

# Section 1

# Mathematical Tables and Measuring Units

BY

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## 1.1 MATHEMATICAL TABLES

by George F. Baumeister

REFERENCES FOR MATHEMATICAL TABLES: Dwight, "Mathematical Tables of Elementary and Some Higher Mathematical Functions," McGraw-Hill. Dwight, "Tables of Integrals and Other Mathematical Data," Macmillan. Jahnke and Emde, "Tables of Functions," B. G. Teubner, Leipzig, or Dover. Pierce-Foster,

"A Short Table of Integrals," Ginn. "Mathematical Tables from Handbook of Chemistry and Physics," Chemical Rubber Co. "Handbook of Mathematical Functions," NBS.

1-2 MATHEMATICAL TABLES

**Table 1.1.1 Segments of Circles, Given  $h/c$**

Given:  $h$  = height;  $c$  = chord. To find the diameter of the circle, the length of arc, or the area of the segment, form the ratio  $h/c$ , and find from the table the value of (diam/ $c$ ), (arc/ $c$ ); then, by a simple multiplication,

$$\begin{aligned} \text{diam} &= c \times (\text{diam}/c) \\ \text{arc} &= c \times (\text{arc}/c) \\ \text{area} &= h \times c \times (\text{area}/h \times c) \end{aligned}$$

The table gives also the angle subtended at the center, and the ratio of  $h$  to  $D$ .

$\frac{h}{c}$	$\frac{\text{Diam}}{c}$	Diff	$\frac{\text{Arc}}{c}$	Diff	$\frac{\text{Area}}{h \times c}$	Diff	Central angle, $\nu$	Diff	$\frac{h}{\text{Diam}}$	Diff
.00			1.000		.6667		0.00°		.0000	
1	25.010		1.000	0	.6667	0	4.58	458	.0004	4
2	12.520	12490	1.001	1	.6669	2	9.16	458	.0016	12
3	8.363	*4157	1.002	1	.6671	2	13.73	457	.0036	20
4	6.290	*2073	1.004	2	.6675	4	18.30	457	.0064	28
		*1240		3		5		454		35
.05	5.050	*823	1.007		.6680		22.84°		.0099	
6	4.227	*586	1.010	3	.6686	6	27.37	453	.0142	43
7	3.641	*436	1.013	3	.6693	7	31.88	451	.0192	50
8	3.205	*337	1.017	4	.6701	8	36.36	448	.0250	58
9	2.868	*268	1.021	4	.6710	9	40.82	446	.0314	64
				5		10		442		71
.10	2.600	*217	1.026		.6720		45.24°		.0385	
1	2.383	*180	1.032	6	.6731	11	49.63	439	.0462	77
2	2.203	*150	1.038	6	.6743	12	53.98	435	.0545	83
3	2.053	*127	1.044	6	.6756	13	58.30	432	.0633	88
4	1.926	*109	1.051	7	.6770	14	62.57	427	.0727	94
				8		15		423		99
.15	1.817	*94	1.059		.6785		66.80°		.0826	
6	1.723	*82	1.067	8	.6801	16	70.98	418	.0929	103
7	1.641	*72	1.075	8	.6818	17	75.11	413	.1036	107
8	1.569	*63	1.084	9	.6836	18	79.20	409	.1147	111
9	1.506	56	1.094	10	.6855	19	83.23	403	.1263	116
				9		20		399		116
.20	1.450	50	1.103		.6875		87.21°		.1379	
1	1.400	44	1.114	11	.6896	21	91.13	392	.1499	120
2	1.356	39	1.124	10	.6918	22	95.00	387	.1622	123
3	1.317	35	1.136	12	.6941	23	98.81	381	.1746	124
4	1.282	32	1.147	11	.6965	24	102.56	375	.1873	127
				12		24		370		127
.25	1.250	28	1.159		.6989		106.26°		.2000	
6	1.222	26	1.171	12	.7014	25	109.90	364	.2128	128
7	1.196	23	1.184	13	.7041	27	113.48	358	.2258	130
8	1.173	21	1.197	13	.7068	27	117.00	352	.2387	129
9	1.152	19	1.211	14	.7096	28	120.45	345	.2517	130
				14		29		341		130
.30	1.133	17	1.225		.7125		123.86°		.2647	
1	1.116	15	1.239	14	.7154	29	127.20	334	.2777	130
2	1.101	13	1.254	15	.7185	31	130.48	328	.2906	129
3	1.088	13	1.269	15	.7216	31	133.70	322	.3034	128
4	1.075	11	1.284	15	.7248	32	136.86	316	.3162	128
				16		32		311		127
.35	1.064	10	1.300		.7280		139.97°		.3289	
6	1.054	8	1.316	16	.7314	34	143.02	305	.3414	125
7	1.046	8	1.332	16	.7348	34	146.01	299	.3538	124
8	1.038	7	1.349	17	.7383	35	148.94	293	.3661	123
9	1.031	6	1.366	17	.7419	36	151.82	288	.3783	122
				17		36		282		119
.40	1.025	5	1.383		.7455		154.64°		.3902	
1	1.020	5	1.401	18	.7492	37	157.41	277	.4021	119
2	1.015	4	1.419	18	.7530	38	160.12	271	.4137	116
3	1.011	3	1.437	18	.7568	38	162.78	266	.4252	115
4	1.008	2	1.455	18	.7607	39	165.39	261	.4364	112
				19		40		256		111
.45	1.006	3	1.474		.7647		167.95°		.4475	
6	1.003	1	1.493	19	.7687	40	170.46	251	.4584	109
7	1.002	1	1.512	19	.7728	41	172.91	245	.4691	107
8	1.001	1	1.531	19	.7769	41	175.32	241	.4796	105
9	1.000	0	1.551	20	.7811	42	177.69	237	.4899	103
				20		43		231		101
.50	1.000		1.571		.7854		180.00°		.5000	

\* Interpolation may be inaccurate at these points.

**Table 1.1.2 Segments of Circles, Given  $h/D$**

Given:  $h$  = height;  $D$  = diameter of circle. To find the chord, the length of arc, or the area of the segment, form the ratio  $h/D$ , and find from the table the value of (chord/ $D$ ), (arc/ $D$ ), or (area/ $D^2$ ); then by a simple multiplication,

$$\begin{aligned} \text{chord} &= D \times (\text{chord}/D) \\ \text{arc} &= D \times (\text{arc}/D) \\ \text{area} &= D^2 \times (\text{area}/D^2) \end{aligned}$$

This table gives also the angle subtended at the center, the ratio of the arc of the segment to the whole circumference, and the ratio of the area of the segment to the area of the whole circle.

