A Course in Fluid Mechanics

Reference Data

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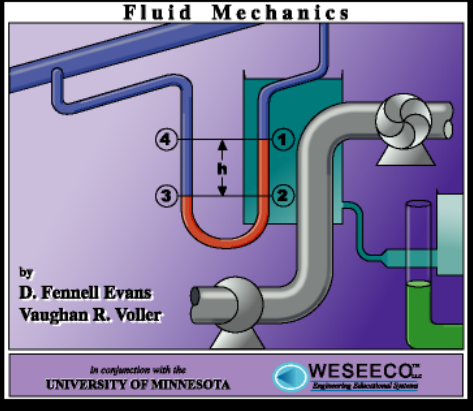

NAVIGATION

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Physical Properties of Air (BGUnits)

Temperature (°F)	Density ρ (slugs/ft³)	Dynamic Viscosity μ (lb·s/ft²)	Kinematic Viscosity ν (ft²/s)	Speed of Sound c (ft/s)
–40	2.939 E–3	3.29 E–7	1.12 E–4	1004
–20	2.805 E–3	3.34 E–7	1.19 E–4	1028
0	2.683 E–3	3.38 E–7	1.26 E–4	1051
10	2.626 E–3	3.44 E–7	1.31 E–4	1062
20	2.571 E–3	3.50 E–7	1.36 E–4	1074
30	2.519 E–3	3.58 E–7	1.42 E–4	1085
40	2.469 E–3	3.60 E–7	1.46 E–4	1096
50	2.420 E–3	3.68 E–7	1.52 E–4	1106
60	2.373 E–3	3.75 E–7	1.58 E–4	1117
70	2.329 E–3	3.82 E–7	1.64 E–4	1128
80	2.286 E–3	3.86 E–7	1.69 E–4	1138
90	2.244 E–3	3.90 E–7	1.74 E–4	1149
100	2.204 E–3	3.94 E–7	1.79 E–4	1159
150				
200	1.870 E–3	4.49 E–7	2.40 E–4	1258
300	1.624 E–3	4.97 E–7	3.06 E–4	1348
400	1.435 E–4	5.24 E–7	3.65 E–4	1431
500	1.285 E–4	5.80 E–7	4.51 E–3	1509

Physical Properties of Air (SI Units)

Temperature (°C)	Density ρ (kg/m³)	Dynamic Viscosity μ (N·s/m²)	Kinematic Viscosity ν (m²/s)	Speed of Sound c (m/s)
–40	1.514	1.57 E–5	1.04 E–5	306.2
–20	1.395	1.63 E–5	1.17 E–5	319.1
0	1.292	1.71 E–5	1.32 E–5	331.4
10	1.247	1.76 E–5	1.41 E–5	337.4
20	1.204	1.82 E–5	1.51 E–5	343.3
30	1.165	1.86 E–5	1.60 E–5	349.1
40	1.127	1.87 E–5	1.66 E–5	354.7
50	1.109	1.95 E–5	1.76 E–5	360.3
60	1.060	1.97 E–5	1.86 E–5	365.7
70	1.029	2.03 E–5	1.97 E–5	371.2
80	0.9996	2.07 E–5	2.07 E–5	376.6
90	0.9721	2.14 E–5	2.20 E–5	381.7
100	0.9461	2.17 E–5	2.29 E–5	386.9
150				
200	0.7461	2.53 E–5	3.39 E–5	434.5
300	0.6159	2.98 E–5	4.84 E–5	476.3
400	0.5243	3.32 E–5	6.34 E–5	514.1
500	0.4565	3.64 E–5	7.97 E–4	548.8

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Physical Properties of Common Liquids (SI Units)

Liquid	Density ρ (kg/m^3)	Dynamic Viscosity μ (kg/(m·s))	Kinematic Viscosity ν	Surface Tension γ N/m	Vapor Pressure p_v N/m^2	Viscosity Parameter C
Benzene	881	2.20 E–4	2.50 E-7	2.88 E–2	1.01 E+4	4.34
Carbon tetrachloride	1,590	9.67 E–4	6.08 E-7	2.70 E–2	1.20 E+4	4.45
Ethanol	789	1.20 E–3	1.52 E-6	2.28 E–2	5.7 E+3	5.72
Ethylene glycol	1,117	2.14 E–2	1.92 E-5	4.84 E–2	1.2 E+1	11.7
Gasoline	680	2.92 E–4	4.29 E-7	2.16 E–2	5.51 E+4	3.68
Glycerin	1,260	1.49	1.18 E-3	6.33 E–2	1.4 E–2	28.0
Mercury	13,550	1.56 E–3	1.15 E-7	4.84 E–1	1.1 E–3	1.07
Methanol	791	5.98 E–4	7.56 E-7	2.25 E–2	1.34 E+4	4.63
SAE 30W oil	891	2.9 E–1	3.25 E-4	3.5 E–2	–	18.3
Water	998	1.00 E–3	1.00 E-6	7.28 E–2	2.34 E+3	
Sea Water	1,025	1.07 E–3	1.04 E-5	7.28 E–2	2.34 E+3	7.28

