8660	0.8660
8	4.8284	2.8284	3.3137	0.7654	0.8284	1.3066	1.0824	0.9239	1.2071
10	7.6942	2.9389	3.2492	0.6180	0.6498	1.6180	1.0515	0.9511	1.5388
12	11.196	3.0000	3.2154	0.5176	0.5359	1.9319	1.0353	0.9659	1.8660



Irregular polygons

$$A = \frac{g_1\,h_1}{2} + \frac{g_2\,h_2}{2} + \ldots$$

$$= \frac{1}{2}\,(g_1\,h_1 + g_2\,h_2 + \ldots)$$

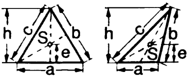
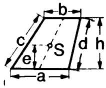
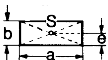
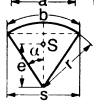
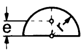
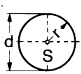
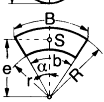
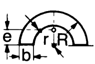
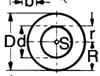
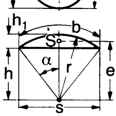
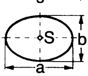


Pythagoras theorem

$$c^2 = a^2 + b^2; \qquad c = \sqrt{a^2 + b^2}$$
$$a^2 = c^2 - b^2; \qquad a = \sqrt{c^2 - b^2}$$
$$b^2 = c^2 - a^2; \qquad b = \sqrt{c^2 - a^2}$$

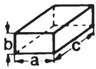
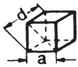
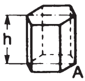
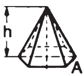
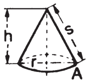
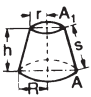
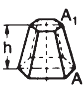
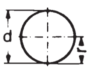
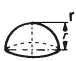
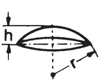
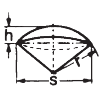
1.4.2 Areas and centres of gravity

Table 1-24

Shape of surface		A = area	U = perimeter S = centre of gravity (cg) e = distance of cg
Triangle		$A = \frac{1}{2}\, a\, h$	$U = a + b + c$ $e = \frac{1}{3}\, h$
Trapezium		$A = \frac{a + b}{2} \cdot h$	$U = a + b + c + d$ $e = \frac{h}{3} \cdot \frac{a + 2\,b}{a + b}$
Rectangle		$A = a\, b$	$U = 2\,(a + b)$
Circle segment		$A = \frac{b\, r}{2} = \frac{\alpha^0}{180}\, r\, \pi$ $b = r\, \pi\, \frac{\alpha^0}{180}$	$U = 2\, r + b$ $e = \frac{2}{3}\, r \frac{\sin \alpha}{\alpha^0} \cdot \frac{180}{\pi}$
Semicircle		$A = \frac{1}{2}\, \pi\, r^2$	$U = r\,(2 + \pi) = 5.14\, r$ $e = \frac{1}{3} \cdot \frac{r}{\pi} = 0.425\, r$
Circle		$A = r^2\, \pi = \pi\, \frac{d^2}{4}$	$U = 2\, \pi\, r = \pi\, d$
Annular segment		$A = \frac{\pi}{180}\, \alpha^0\, (R^2 - r^2)$	$U = 2\,(R - r) + B + b$ $e = \frac{2}{3} \cdot \frac{R^2 - r^2}{R^2 - r^2} \cdot \frac{\sin \alpha}{\alpha^0} \cdot \frac{180}{\pi}$
Semi-annulus		$A = \frac{\pi}{2}\, \alpha^0\, (R^2 - r^2)$	if $b < 0.2\, R$, then $e \approx 0.32\, (R + r)$
Annulus		$A = \pi\, (R^2 - r^2)$	$U = 2\, \pi\, (R + r)$
Circular segment		$A = \frac{\alpha^0}{180}\, r^2\, \pi - \frac{s\, h}{2}$ $s = 2\, \sqrt{r^2 - h^2}$	$U = 2\, \sqrt{r^2 - h^2} + \frac{\pi\, r\, \alpha^0}{90}$ $e = \frac{s^2}{12 \cdot A}$
Ellipse		$A = \frac{a\, b}{4}\, \pi$	$U = \frac{\pi}{2} \left[\, 1.5\, (a + b) - \sqrt{ab}\, \right]$