$\frac{h}{D}$	$\frac{\text{Arc}}{D}$	Diff	$\frac{\text{Area}}{D^2}$	Diff	Central angle, $\nu$	Diff	$\frac{\text{Chord}}{D}$	Diff	$\frac{\text{Arc}}{\text{Circum}}$	Diff	$\frac{\text{Area}}{\text{Circle}}$	Diff
.00	0.000	2003	.0000	13	0.00°	2296	.0000	*1990	.0000	*638	.0000	
1	.2003	*835	.0013	24	22.96	*956	.1990	*810	.0638	*265	.0017	17
2	.2838	*644	.0037	32	32.52	*738	.2800	*612	.0903	*205	.0048	31
3	.3482	*545	.0069	36	39.90	*625	.3412	*507	.1108	*174	.0087	39
4	.4027	*483	.0105	42	46.15	*553	.3919	*440	.1282	*154	.0134	47
.05	.4510	*439	.0147	45	51.68°	*504	.4359	*391	.1436	*139	.0187	53
6	.4949	*406	.0192	50	56.72	*465	.4750	*353	.1575	*130	.0245	58
7	.5355	*380	.0242	52	61.37	*435	.5103	*323	.1705	121	.0308	63
8	.5735	*359	.0294	56	65.72	*411	.5426	*298	.1826	114	.0375	67
9	.6094	*341	.0350	59	69.83	*391	.5724	*276	.1940	108	.0446	71
.10	.6435	*326	.0409	61	73.74°	*374	.6000	*258	.2048	104	.0520	74
1	.6761	*314	.0470	64	77.48	*359	.6258	*241	.2152	100	.0598	78
2	.7075	*302	.0534	66	81.07	*347	.6499	*227	.2252	96	.0680	82
3	.7377	*293	.0600	68	84.54	*335	.6726	*214	.2348	93	.0764	84
4	.7670	*284	.0668	71	87.89	*326	.6940	*201	.2441	91	.0851	87
.15	.7954	276	.0739	72	91.15°	316	.7141	*191	.2532	88	.0941	90
6	.8230	270	.0811	74	94.31	309	.7332	*181	.2620	86	.1033	92
7	.8500	263	.0885	76	97.40	302	.7513	*171	.2706	83	.1127	94
8	.8763	258	.0961	78	100.42	295	.7684	162	.2789	82	.1224	97
9	.9021	252	.1039	79	103.37	289	.7846	154	.2871	81	.1323	99
.20	0.9273	248	.1118	81	106.26°	284	.8000	146	.2952	79	.1424	101
1	0.9521	243	.1199	82	109.10	279	.8146	139	.3031	77	.1527	103
2	0.9764	240	.1281	84	111.89	274	.8285	132	.3108	76	.1631	104
3	1.0004	235	.1365	84	114.63	271	.8417	125	.3184	75	.1738	107
4	1.0239	233	.1449	86	117.34	266	.8542	118	.3259	74	.1846	108
.25	1.0472	229	.1535	88	120.00°	263	.8660	113	.3333	73	.1955	109
6	1.0701	227	.1623	88	122.63	260	.8773	106	.3406	72	.2066	111
7	1.0928	224	.1711	89	125.23	256	.8879	101	.3478	72	.2178	112
8	1.1152	222	.1800	90	127.79	254	.8980	95	.3550	70	.2292	114
9	1.1374	219	.1890	92	130.33	251	.9075	90	.3620	70	.2407	115
.30	1.1593	217	.1982	92	132.84°	249	.9165	85	.3690	69	.2523	116
1	1.1810	215	.2074	93	135.33	247	.9250	80	.3759	69	.2640	117
2	1.2025	214	.2167	93	137.80	245	.9330	74	.3828	68	.2759	119
3	1.2239	212	.2260	95	140.25	242	.9404	70	.3896	67	.2878	119
4	1.2451	210	.2355	95	142.67	241	.9474	65	.3963	67	.2998	120
.35	1.2661	209	.2450	96	145.08°	240	.9539	61	.4030	67	.3119	121
6	1.2870	208	.2546	96	147.48	238	.9600	56	.4097	66	.3241	122
7	1.3078	206	.2642	97	149.86	237	.9656	52	.4163	66	.3364	123
8	1.3284	206	.2739	97	152.23	235	.9708	47	.4229	66	.3487	123
9	1.3490	204	.2836	98	154.58	235	.9755	43	.4294	65	.3611	124
.40	1.3694	204	.2934	98	156.93°	233	.9798	39	.4359	65	.3735	124
1	1.3898	203	.3032	98	159.26	233	.9837	34	.4424	65	.3860	125
2	1.4101	202	.3130	99	161.59	231	.9871	31	.4489	64	.3986	126
3	1.4303	202	.3229	99	163.90	232	.9902	26	.4553	64	.4112	126
4	1.4505	201	.3328	100	166.22	230	.9928	22	.4617	64	.4238	126
.45	1.4706	201	.3428	99	168.52°	230	.9950	18	.4681	64	.4364	127
6	1.4907	201	.3527	100	170.82	230	.9968	14	.4745	64	.4491	127
7	1.5108	200	.3627	100	173.12	229	.9982	10	.4809	64	.4618	127
8	1.5308	200	.3727	100	175.41	229	.9992	6	.4873	63	.4745	127
9	1.5508	200	.3827	100	177.71	229	.9998	2	.4936	64	.4873	128
.50	1.5708		.3927		180.00°		1.0000		.5000		.5000	127

\* Interpolation may be inaccurate at these points.

1-4 MATHEMATICAL TABLES

**Table 1.1.3 Regular Polygons**

$n$  = number of sides  
 $v = 360^\circ/n$  = angle subtended at the center by one side  
 $a$  = length of one side =  $R \left( 2 \sin \frac{v}{2} \right) = r \left( 2 \tan \frac{v}{2} \right)$   
 $R$  = radius of circumscribed circle =  $a \left( \frac{1}{2} \csc \frac{v}{2} \right) = r \left( \sec \frac{v}{2} \right)$   
 $r$  = radius of inscribed circle =  $R \left( \cos \frac{v}{2} \right) = a \left( \frac{1}{2} \cot \frac{v}{2} \right)$   
 Area =  $a^2 \left( \frac{1}{4} n \cot \frac{v}{2} \right) = R^2 \left( \frac{1}{2} n \sin v \right) = r^2 \left( n \tan \frac{v}{2} \right)$

$n$	$v$	$\frac{\text{Area}}{a^2}$	$\frac{\text{Area}}{R^2}$	$\frac{\text{Area}}{r^2}$	$\frac{R}{a}$	$\frac{R}{r}$	$\frac{a}{R}$	$\frac{a}{r}$	$\frac{r}{R}$	$\frac{r}{a}$
3	120°	0.4330	1.299	5.196	0.5774	2.000	1.732	3.464	0.5000	0.2887
4	90°	1.000	2.000	4.000	0.7071	1.414	1.414	2.000	0.7071	0.5000
5	72°	1.721	2.378	3.633	0.8507	1.236	1.176	1.453	0.8090	0.6882
6	60°	2.598	2.598	3.464	1.0000	1.155	1.000	1.155	0.8660	0.8660
7	51° 43'	3.634	2.736	3.371	1.152	1.110	0.8678	0.9631	0.9010	1.038
8	45°	4.828	2.828	3.314	1.307	1.082	0.7654	0.8284	0.9239	1.207
9	40°	6.182	2.893	3.276	1.462	1.064	0.6840	0.7279	0.9397	1.374
10	36°	7.694	2.939	3.249	1.618	1.052	0.6180	0.6498	0.9511	1.539
12	30°	11.20	3.000	3.215	1.932	1.035	0.5176	0.5359	0.9659	1.866
15	24°	17.64	3.051	3.188	2.405	1.022	0.4158	0.4251	0.9781	2.352
16	22° 50'	20.11	3.062	3.183	2.563	1.020	0.3902	0.3978	0.9808	2.514
20	18°	31.57	3.090	3.168	3.196	1.013	0.3129	0.3168	0.9877	3.157
24	15°	45.58	3.106	3.160	3.831	1.009	0.2611	0.2633	0.9914	3.798
32	11° 25'	81.23	3.121	3.152	5.101	1.005	0.1960	0.1970	0.9952	5.077
48	7° 50'	183.1	3.133	3.146	7.645	1.002	0.1308	0.1311	0.9979	7.629
64	5° 6.25'	325.7	3.137	3.144	10.19	1.001	0.0981	0.0983	0.9968	10.18