Physical Properties of Common Gases (SI Units)

Gas	Moleular Weight	Density R ($m^2/(s^2 \cdot K)$)	Dynamic Viscosity μ ($N \cdot s/m^2$)	Kinematic Viscosity ν	Power-law Exponent $n^\dagger$
Air (dry)	28.96	287	1.80 E–5	6.27 E-8	0.67
Argon	39.944	208	2.24 E–5	1.08 E-7	0.72
Carbon dioxide	44.01	189	1.48 E–5	7.83 E-8	0.79
Carbon monoxide	28.01	297	1.82 E–5	6.13 E-8	0.71
Hydrogen	2.016	4124	9.05 E–6	2.19 E-9	0.68
Helium	4.003	2077	1.97 E–5	9.48 E-9	0.67
Methane	16.04	518	1.34 E–5	2.59 E-8	0.87
Nitrogen	28.02	297	1.76 E–5	5.93 E-8	0.67
Oxygen	32.00	260	2.00 E–5	7.69 E-8	0.69
Water	18.02	461	1.02 E–5	2.21 E-8	1.15

Physical Properties of Water (SI Units)

Temperature (°C)	Density ρ ((kg/m^3)	Dynamic Viscosity μ (N·s/m^2)	Kinematic Viscosity ν (m^2/s)	Surface Tension σ (N/m)	Vapor Pressure p_v [N/m^2(abs)]	Speed of Sound c (m/s)
0	999.9	1.787 E–3	1.787 E–6	7.56 E–2	6.105 E+2	1403
5	1000.0	1.519 E–3	1.519 E–6	7.49 E–2	8.722 E+2	1427
10	999.7	1.307 E–3	1.307 E–6	7.42 E–2	1.228 E+3	1447
20	998.2	1.002 E–3	1.004 E–6	7.28 E–2	2.338 E+3	1481
30	995.7	7.975 E–4	8.009 E–7	7.12 E–2	4.243 E+3	1507
40	992.2	6.529 E–4	6.580 E–7	6.96 E–2	7.376 E+3	1526
50	988.1	5.468 E–4	5.534 E–7	6.79 E–2	1.233 E+4	1541
60	983.2	4.665 E–4	4.745 E–7	6.62 E–2	1.992 E+4	1552
70	977.8	1.042 E–4	4.134 E–7	6.44 E–2	3.116 E+4	1555
80	971.8	3.547 E–4	3.650 E–7	6.26 E–2	4.734 E+4	1555
90	965.3	3.147 E–4	3.260 E–7	6.08 E–2	7.010 E+4	1550
100	958.4	2.818 E–4	2.940 E–7	5.89 E–2	1.013 E+5	1543

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Physical Properties of Water (BG Units)

Temperature (°C)	Density ρ ((kg/m^3)	Dynamic Viscosity μ (lb·s/ft^2)	Kinematic Viscosity ν (ft^2/s)	Surface Tension σ (lb/ft)	Vapor Pressure p_v [lb/in.^{2}(abs)]	Speed of Sound c (ft/s)
32	1.940	3.732 E–5	1.924 E–5	5.18 E–3	8.854 E–2	4603
40	1.940	3.228 E–5	1.664 E–5	5.13 E–3	1.217 E–1	4672
50	1.940	2.730 E–5	1.407 E–5	5.09 E–3	1.781 E–1	4748
60	1.938	2.344 E–5	1.210 E–5	5.03 E–3	2.563 E–1	4814
70	1.936	2.037 E–5	1.052 E–5	4.97 E–3	3.631 E–1	4871
80	1.934	1.791 E–5	9.262 E–6	4.91 E–3	5.069 E–1	4819
90	1.931	1.500 E–5	8.233 E–6	4.86 E–3	6.979 E–1	4960
100	1.927	1.423 E–5	7.383 E–6	4.79 E–3	9.493 E–1	4995
120	1.918	1.164 E–5	6.067 E–6	4.67 E–3	1.692 E+0	5049
140	1.908	9.743 E–6	5.106 E–6	4.53 E–3	2.888 E+0	5091
160	1.896	8.315 E–6	4.385 E–6	4.40 E–3	4.736 E+0	5101
180	1.883	7.207 E–6	3.827 E–6	4.26 E–3	7.507 E+0	5195
200	1.869	6.342 E–6	3.393 E–6	4.12 E–3	1.152 E+1	5089
212	1.860	5.886 E–6	3.165 E–6	4.04 E–3	1.469 E+1	5062

