

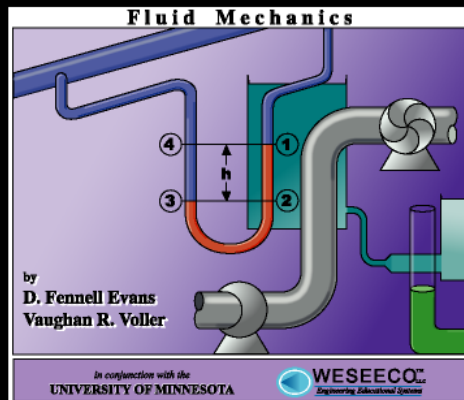
*A Course in Fluid Mechanics*

## Reference Data

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### NAVIGATION

Each content page has a title  
and can be accessed from the  
Table of Contents Page button  
(TOC)










TOC


# Table of Contents

## Table of Properties

-  p1 Properties of Air
-  p2 Properties of Common Liquids (Si)
-  p3 Properties of Common Gases (Si)
-  p4 Properties of Water (Si)
-  p5 Properties of Water (BG)

## Symbols

-  p1 ABCDE
-  p2 FHIG
-  p3 JKLMN
-  p4 OPQRS
-  p5 TUVWX
-  p6 YZ.
-  p7 Alpha-Omega

-  Unit Conversions

## Physical Properties of Air (BGUnits)

## Physical Properties of Air (SI Units)

Temperature (°F)	Density $\rho$ (slugs/ft <sup>3</sup> )	Dynamic Viscosity $\mu$ (lb·s/ft <sup>2</sup> )	Kinematic Viscosity $\nu$ (ft <sup>2</sup> /s)	Speed of Sound $c$ (ft/s)	Temperature (°C)	Density $\rho$ (kg/m <sup>3</sup> )	Dynamic Viscosity $\mu$ (N·s/m <sup>2</sup> )	Kinematic Viscosity $\nu$ (m <sup>2</sup> /s)	Speed of Sound $c$ (m/s)
-40	2.939 E-3	3.29 E-7	1.12 E-4	1004	-40	1.514	1.57 E-5	1.04 E-5	306.2
-20	2.805 E-3	3.34 E-7	1.19 E-4	1028	-20	1.395	1.63 E-5	1.17 E-5	319.1
0	2.683 E-3	3.38 E-7	1.26 E-4	1051	0	1.292	1.71 E-5	1.32 E-5	331.4
10	2.626 E-3	3.44 E-7	1.31 E-4	1062	10	1.247	1.76 E-5	1.41 E-5	337.4
20	2.571 E-3	3.50 E-7	1.36 E-4	1074	20	1.204	1.82 E-5	1.51 E-5	343.3
30	2.519 E-3	3.58 E-7	1.42 E-4	1085	30	1.165	1.86 E-5	1.60 E-5	349.1
40	2.469 E-3	3.60 E-7	1.46 E-4	1096	40	1.127	1.87 E-5	1.66 E-5	354.7
50	2.420 E-3	3.68 E-7	1.52 E-4	1106	50	1.109	1.95 E-5	1.76 E-5	360.3
60	2.373 E-3	3.75 E-7	1.58 E-4	1117	60	1.060	1.97 E-5	1.86 E-5	365.7
70	2.329 E-3	3.82 E-7	1.64 E-4	1128	70	1.029	2.03 E-5	1.97 E-5	371.2
80	2.286 E-3	3.86 E-7	1.69 E-4	1138	80	0.9996	2.07 E-5	2.07 E-5	376.6
90	2.244 E-3	3.90 E-7	1.74 E-4	1149	90	0.9721	2.14 E-5	2.20 E-5	381.7
100	2.204 E-3	3.94 E-7	1.79 E-4	1159	100	0.9461	2.17 E-5	2.29 E-5	386.9
150					150				
200	1.870 E-3	4.49 E-7	2.40 E-4	1258	200	0.7461	2.53 E-5	3.39 E-5	434.5
300	1.624 E-3	4.97 E-7	3.06 E-4	1348	300	0.6159	2.98 E-5	4.84 E-5	476.3
400	1.435 E-4	5.24 E-7	3.65 E-4	1431	400	0.5243	3.32 E-5	6.34 E-5	514.1
500	1.285 E-4	5.80 E-7	4.51 E-3	1509	500	0.4565	3.64 E-5	7.97 E-4	548.8

## Physical Properties of Common Liquids (SI Units)

Liquid	Density $\rho$ (kg/m <sup>3</sup> )	Dynamic Viscosity $\mu$ (kg/(m·s))	Kinematic Viscosity $\nu$	Surface Tension $\gamma$ N/m	Vapor Pressure $p_v$ N/m <sup>2</sup>	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	Molecular Weight	Density $\rho$ ( $m^3/(s^2 \cdot K)$ )	Dynamic Viscosity $\mu$ ( $N \cdot s/m^2$ )	Kinematic Viscosity $\nu$	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 $\rho$ ((kg/m <sup>3</sup> ))	Dynamic Viscosity $\mu$ (N·s/m <sup>2</sup> )	Kinematic Viscosity $\nu$ (m <sup>2</sup> /s)	Surface Tension $\sigma$ (N/m)	Vapor Pressure $p_v$ [N/m <sup>2</sup> (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

## Physical Properties of Water (BG Units)

Temperature (°C)	Density $\rho$ (kg/m <sup>3</sup> )	Dynamic Viscosity $\mu$ (lb s/ft <sup>2</sup> )	Kinematic Viscosity $\nu$ (ft <sup>2</sup> /s)	Surface Tension $\sigma$ (lb/ft)	Vapor Pressure $p_v$ [lb/in. <sup>2</sup> (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