**Table 1.1.4 Binomial Coefficients**

$(n)_0 = 1$   $(n)_1 = n$   $(n)_2 = \frac{n(n-1)}{1 \times 2}$   $(n)_3 = \frac{n(n-1)(n-2)}{1 \times 2 \times 3}$  etc. in general  $(n)_r = \frac{n(n-1)(n-2) \cdots [n-(r-1)]}{1 \times 2 \times 3 \times \cdots \times r}$ . Other notations:  $nC_r = \binom{n}{r} = (n)_r$

$n$	$(n)_0$	$(n)_1$	$(n)_2$	$(n)_3$	$(n)_4$	$(n)_5$	$(n)_6$	$(n)_7$	$(n)_8$	$(n)_9$	$(n)_{10}$	$(n)_{11}$	$(n)_{12}$	$(n)_{13}$
1	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	1	2	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	1	3	3	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	1	4	6	4	1	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	1	5	10	10	5	1	.....	.....	.....	.....	.....	.....	.....	.....
6	1	6	15	20	15	6	1	.....	.....	.....	.....	.....	.....	.....
7	1	7	21	35	35	21	7	1	.....	.....	.....	.....	.....	.....
8	1	8	28	56	70	56	28	8	1	.....	.....	.....	.....	.....
9	1	9	36	84	126	126	84	36	9	1	.....	.....	.....	.....
10	1	10	45	120	210	252	210	120	45	10	1	.....	.....	.....
11	1	11	55	165	330	462	462	330	165	55	11	1	.....	.....
12	1	12	66	220	495	792	924	792	495	220	66	12	1	.....
13	1	13	78	286	715	1287	1716	1716	1287	715	286	78	13	1
14	1	14	91	364	1001	2002	3003	3432	3003	2002	1001	364	91	14
15	1	15	105	455	1365	3003	5005	6435	6435	5005	3003	1365	455	105

NOTE: For  $n = 14$ ,  $(n)_{14} = 1$ ; for  $n = 15$ ,  $(n)_{14} = 15$ , and  $(n)_{15} = 1$ .

**Table 1.1.5 Compound Interest. Amount of a Given Principal**

The amount  $A$  at the end of  $n$  years of a given principal  $P$  placed at compound interest today is  $A = P \times x$  or  $A = P \times y$ , according as the interest (at the rate of  $r$  percent per annum) is compounded annually, or continuously; the factor  $x$  or  $y$  being taken from the following tables.

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $x$ (interest compounded annually: $A = P \times x$ )									
1	1.0600	1.0800	1.1000	1.1200	1.1400	1.1600	1.1800	1.2000	1.2200
2	1.1236	1.1664	1.2100	1.2544	1.2996	1.3456	1.3924	1.4400	1.4884
3	1.1910	1.2597	1.3310	1.4049	1.4815	1.5609	1.6430	1.7280	1.8158
4	1.2625	1.3605	1.4641	1.5735	1.6890	1.8106	1.9388	2.0736	2.2153
5	1.3382	1.4693	1.6105	1.7623	1.9254	2.1003	2.2878	2.4883	2.7027
6	1.4185	1.5869	1.7716	1.9738	2.1950	2.4364	2.6996	2.9860	3.2973
7	1.5036	1.7138	1.9487	2.2107	2.5023	2.8262	3.1855	3.5832	4.0227
8	1.5938	1.8509	2.1436	2.4760	2.8526	3.2784	3.7589	4.2998	4.9077
9	1.6895	1.9990	2.3579	2.7731	3.2519	3.8030	4.4355	5.1598	5.9874
10	1.7908	2.1589	2.5937	3.1058	3.7072	4.4114	5.2338	6.1917	7.3046
11	1.8983	2.3316	2.8531	3.4786	4.2262	5.1173	6.1759	7.4301	8.9117
12	2.0122	2.5182	3.1384	3.8960	4.8179	5.9360	7.2876	8.9161	10.872
13	2.1329	2.7196	3.4523	4.3635	5.4924	6.8858	8.5994	10.699	13.264
14	2.2609	2.9372	3.7975	4.8871	6.2613	7.9875	10.147	12.839	16.182
15	2.3966	3.1722	4.1772	5.4736	7.1379	9.2655	11.974	15.407	19.742
16	2.5404	3.4259	4.5950	6.1304	8.1372	10.748	14.129	18.488	24.086
17	2.6928	3.7000	5.0545	6.8660	9.2765	12.468	16.672	22.186	29.384
18	2.8543	3.9960	5.5599	7.6900	10.575	14.463	19.673	26.623	35.849
19	3.0256	4.3157	6.1159	8.6128	12.056	16.777	23.214	31.948	43.736
20	3.2071	4.6610	6.7275	9.6463	13.743	19.461	27.393	38.338	53.358
25	4.2919	6.8485	10.835	17.000	26.462	40.874	62.669	95.396	144.21
30	5.7435	10.063	17.449	29.960	50.950	85.850	143.37	237.38	389.76
40	10.286	21.725	45.259	93.051	188.88	378.72	750.38	1469.8	2847.0
50	18.420	46.902	117.39	289.00	700.23	1670.7	3927.4	9100.4	20796.6
60	32.988	101.26	304.48	897.60	2595.9	7370.2	20555.1	56347.5	151911.2

NOTE: This table is computed from the formula  $x = [1 + (r/100)]^n$ .