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Symbol	SI units	M,L,t,T	Quantity
A	m^2	L^2	area
a	ms^{-2}	Lt^{-2}	acceleration
BC			center of buoyancy
b	m	L	width
C	°C	T	temperature, Celsius
C			discharge coefficient
CG			center of gravity
C_D			total drag coefficient
c_f			wall shear coefficient
D	m	L	diameter
D_h	m	L	equivalent diameter
D_{vc}	m		diameter of a vena contracta
E	$J = kgm^2s^{-2}$	ML^2t^{-2}	energy
$\dot{E}$	Js^{-1}	ML^2t^{-3}	energy/time
e	Jkg^{-1}	L^2t^{-2}	energy per unit mass
$\dot{e}$	$Jkg^{-1}s^{-1}$	L^2t^{-3}	energy/mass/time
EGL	m	L	energy grade line

Symbol	SI units	M,L,t,T	Quantity
F	°F	T	temperature, Fahrenheit
F	$N = kgms^{-2}$	MLt^{-2}	force
F_B	N	MLt^{-2}	buoyant force
F_D	N	MLt^{-2}	drag force
F_h	N	MLt^{-2}	horizontal force
F_v	N	MLt^{-2}	vertical force
f			friction factor
G	$Pa = Nm^{-2}$	$ML^{-1}t^{2}$	shear modulus
g	ms^{-2}	Lt^{-2}	acceleration due to gravity
GM	m	L	metacentric height
H	$J = kgm^2s^{-2}$	ML^2t^{-2}	enthalpy
HGL	m	L	hydraulic grade line
h_f	Jkg^{-1}	L^2t^{-2}	frictional losses
h_f/g	m	L	head associated with frictional losses
I	m^4	L^4	moment of inertia about centroid
I_o	m^4	L^4	second moment of inertia
$\bar{i}$	m	L	unit vector in the x-direction

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Symbol	SI units	M,L,t,T	Quantity
J	$J = kgm^2s^{-2}$	ML^2t^{-2}	Joule
$\bar{j}$	m	L	unit vector in the y-direction
K			loss coefficient
K	K	T	temperature, Kelvin
K_{con}			loss coefficient, contraction
K_{ex}			loss coefficient, expansion
$\bar{k}$	m	L	unit vector in the z-direction
L_e	m	L	equivalent length
L_{ent}	m	L	entrance lenght
M			metacenter
m	kg	M	mass
$\dot{m}$	kgs^{-1}	Mt^{-1}	mass flow rate
N	$kgms^{-2}$	MLt^{-2}	Newton
N_{Ca}			cavitation number
N_{Eu}			Euler number
N_{Fr}			Froude number
N_{Ma}			Mach number
N_{Re}			Reynolds number

Symbol	SI units	M,L,t,T	Quantity
P	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	Pressure
$P/\rho g$	m	L	pressure head
Pa	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	Pascal
P_{abs}	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	absolute pressure
P_{gauge}	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	gauge pressure
P_o	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	static or free stream pressure
P_s	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	stagnation pressure
P_v	$Pa = Nm^{-2}$	$ML^{-1}t^{-2}$	vapor pressure
Q	$J = kgm^2s^{-2}$	ML^2t^{-2}	heat
$\dot{Q}$	m^3s^{-1}	L^3t^{-1}	Volumetric flow rate
$\dot{Q}$	Js^{-1}	ML^2t^{-3}	rate of heating
$\dot{q}$	$Jkg^{-1}s^{-1}$	L^2t^{-3}	heat flux
R	m	L	radius
R	$JK^{-1}mol^{-1}$	$ML^2t^{-2}mol^{-1}$	gas constant
R	°R	T	temperature, Rankine
R_h	m	L	hydraulic radius
r			coordinate
s	s	t	second