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




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

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

Symbol	SI units	M,L,t,T	Quantity
P	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	Pressure
$P/\rho g$	m	L	pressure head
$\text{Pa}$	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	Pascal
$P_{\text{abs}}$	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	absolute pressure
$P_{\text{gauge}}$	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	gauge pressure
$P_o$	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	static or free stream pressure
$P_s$	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	stagnation pressure
$P_v$	$\text{Pa} = \text{Nm}^{-2}$	$\text{ML}^{-1}\text{t}^{-2}$	vapor pressure
Q	$\text{J} = \text{kgm}^2\text{s}^{-2}$	$\text{ML}^2\text{t}^{-2}$	heat
$\dot{Q}$	$\text{m}^3\text{s}^{-1}$	$\text{L}^3\text{t}^{-1}$	Volumetric flow rate
$\dot{Q}$	$\text{Js}^{-1}$	$\text{ML}^2\text{t}^{-3}$	rate of heating
$\dot{q}$	$\text{Jkg}^{-1}\text{s}^{-1}$	$\text{L}^2\text{t}^{-3}$	heat flux
R	m	L	radius
R	$\text{JK}^{-1}\text{mol}^{-1}$	$\text{ML}^2\text{t}^{-2}\text{mol}^{-1}$	gas constant
R	$^{\circ}\text{R}$	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	$\text{Jkg}^{-1}$	$\text{L}^2\text{t}^{-2}$	internal energy/mass
V	$\text{m}^3$	$\text{L}^3$	volume
v	$\text{ms}^{-1}$	$\text{Lt}^{-1}$	velocity
$v_\infty$	$\text{ms}^{-1}$	$\text{Lt}^{-1}$	unperturbed velocity
$v^2/2g$	m	L	velocity head
W	$\text{Js}^{-1}$	$\text{ML}^2\text{t}^{-3}$	Watt
W	$\text{J} = \text{kgm}^2\text{s}^{-2}$	$\text{ML}^2\text{t}^{-2}$	work
$\dot{W}$	$\text{js}^{-1}$	$\text{ML}^2\text{t}^{-3}$	rate of work
$W_s$	$\text{J} = \text{kgm}^2\text{s}^{-2}$	$\text{ML}^2\text{t}^{-2}$	shaft work
$W_{pv}$	$\text{J} = \text{kgm}^2\text{s}^{-2}$	$\text{ML}^2\text{t}^{-2}$	expansion work
w	$\text{Jkg}^{-1}$	$\text{L}^2\text{t}^{-2}$	work/mass
$w_s$	$\text{Jkg}^{-1}$	$\text{L}^2\text{t}^{-2}$	shaft work/mass
$w_{pv}$	$\text{J} = \text{kgm}^2\text{s}^{-2}$	$\text{ML}^2\text{t}^{-2}$	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
$\alpha$			angle or kinetic energy correction
$\beta$			ratio of pipe diameters
$\epsilon$	m	L	roughness
$\delta$	m	L	thickness of the boundary layer
$\delta^*$	m	L	displacement distance
$\phi$			coordinate, angular
$\phi$	$m^2s^{-1}$	$L^2t^{-1}$	potential function
$\Psi$	$m^2s^{-1}$	$L^2t^{-1}$	stream function
$\gamma$	$Nm^{-3}$	$ML^{-2}t^{-2}$	specific weight
$\gamma$	$Nm^{-1}$ or $Jm^{-2}$	$Mt^2$	surface tension
$\Gamma$	$m^2s^{-1}$	$L^2t^{-1}$	circulation
$\eta$			pump or turbine efficiency
$\theta$			coordinate, angular
$\rho$	$kgm^{-3}$	$ML^{-3}$	density
$\zeta$	$rads^{-1}$ or $s^{-1}$	$t^{-1}$	vorticity
$\mu$	$m^2s$	$L^2t$	dynamic viscosity
$\nu$	$m^3s^{-1}$	$L^3t^{-1}$	kinematic viscosity
$\tau$	$Nm^{-2}$ or Pa	$ML^{-1}t^{-2}$	shear
$\tau_w$	$Nm^{-2}$ or Pa	$ML^{-1}t^{-2}$	wall shear
$\omega$	$rads^{-1}$ or $s^{-1}$	$t^{-1}$	angular rotation
			position of centroid

## Conversion Factors

To convert from **BG to SI units**, multiply by

Acceleration	ft/s <sup>2</sup>	m/s <sup>2</sup>	0.3048
Areas	ft <sup>2</sup>	m <sup>2</sup>	9.2903 E-2
Density	slug/ft <sup>3</sup>	kg/m <sup>3</sup>	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**, multiply by

Pressure	lb/ft <sup>2</sup>	Pa	4.788 E+1
	Pa =N/m <sup>2</sup>		
Pa =N/m <sup>2</sup>	lb/in <sup>2</sup>	Pa	6.895 E+3
	atm	Pa	1.013 E+5
(Hg at 60° F)	mmHg	Pa	1.333 E+2
Specific weight	lb/ft <sup>3</sup>	N/m <sup>3</sup>	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	lb·s/ft <sup>2</sup>	N·s/m <sup>2</sup>	4.788 E+1
	ft <sup>2</sup> /s	m <sup>2</sup> /s	9.290 E-2
Volume	ft <sup>3</sup>	m <sup>3</sup>	2.8317 E-2
	gal	m <sup>3</sup>	3.7854 E-3
Volume flow	ft <sup>3</sup> /min	m <sup>3</sup> /s	2.832 E-2
	gal/min	m <sup>3</sup> /s	6.309 E-5

To convert from **SI to BG units**, divide by



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