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $y$ (interest compounded continuously: $A = P \times y$ )									
1	1.0618	1.0833	1.1052	1.1275	1.1503	1.1735	1.1972	1.2214	1.2461
2	1.1275	1.1735	1.2214	1.2712	1.3231	1.3771	1.4333	1.4918	1.5527
3	1.1972	1.2712	1.3499	1.4333	1.5220	1.6161	1.7160	1.8221	1.9348
4	1.2712	1.3771	1.4918	1.6161	1.7507	1.8965	2.0544	2.2255	2.4109
5	1.3499	1.4918	1.6487	1.8221	2.0138	2.2255	2.4596	2.7183	3.0042
6	1.4333	1.6161	1.8221	2.0544	2.3164	2.6117	2.9447	3.3201	3.7434
7	1.5220	1.7507	2.0138	2.3164	2.6645	3.0649	3.5254	4.0552	4.6646
8	1.6161	1.8965	2.2255	2.6117	3.0649	3.5966	4.2207	4.9530	5.8124
9	1.7160	2.0544	2.4596	2.9447	3.5254	4.2207	5.0531	6.0496	7.2427
10	1.8221	2.2255	2.7183	3.3201	4.0552	4.9530	6.0496	7.3891	9.0250
11	1.9348	2.4109	3.0042	3.7434	4.6646	5.8124	7.2427	9.0250	11.246
12	2.0544	2.6117	3.3201	4.2207	5.3656	6.8210	8.6711	11.023	14.013
13	2.1815	2.8292	3.6693	4.7588	6.1719	8.0045	10.381	13.464	17.462
14	2.3164	3.0649	4.0552	5.3656	7.0993	9.3933	12.429	16.445	21.758
15	2.4596	3.3201	4.4817	6.0496	8.1662	11.023	14.880	20.086	27.113
16	2.6117	3.5966	4.9530	6.8210	9.3933	12.936	17.814	24.533	33.784
17	2.7732	3.8962	5.4739	7.6906	10.805	15.180	21.328	29.964	42.098
18	2.9447	4.2207	6.0496	8.6711	12.429	17.814	25.534	36.598	52.457
19	3.1268	4.5722	6.6859	9.7767	14.296	20.905	30.569	44.701	65.366
20	3.3201	4.9530	7.3891	11.023	16.445	24.533	36.598	54.598	81.451
25	4.4817	7.3891	12.182	20.086	33.115	54.598	90.017	148.41	244.69
30	6.0496	11.023	20.086	36.598	66.686	121.51	221.41	403.43	735.10
40	11.023	24.533	54.598	121.51	270.43	601.85	1339.4	2981.0	6634.2
50	20.086	54.598	148.41	403.43	1096.6	2981.0	8103.1	22026.5	59874.1
60	36.598	121.51	403.43	1339.4	4447.1	14764.8	49020.8	162754.8	540364.9

FORMULA:  $y = e^{(r/100) \times n}$ .

1-6 MATHEMATICAL TABLES

**Table 1.1.6 Principal Which Will Amount to a Given Sum**

The principal  $P$ , which, if placed at compound interest today, will amount to a given sum  $A$  at the end of  $n$  years  $P = A \times x'$  or  $P = A \times y'$ , according as the interest (at the rate of  $r$  percent per annum) is compounded annually, or continuously; the factor  $x'$  or  $y'$  being taken from the following tables.

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $x'$ (interest compounded annually: $P = A \times x'$ )									
1	.94340	.92593	.90909	.89286	.87719	.86207	.84746	.83333	.81967
2	.89000	.85734	.82645	.79719	.76947	.74316	.71818	.69444	.67186
3	.83962	.79383	.75131	.71178	.67497	.64066	.60863	.57870	.55071
4	.79209	.73503	.68301	.63552	.59208	.55229	.51579	.48225	.45140
5	.74726	.68058	.62092	.56743	.51937	.47611	.43711	.40188	.37000
6	.70496	.63017	.56447	.50663	.45559	.41044	.37043	.33490	.30328
7	.66506	.58349	.51316	.45235	.39964	.35383	.31393	.27908	.24859
8	.62741	.54027	.46651	.40388	.35056	.30503	.26604	.23257	.20376
9	.59190	.50025	.42410	.36061	.30751	.26295	.22546	.19381	.16702
10	.55839	.46319	.38554	.32197	.26974	.22668	.19106	.16151	.13690
11	.52679	.42888	.35049	.28748	.23662	.19542	.16192	.13459	.11221
12	.49697	.39711	.31863	.25668	.20756	.16846	.13722	.11216	.09198
13	.46884	.36770	.28966	.22917	.18207	.14523	.11629	.09346	.07539
14	.44230	.34046	.26333	.20462	.15971	.12520	.09855	.07789	.06180
15	.41727	.31524	.23939	.18270	.14010	.10793	.08352	.06491	.05065
16	.39365	.29189	.21763	.16312	.12289	.09304	.07078	.05409	.04152
17	.37136	.27027	.19784	.14564	.10780	.08021	.05998	.04507	.03403
18	.35034	.25025	.17986	.13004	.09456	.06914	.05083	.03756	.02789
19	.33051	.23171	.16351	.11611	.08295	.05961	.04308	.03130	.02286
20	.31180	.21455	.14864	.10367	.07276	.05139	.03651	.02608	.01874
25	.23300	.14602	.09230	.05882	.03779	.02447	.01596	.01048	.00693
30	.17411	.09938	.05731	.03338	.01963	.01165	.00697	.00421	.00257
40	.09722	.04603	.02209	.01075	.00529	.00264	.00133	.00068	.00035
50	.05429	.02132	.00852	.00346	.00143	.00060	.00025	.00011	.00005
60	.03031	.00988	.00328	.00111	.00039	.00014	.00005	.00002	.00001

FORMULA:  $x' = [1 + (r/100)]^{-n} = 1/x$ .

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $y'$ (interest compounded continuously: $P = A \times y'$ )									
1	.94176	.92312	.90484	.88692	.86936	.85214	.83527	.81873	.80252
2	.88692	.85214	.81873	.78663	.75578	.72615	.69768	.67032	.64404
3	.83527	.78663	.74082	.69768	.65705	.61878	.58275	.54881	.51685
4	.78663	.72615	.67032	.61878	.57121	.52729	.48675	.44933	.41478
5	.74082	.67032	.60653	.54881	.49659	.44933	.40657	.36788	.33287
6	.69768	.61878	.54881	.48675	.43171	.38289	.33960	.30119	.26714
7	.65705	.57121	.49659	.43171	.37531	.32628	.28365	.24660	.21438
8	.61878	.52729	.44933	.38289	.32628	.27804	.23693	.20190	.17204
9	.58275	.48675	.40657	.33960	.28365	.23693	.19790	.16530	.13807
10	.54881	.44933	.36788	.30119	.24660	.20190	.16530	.13534	.11080
11	.51685	.41478	.33287	.26714	.21438	.17204	.13807	.11080	.08892
12	.48675	.38289	.30119	.23693	.18637	.14661	.11533	.09072	.07136
13	.45841	.35345	.27253	.21014	.16203	.12493	.09633	.07427	.05727
14	.43171	.32628	.24660	.18637	.14086	.10646	.08046	.06081	.04596
15	.40657	.30119	.22313	.16530	.12246	.09072	.06721	.04979	.03688
16	.38289	.27804	.20190	.14661	.10646	.07730	.05613	.04076	.02960
17	.36059	.25666	.18268	.13003	.09255	.06587	.04689	.03375	.02375
18	.33960	.23693	.16530	.11533	.08046	.05613	.03916	.02732	.01906
19	.31982	.21871	.14957	.10228	.06995	.04783	.03271	.02237	.01530
20	.30119	.20190	.13534	.09072	.06081	.04076	.02732	.01832	.01228
25	.22313	.13534	.08208	.04979	.03020	.01832	.01111	.00674	.00409
30	.16530	.09072	.04979	.02732	.01500	.00823	.00452	.00248	.00136
40	.09072	.04076	.01832	.00823	.00370	.00166	.00075	.00034	.00015
50	.04979	.01832	.00674	.00248	.00091	.00034	.00012	.00005	.00002
60	.02732	.00823	.00248	.00075	.00022	.00007	.00002	.00001	.00000

FORMULA:  $y' = e^{-(r/100) \times n} = 1/y$ .