Symbol	SI units	M,L,t,T	Quantity
T	K	T	temperature
t	s	t	time
u	Jkg^{-1}	L^2t^{-2}	internal energy/mass
V	m^3	L^3	volume
v	ms^{-1}	Lt^{-1}	velocity
v_∞	ms^{-1}	Lt^{-1}	unperturbed velocity
$v^2/2g$	m	L	velocity head
W	Js^{-1}	ML^2t^{-3}	Watt
W	$J = kgm^2s^{-2}$	ML^2t^{-2}	work
$\dot{W}$	js^{-1}	ML^2t^{-3}	rate of work
W_s	$J = kgm^2s^{-2}$	ML^2t^{-2}	shaft work
W_{PV}	$J = kgm^2s^{-2}$	ML^2t^{-2}	expansion work
w	Jkg^{-1}	L^2t^{-2}	work/mass
w_s	Jkg^{-1}	L^2t^{-2}	shaft work/mass
w_{PV}	$J = kgm^2s^{-2}$	ML^2t^{-2}	expansion work
x	m	L	coordinate

Symbol	SI units	M,L,t,T	Quantity
y	m	L	coordinate
y_c	m	L	centroid distance
y_{cp}	m	L	center of pressure distance
z	m	L	height or coordinate
$\bar{z}$	m	L	coordinate

Symbol	SI units	M,L,t,T	Quantity
α			angle or kinetic energy correction
β			ratio of pipe diameters
ε	m	L	roughness
δ	m	L	thickness of the boundary layer
δ^*	m	L	displacement distance
ϕ			coordinate, angular
ϕ	m^2s^{-1}	L^2t^{-1}	potential function
Ψ	m^2s^{-1}	L^2t^{-1}	stream function
γ	Nm^{-3}	$ML^{-2}t^{-2}$	specific weight
γ	Nm^{-1} or Jm^{-2}	Mt^{-2}	surface tension
Γ	m^2s^{-1}	L^2t^{-1}	circulation
η			pump or turbine efficiency
θ			coordinate, angular
ρ	kgm^{-3}	M/L^{-3}	density
ζ	$rads^{-1}$ or s^{-1}	t^{-1}	vorticity
μ	m^2s	L^2t	dynamic viscosity
ν	m^3s^{-1}	L^3t^{-1}	kinematic viscosity
τ	Nm^{-2} or Pa	$ML^{-1}t^{-2}$	shear
τ_w	Nm^{-2} or Pa	$ML^{-1}t^{-2}$	wall shear
ω	$rads^{-1}$ or s^{-1}	t^{-1}	angular rotation
			position of centroid

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Conversion Factors

To convert from BG to SI units, mutiply by

Acceleration	ft/s^2	m/s^2	0.3048
Areas	ft^2	m^2	9.2903 E-2
Density	$slug/ft^3$	kg/m^3	5.1538 E-2
Energy	ft-lbf	J	1.3558
	BTU	J	1.0551 E+3
Force	lbf	N	4.4482
Length	ft	m	0.3048
	in	m	2.5400 E-2
	mi	m	1.6093 E+6
Mass	slug	kg	1.4594 E+1
Mass Flow	slug/s	kg/s	1.4594 E+1
Rate	lbm/s	kg/s	4.5359 E-1
Power	ft-lb/s	W	1.3558
	hp	W	7.4570 E+2

To convert from SI to BG units, divide by

To convert from BG to SI units, mutiply by

Pressure	lbf/ft^2	Pa	4.788 E+1
Pa =N/m^2	lbf/in^2	Pa	6.895 E+3
	atm	Pa	1.013 E+5
(Hg at 60° F)	mmHg	Pa	1.333 E+2
Specific weight	lbf/ft^3	N/m^3	1.571 E+2
Temperature	° F	° C	$T_c = 5/9(t_f - 32°)$
	° R	K	5.556 E-1
Velocity	ft/s	m/s	3.048 E-1
	mi/hr	m/s	4.470 E-1
Viscosity	$lbf\text{-}s/ft^2$	$N\text{-}s/m^2$	4.788 E+1
	ft^2/s	m^2/s	9.290 E-2
Volume	ft^3	m^3	2.8317 E-2
	gal	m^3	3.7854 E-3
Volume flow	ft^3/s	m^3/s	2.832 E-2
	gal/min	m^3/s	6.309 E-5

To convert from SI to BG units, divide by

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