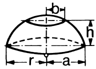
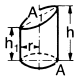
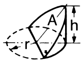
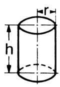
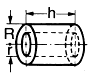
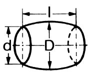
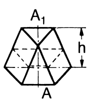
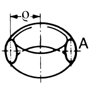
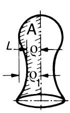
1.4.3 Volumes and surface areas of solid bodies

Table 1-25

Shape of body	V = volume	O = Surface A = Area
Solid rectangle 	$V = a\,b\,c$	$O = 2\,(a\,b + a\,c + b\,c)$
Cube 	$V = a^3 = \dfrac{d^3}{2.828}$	$O = 6\,a^2 = 3\,d^2$
Prism 	$V = A\,h$	$O = U\,h + 2\,A$ A = base surface
Pyramid 	$V = \dfrac{1}{3}\,A\,h$	O = A + Nappe
Cone 	$V = \dfrac{1}{3}\,A\,h$	$O = \pi\,r\,s + \pi\,r^2$ $s = \sqrt{h^2 + r^2}$
Truncated cone 	$V = (R^2 + r^2 + R\,r) \cdot \dfrac{\pi\,h}{3}$	$O = (R + r)\,\pi\,s + \pi\,(R^2 + r^2)$ $s = \sqrt{h^2 + (R - r)^2}$
Truncated pyramid 	$V = \dfrac{1}{3}\,h\,(A + A_1 + \sqrt{AA_1})$	$O = A + A_1$ + Nappe
Sphere 	$V = \dfrac{4}{3}\,\pi\,r^3$	$O = 4\,\pi\,r^2$
Hemisphere 	$V = \dfrac{2}{3}\,\pi\,r^3$	$O = 3\,\pi\,r^2$
Spherical segment 	$V = \pi\,h^2 \left(r - \dfrac{1}{3}\,h\right)$	$O = 2\,\pi\,r\,h + \pi\,(2\,r\,h - h^2) =$ $\pi\,h\,(4\,r - h)$
Spherical sector 	$V = \dfrac{2}{3}\,\pi\,r^2\,h$	$O = \dfrac{\pi\,r}{2}\,(4\,h + s)$

(continued)

Table 1-25 (continued)

Shape of body		V = Volume	O = Surface A = Area
Zone of sphere		$V = \frac{\pi h}{3}(3a^2 + 3b^2 + h^2)$	$O = \pi(2rh + a^2 + b^2)$
Obliquely cut cylinder		$V = \pi r^2 \frac{h + h_1}{2}$	$O = \pi r(h + h_1) + A + A_1$
Cylindrical wedge		$V = \frac{2}{3} r^2 h$	$0 = 2rh + \frac{\pi}{2} r^2 + A$
Cylinder		$V = \pi r^2 h$	$O = 2\pi r h + 2\pi r^2$
Hollow cylinder		$V = \pi h(R^2 - r^2)$	$O = 2\pi h(R + r) + 2\pi(R^2 - r^2)$
Barrel		$V = \frac{\pi}{15} l \cdot$ $(2D^2 + Dd + 0.75d^2)$	$O = \frac{D + d}{2}\pi d + \frac{\pi}{2} d^2$ (approximate)
Frustum		$V = \left(\frac{A - A_1}{2} + A_1\right) h$	$O = A + A_1$ + areas of sides
Body of rotation (ring)		$V = 2\pi \varrho A$ A = cross-section	O = circumference of cross-section x $2\pi\varrho$
Pappus' theorem for bodies of revolution		Volume of turned surface (hatched) x path of its centre of gravity $V = A\, 2\pi \varrho$	Length of turned line x path of its centre of gravity $O = L\, 2\pi \varrho_1$