**Table 1.1.7 Amount of an Annuity**

The amount  $S$  accumulated at the end of  $n$  years by a given annual payment  $Y$  set aside at the end of each year is  $S = Y \times v$ , where the factor  $v$  is to be taken from the following table (interest at  $r$  percent per annum, compounded annually).

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $v$									
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	2.0600	2.0800	2.1000	2.1200	2.1400	2.1600	2.1800	2.2000	2.2200
3	3.1836	3.2464	3.3100	3.3744	3.4396	3.5056	3.5724	3.6400	3.7084
4	4.3746	4.5061	4.6410	4.7793	4.9211	5.0665	5.2154	5.3680	5.5242
5	5.6371	5.8666	6.1051	6.3528	6.6101	6.8771	7.1542	7.4416	7.7396
6	6.9753	7.3359	7.7156	8.1152	8.5355	8.9775	9.4420	9.9299	10.442
7	8.3938	8.9228	9.4872	10.089	10.730	11.414	12.142	12.916	13.740
8	9.8975	10.637	11.436	12.300	13.233	14.240	15.327	16.499	17.762
9	11.491	12.488	13.579	14.776	16.085	17.519	19.086	20.799	22.670
10	13.181	14.487	15.937	17.549	19.337	21.321	23.521	25.959	28.657
11	14.972	16.645	18.531	20.655	23.045	25.733	28.755	32.150	35.962
12	16.870	18.977	21.384	24.133	27.271	30.850	34.931	39.581	44.874
13	18.882	21.495	24.523	28.029	32.089	36.786	42.219	48.497	55.746
14	21.015	24.215	27.975	32.393	37.581	43.672	50.818	59.196	69.010
15	23.276	27.152	31.772	37.280	43.842	51.660	60.965	72.035	85.192
16	25.673	30.324	35.950	42.753	50.980	60.925	72.939	87.442	104.93
17	28.213	33.750	40.545	48.884	59.118	71.673	87.068	105.93	129.02
18	30.906	37.450	45.599	55.750	68.394	84.141	103.74	128.12	158.40
19	33.760	41.446	51.159	63.440	78.969	98.603	123.41	154.74	194.25
20	36.786	45.762	57.275	72.052	91.025	115.38	146.63	186.69	237.99
25	54.865	73.106	98.347	133.33	181.87	249.21	342.60	471.98	650.96
30	79.058	113.28	164.49	241.33	356.79	530.31	790.95	1181.9	1767.1
40	154.76	259.06	422.59	767.09	1342.0	2360.8	4163.2	7343.9	12936.5
50	290.34	573.77	1163.9	2400.0	4994.5	10435.6	21813.1	45497.2	94525.3
60	533.13	1253.2	3034.8	7471.6	18535.1	46057.5	114189.7	281732.6	690501.0

FORMULA:  $v = [1 + (r/100)]^n - 1 \div (r/100) = (x - 1) \div (r/100)$ .

**Table 1.1.8 Annuity Which Will Amount to a Given Sum (Sinking Fund)**

The annual payment  $Y$  which, if set aside at the end of each year, will amount with accumulated interest to a given sum  $S$  at the end of  $n$  years is  $Y = S \times v'$ , where the factor  $v'$  is given below (interest at  $r$  percent per annum, compounded annually).

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $v'$									
1	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000	1.00000
2	.48544	.48077	.47619	.47170	.46729	.46296	.45872	.45455	.45045
3	.31411	.30803	.30211	.29635	.29073	.28526	.27992	.27473	.26966
4	.22859	.22192	.21547	.20923	.20320	.19738	.19174	.18629	.18102
5	.17740	.17046	.16380	.15741	.15128	.14541	.13978	.13438	.12921
6	.14336	.13632	.12961	.12323	.11716	.11139	.10591	.10071	.09576
7	.11914	.11207	.10541	.09912	.09319	.08761	.08236	.07742	.07278
8	.10104	.09401	.08744	.08130	.07557	.07022	.06524	.06061	.05630
9	.08702	.08008	.07364	.06768	.06217	.05708	.05239	.04808	.04411
10	.07587	.06903	.06275	.05698	.05171	.04690	.04251	.03852	.03489
11	.06679	.06008	.05396	.04842	.04339	.03886	.03478	.03110	.02781
12	.05928	.05270	.04676	.04144	.03667	.03241	.02863	.02526	.02228
13	.05296	.04652	.04078	.03568	.03116	.02718	.02369	.02062	.01794
14	.04758	.04130	.03575	.03087	.02661	.02290	.01968	.01689	.01449
15	.04296	.03683	.03147	.02682	.02281	.01936	.01640	.01388	.01174
16	.03895	.03298	.02782	.02339	.01962	.01641	.01371	.01144	.00953
17	.03544	.02963	.02466	.02046	.01692	.01395	.01149	.00944	.00775
18	.03236	.02670	.02193	.01794	.01462	.01188	.00964	.00781	.00631
19	.02962	.02413	.01955	.01576	.01266	.01014	.00810	.00646	.00515
20	.02718	.02185	.01746	.01388	.01099	.00867	.00682	.00536	.00420
25	.01823	.01368	.01017	.00750	.00550	.00401	.00292	.00212	.00154
30	.01265	.00883	.00608	.00414	.00280	.00189	.00126	.00085	.00057
40	.00646	.00386	.00226	.00130	.00075	.00042	.00024	.00014	.00008
50	.00344	.00174	.00086	.00042	.00020	.00010	.00005	.00002	.00001
60	.00188	.00080	.00033	.00013	.00005	.00002	.00001	.00000	.00000

FORMULA:  $v' = (r/100) \div [1 + (r/100)]^n - 1 = 1/v$ .

1-8 MATHEMATICAL TABLES

**Table 1.1.9 Present Worth of an Annuity**

The capital  $C$  which, if placed at interest today, will provide for a given annual payment  $Y$  for a term of  $n$  years before it is exhausted is  $C = Y \times w$ , where the factor  $w$  is given below (interest at  $r$  percent per annum, compounded annually).

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $w$									
1	.94340	.92590	.90910	.89290	.87720	.86210	.84750	.83330	.81970
2	1.8334	1.7833	1.7355	1.6901	1.6467	1.6052	1.5656	1.5278	1.4915
3	2.6730	2.5771	2.4869	2.4018	2.3216	2.2459	2.1743	2.1065	2.0422
4	3.4651	3.3121	3.1699	3.0373	2.9137	2.7982	2.6901	2.5887	2.4936
5	4.2124	3.9927	3.7908	3.6048	3.4331	3.2743	3.1272	2.9906	2.8636
6	4.9173	4.6229	4.3553	4.1114	3.8887	3.6847	3.4976	3.3255	3.1669
7	5.5824	5.2064	4.8684	4.5638	4.2883	4.0386	3.8115	3.6046	3.4155
8	6.2098	5.7466	5.3349	4.9676	4.6389	4.3436	4.0776	3.8372	3.6193
9	6.8017	6.2469	5.7590	5.3282	4.9464	4.6065	4.3030	4.0310	3.7863
10	7.3601	6.7101	6.1446	5.6502	5.2161	4.8332	4.4941	4.1925	3.9232
11	7.8869	7.1390	6.4951	5.9377	5.4527	5.0286	4.6560	4.3271	4.0354
12	8.3838	7.5361	6.8137	6.1944	5.6603	5.1971	4.7932	4.4392	4.1274
13	8.8527	7.9038	7.1034	6.4235	5.8424	5.3423	4.9095	4.5327	4.2028
14	9.2950	8.2442	7.3667	6.6282	6.0021	5.4675	5.0081	4.6106	4.2646
15	9.7122	8.5595	7.6061	6.8109	6.1422	5.5755	5.0916	4.6755	4.3152
16	10.106	8.8514	7.8237	6.9740	6.2651	5.6685	5.1624	4.7296	4.3567
17	10.477	9.1216	8.0216	7.1196	6.3729	5.7487	5.2223	4.7746	4.3908
18	10.828	9.3719	8.2014	7.2497	6.4674	5.8178	5.2732	4.8122	4.4187
19	11.158	9.6036	8.3649	7.3658	6.5504	5.8775	5.3162	4.8435	4.4415
20	11.470	9.8181	8.5136	7.4694	6.6231	5.9288	5.3527	4.8696	4.4603
25	12.783	10.675	9.0770	7.8431	6.8729	6.0971	5.4669	4.9476	4.5139
30	13.765	11.258	9.4269	8.0552	7.0027	6.1772	5.5168	4.9789	4.5338
40	15.046	11.925	9.7791	8.2438	7.1050	6.2335	5.5482	4.9966	4.5439
50	15.762	12.233	9.9148	8.3045	7.1327	6.2463	5.5541	4.9995	4.5452
60	16.161	12.377	9.9672	8.3240	7.1401	6.2492	5.5553	4.9999	4.5454

FORMULA:  $w = [1 - [1 + (r/100)]^{-n}] \div [r/100] = v/x$ .

**Table 1.1.10 Annuity Provided for by a Given Capital**

The annual payment  $Y$  provided for a term of  $n$  years by a given capital  $C$  placed at interest today is  $Y = C \times w'$  (interest at  $r$  percent per annum, compounded annually; the fund supposed to be exhausted at the end of the term).

Years	$r = 6$	8	10	12	14	16	18	20	22
Values of $w'$									
1	1.0600	1.0800	1.1000	1.1200	1.1400	1.1600	1.1800	1.2000	1.2200
2	.54544	.56077	.57619	.59170	.60729	.62296	.63872	.65455	.67045
3	.37411	.38803	.40211	.41635	.43073	.44526	.45992	.47473	.48966
4	.28859	.30192	.31547	.32923	.34320	.35738	.37174	.38629	.40102
5	.23740	.25046	.26380	.27741	.29128	.30541	.31978	.33438	.34921
6	.20336	.21632	.22961	.24323	.25716	.27139	.28591	.30071	.31576
7	.17914	.19207	.20541	.21912	.23319	.24761	.26236	.27742	.29278
8	.16104	.17401	.18744	.20130	.21557	.23022	.24524	.26061	.27630
9	.14702	.16008	.17364	.18768	.20217	.21708	.23239	.24808	.26411
10	.13587	.14903	.16275	.17698	.19171	.20690	.22251	.23852	.25489
11	.12679	.14008	.15396	.16842	.18339	.19886	.21478	.23110	.24781
12	.11928	.13270	.14676	.16144	.17667	.19241	.20863	.22526	.24228
13	.11296	.12652	.14078	.15568	.17116	.18718	.20369	.22062	.23794
14	.10758	.12130	.13575	.15087	.16661	.18290	.19968	.21689	.23449
15	.10296	.11683	.13147	.14682	.16281	.17936	.19640	.21388	.23174
16	.09895	.11298	.12782	.14339	.15962	.17641	.19371	.21144	.22953
17	.09544	.10963	.12466	.14046	.15692	.17395	.19149	.20944	.22775
18	.09236	.10670	.12193	.13794	.15462	.17188	.18964	.20781	.22631
19	.08962	.10413	.11955	.13576	.15266	.17014	.18810	.20646	.22515
20	.08718	.10185	.11746	.13388	.15099	.16867	.18682	.20536	.22420
25	.07823	.09368	.11017	.12750	.14550	.16401	.18292	.20212	.22154
30	.07265	.08883	.10608	.12414	.14280	.16189	.18126	.20085	.22057
40	.06646	.08386	.10226	.12130	.14075	.16042	.18024	.20014	.22008
50	.06344	.08174	.10086	.12042	.14020	.16010	.18005	.20002	.22001
60	.06188	.08080	.10033	.12013	.14005	.16002	.18001	.20000	.22000

FORMULA:  $w' = [r/100] \div [1 - [1 + (r/100)]^{-n}] = 1/w = v' + (r/100)$ .



**Table 1.1.11 Ordinates of the Normal Density Function**

$$f(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2}$$

<i>x</i>	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.3989	.3989	.3989	.3988	.3986	.3984	.3982	.3980	.3977	.3973
.1	.3970	.3965	.3961	.3956	.3951	.3945	.3939	.3932	.3925	.3918
.2	.3910	.3902	.3894	.3885	.3876	.3867	.3857	.3847	.3836	.3825
.3	.3814	.3802	.3790	.3778	.3765	.3752	.3739	.3725	.3712	.3697
.4	.3683	.3668	.3653	.3637	.3621	.3605	.3589	.3572	.3555	.3538
.5	.3521	.3503	.3485	.3467	.3448	.3429	.3410	.3391	.3372	.3352
.6	.3332	.3312	.3292	.3271	.3251	.3230	.3209	.3187	.3166	.3144
.7	.3123	.3101	.3079	.3056	.3034	.3011	.2989	.2966	.2943	.2920
.8	.2897	.2874	.2850	.2827	.2803	.2780	.2756	.2732	.2709	.2685
.9	.2661	.2637	.2613	.2589	.2565	.2541	.2516	.2492	.2468	.2444
1.0	.2420	.2396	.2371	.2347	.2323	.2299	.2275	.2251	.2227	.2203
1.1	.2179	.2155	.2131	.2107	.2083	.2059	.2036	.2012	.1989	.1965
1.2	.1942	.1919	.1895	.1872	.1849	.1826	.1804	.1781	.1758	.1736
1.3	.1714	.1691	.1669	.1647	.1626	.1604	.1582	.1561	.1539	.1518
1.4	.1497	.1476	.1456	.1435	.1415	.1394	.1374	.1354	.1334	.1315
1.5	.1295	.1276	.1257	.1238	.1219	.1200	.1182	.1163	.1144	.1127
1.6	.1109	.1092	.1074	.1057	.1040	.1023	.1006	.0989	.0973	.0957
1.7	.0940	.0925	.0909	.0893	.0878	.0863	.0848	.0833	.0818	.0804
1.8	.0790	.0775	.0761	.0748	.0734	.0721	.0707	.0694	.0681	.0669
1.9	.0656	.0644	.0632	.0620	.0608	.0596	.0584	.0573	.0562	.0551
2.0	.0540	.0529	.0519	.0508	.0498	.0488	.0478	.0468	.0459	.0449
2.1	.0440	.0431	.0422	.0413	.0404	.0396	.0387	.0379	.0371	.0363
2.2	.0355	.0347	.0339	.0332	.0325	.0317	.0310	.0303	.0297	.0290
2.3	.0283	.0277	.0270	.0264	.0258	.0252	.0246	.0241	.0235	.0229
2.4	.0224	.0219	.0213	.0208	.0203	.0198	.0194	.0189	.0184	.0180
2.5	.0175	.0171	.0167	.0163	.0158	.0154	.0151	.0147	.0143	.0139
2.6	.0136	.0132	.0129	.0126	.0122	.0119	.0116	.0113	.0110	.0107
2.7	.0104	.0101	.0099	.0096	.0093	.0091	.0088	.0086	.0084	.0081
2.8	.0079	.0077	.0075	.0073	.0071	.0069	.0067	.0065	.0063	.0061
2.9	.0060	.0058	.0056	.0055	.0053	.0051	.0050	.0048	.0047	.0046
3.0	.0044	.0043	.0042	.0040	.0039	.0038	.0037	.0036	.0035	.0034
3.1	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026	.0025	.0025
3.2	.0024	.0023	.0022	.0022	.0021	.0020	.0020	.0019	.0018	.0018
3.3	.0017	.0017	.0016	.0016	.0015	.0015	.0014	.0014	.0013	.0013
3.4	.0012	.0012	.0012	.0011	.0011	.0010	.0010	.0010	.0009	.0009
3.5	.0009	.0008	.0008	.0008	.0008	.0007	.0007	.0007	.0007	.0006
3.6	.0006	.0006	.0006	.0005	.0005	.0005	.0005	.0005	.0005	.0004
3.7	.0004	.0004	.0004	.0004	.0004	.0004	.0003	.0003	.0003	.0003
3.8	.0003	.0003	.0003	.0003	.0003	.0002	.0002	.0002	.0002	.0002
3.9	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0001	.0001

NOTE: *x* is the value in left-hand column + the value in top row.  
*f(x)* is the value in the body of the table. Example: *x* = 2.14; *f(x)* = 0.0404.

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**Table 1.1.12 Cumulative Normal Distribution**

$$F(x) = \int_{-\infty}^x \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt$$

x	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5735
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7703	.7734	.7764	.7793	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8906	.8925	.8943	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9812	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9986	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

NOTE:  $x = (a - \mu)/\sigma$  where  $a$  is the observed value,  $\mu$  is the mean, and  $\sigma$  is the standard deviation.  
 $x$  is the value in the left-hand column + the value in the top row.  
 $F(x)$  is the probability that a point will be less than or equal to  $x$ .  
 $F(x)$  is the value in the body of the table. *Example:* The probability that an observation will be less than or equal to 1.04 is .8508.  
 NOTE:  $F(-x) = 1 - F(x)$ .

**Table 1.1.13 Cumulative Chi-Square Distribution**

$$F(t) = \int_0^t \frac{x^{(n-2)/2} e^{-x/2} dx}{2^{n/2} [(n-2)/2]!}$$

<i>n</i> \ <i>F</i>	.005	.010	.025	.050	.100	.250	.500	.750	.900	.950	.975	.990	.995
1	.000039	.00016	.00098	.0039	.0158	.101	.455	1.32	2.70	3.84	5.02	6.62	7.86
2	.0100	.0201	.0506	.103	.211	.575	1.39	2.77	4.61	5.99	7.38	9.21	10.6
3	.0717	.155	.216	.352	.584	1.21	2.37	4.11	6.25	7.81	9.35	11.3	12.8
4	.207	.297	.484	.711	1.06	1.92	3.36	5.39	7.78	9.49	11.1	13.3	14.9
5	.412	.554	.831	1.15	1.61	2.67	4.35	6.63	9.24	11.1	12.8	15.1	16.7
6	.676	.872	1.24	1.64	2.20	3.45	5.35	7.84	10.6	12.6	14.4	16.8	18.5
7	.989	1.24	1.69	2.17	2.83	4.25	6.35	9.04	12.0	14.1	16.0	18.5	20.3
8	1.34	1.65	2.18	2.73	3.49	5.07	7.34	10.2	13.4	15.5	17.5	20.1	22.0
9	1.73	2.09	2.70	3.33	4.17	5.90	8.34	11.4	14.7	16.9	19.0	21.7	23.6
10	2.16	2.56	3.25	3.94	4.87	6.74	9.34	12.5	16.0	18.3	20.5	23.2	25.2
11	2.60	3.05	3.82	4.57	5.58	7.58	10.3	13.7	17.3	19.7	21.9	24.7	26.8
12	3.07	3.57	4.40	5.23	6.30	8.44	11.3	14.8	18.5	21.0	23.3	26.2	28.3
13	3.57	4.11	5.01	5.89	7.04	9.30	12.3	16.0	19.8	22.4	24.7	27.7	29.8
14	4.07	4.66	5.63	6.57	7.79	10.2	13.3	17.1	21.1	23.7	26.1	29.1	31.3
15	4.60	5.23	6.26	7.26	8.55	11.0	14.3	18.2	22.3	25.0	27.5	30.6	32.8
16	5.14	5.81	6.91	7.96	9.31	11.9	15.3	19.4	23.5	26.3	28.8	32.0	34.3
17	5.70	6.41	7.56	8.67	10.1	12.8	16.3	20.5	24.8	27.6	30.2	33.4	35.7
18	6.26	7.01	8.23	9.39	10.9	13.7	17.3	21.6	26.0	28.9	31.5	34.8	37.2
19	6.84	7.63	8.91	10.1	11.7	14.6	18.3	22.7	27.2	30.1	32.9	36.2	38.6
20	7.43	8.26	9.59	10.9	12.4	15.5	19.3	23.8	28.4	31.4	34.2	37.6	40.0
21	8.03	8.90	10.3	11.6	13.2	16.3	20.3	24.9	29.6	32.7	35.5	38.9	41.4
22	8.64	9.54	11.0	12.3	14.0	17.2	21.3	26.0	30.8	33.9	36.8	40.3	42.8
23	9.26	10.2	11.7	13.1	14.8	18.1	22.3	27.1	32.0	35.2	38.1	41.6	44.2
24	9.89	10.9	12.4	13.8	15.7	19.0	23.3	28.2	33.2	36.4	39.4	43.0	45.6
25	10.5	11.5	13.1	14.6	16.5	19.9	24.3	29.3	34.4	37.7	40.6	44.3	46.9
26	11.2	12.2	13.8	15.4	17.3	20.8	25.3	30.4	35.6	38.9	41.9	45.6	48.3
27	11.8	12.9	14.6	16.2	18.1	21.7	26.3	31.5	36.7	40.1	43.2	47.0	49.6
28	12.5	13.6	15.3	16.9	18.9	22.7	27.3	32.6	37.9	41.3	44.5	48.3	51.0
29	13.1	14.3	16.0	17.7	19.8	23.6	28.3	33.7	39.1	42.6	45.7	49.6	52.3
30	13.8	15.0	16.8	18.5	20.6	24.5	29.3	34.8	40.3	43.8	47.0	50.9	53.7

NOTE: *n* is the number of degrees of freedom.  
 Values for *t* are in the body of the table. Example: The probability that, with 16 degrees of freedom, a point will be  $\leq 23.5$  is .900.

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Table 1.1.14 Cumulative "Student's" Distribution

$$F(t) = \int_{-\infty}^t \frac{\left(\frac{n-1}{2}\right)!}{\left(\frac{n-2}{2}\right)! \sqrt{\pi n} \left(1 + \frac{x^2}{n}\right)^{(n+1)/2}} dx$$

n \ F	F						
	.75	.90	.95	.975	.99	.995	.9995
1	1.000	3.078	6.314	12.70	31.82	63.66	636.3
2	.816	1.886	2.920	4.303	6.965	9.925	31.60
3	.765	1.638	2.353	3.182	4.541	5.841	12.92
4	.741	1.533	2.132	2.776	3.747	4.604	8.610
5	.727	1.476	2.015	2.571	3.365	4.032	6.859
6	.718	1.440	1.943	2.447	3.143	3.707	5.959
7	.711	1.415	1.895	2.365	2.998	3.499	5.408
8	.706	1.397	1.860	2.306	2.896	3.355	5.041
9	.703	1.383	1.833	2.262	2.821	3.250	4.781
10	.700	1.372	1.812	2.228	2.764	3.169	4.587
11	.697	1.363	1.796	2.201	2.718	3.106	4.437
12	.695	1.356	1.782	2.179	2.681	3.055	4.318
13	.694	1.350	1.771	2.160	2.650	3.012	4.221
14	.692	1.345	1.761	2.145	2.624	2.977	4.140
15	.691	1.341	1.753	2.131	2.602	2.947	4.073
16	.690	1.337	1.746	2.120	2.583	2.921	4.015
17	.689	1.333	1.740	2.110	2.567	2.898	3.965
18	.688	1.330	1.734	2.101	2.552	2.878	3.922
19	.688	1.328	1.729	2.093	2.539	2.861	3.883
20	.687	1.325	1.725	2.086	2.528	2.845	3.850
21	.686	1.323	1.721	2.080	2.518	2.831	3.819
22	.686	1.321	1.717	2.074	2.508	2.819	3.792
23	.685	1.319	1.714	2.069	2.500	2.807	3.768
24	.685	1.318	1.711	2.064	2.492	2.797	3.745
25	.684	1.316	1.708	2.060	2.485	2.787	3.725
26	.684	1.315	1.706	2.056	2.479	2.779	3.707
27	.684	1.314	1.703	2.052	2.473	2.771	3.690
28	.683	1.313	1.701	2.048	2.467	2.763	3.674
29	.683	1.311	1.699	2.045	2.462	2.756	3.659
30	.683	1.310	1.697	2.042	2.457	2.750	3.646
40	.681	1.303	1.684	2.021	2.423	2.704	3.551
60	.679	1.296	1.671	2.000	2.390	2.660	3.460
120	.677	1.289	1.658	1.980	2.385	2.617	3.373

NOTE: n is the number of degrees of freedom.

Values for t are in the body of the table. Example: The probability that, with 16 degrees of freedom, a point will be  $\leq 2.921$  is .995.

NOTE:  $F(-t) = 1 - F(t)$ .



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**Table 1.1.16 Standard Distribution of Residuals**

$a$  = any positive quantity  
 $y$  = the number of residuals which are numerically  $< a$   
 $r$  = the probable error of a single observation  
 $n$  = number of observations

$\frac{a}{r}$	$\frac{y}{n}$	Diff	$\frac{a}{r}$	$\frac{y}{n}$	Diff
0.0	.000		2.5	.908	13
1	.054	54	6	.921	10
2	.107	53	7	.931	10
3	.160	53	8	.941	9
4	.213	51	9	.950	7
0.5	.264		3.0	.957	
6	.314	50	1	.963	6
7	.363	49	2	.969	6
8	.411	48	3	.974	5
9	.456	45	4	.978	4
		44			4
1.0	.500		3.5	.982	
1	.542	42	6	.985	3
2	.582	40	7	.987	2
3	.619	37	8	.990	3
4	.655	36	9	.991	1
		33			2
1.5	.688		4.0	.993	
6	.719	31			6
7	.748	29	5.0	.999	
8	.775	27			
9	.800	25			
		23			
2.0	.823				
1	.843	20			
2	.862	19			
3	.879	17			
4	.895	16			
		13			

**Table 1.1.17 Factors for Computing Probable Error**

$n$	Bessel		Peters		$n$	Bessel		Peters	
	$\frac{0.6745}{\sqrt{(n-1)}}$	$\frac{0.6745}{\sqrt{n(n-1)}}$	$\frac{0.8453}{\sqrt{n(n-1)}}$	$\frac{0.8453}{n\sqrt{n-1}}$		$\frac{0.6745}{\sqrt{(n-1)}}$	$\frac{0.6745}{\sqrt{n(n-1)}}$	$\frac{0.8453}{\sqrt{n(n-1)}}$	$\frac{0.8453}{n\sqrt{n-1}}$
2	.6745	.4769	.5978	.4227	30	.1252	.0229	.0287	.0052
3	.4769	.2754	.3451	.1993	31	.1231	.0221	.0277	.0050
4	.3894	.1947	.2440	.1220	32	.1211	.0214	.0268	.0047
5	.3372	.1508	.1890	.0845	33	.1192	.0208	.0260	.0045
6	.3016	.1231	.1543	.0630	34	.1174	.0201	.0252	.0043
7	.2754	.1041	.1304	.0493	35	.1157	.0196	.0245	.0041
8	.2549	.0901	.1130	.0399	36	.1140	.0190	.0238	.0040
9	.2385	.0795	.0996	.0332	37	.1124	.0185	.0232	.0038
10	.2248	.0711	.0891	.0282	38	.1109	.0180	.0225	.0037
11	.2133	.0643	.0806	.0243	39	.1094	.0175	.0220	.0035
12	.2034	.0587	.0736	.0212	40	.1080	.0171	.0214	.0034
13	.1947	.0540	.0677	.0188	45	.1017	.0152	.0190	.0028
14	.1871	.0500	.0627	.0167	50	.0964	.0136	.0171	.0024
15	.1803	.0465	.0583	.0151	55	.0918	.0124	.0155	.0021
16	.1742	.0435	.0546	.0136	60	.0878	.0113	.0142	.0018
17	.1686	.0409	.0513	.0124	65	.0843	.0105	.0131	.0016
18	.1636	.0386	.0483	.0114	70	.0812	.0097	.0122	.0015
19	.1590	.0365	.0457	.0105	75	.0784	.0091	.0113	.0013
20	.1547	.0346	.0434	.0097	80	.0759	.0085	.0106	.0012
21	.1508	.0329	.0412	.0090	85	.0736	.0080	.0100	.0011
22	.1472	.0314	.0393	.0084	90	.0715	.0075	.0094	.0010
23	.1438	.0300	.0376	.0078	95	.0696	.0071	.0089	.0009
24	.1406	.0287	.0360	.0073	100	.0678	.0068	.0085	.0008
25	.1377	.0275	.0345	.0069					
26	.1349	.0265	.0332	.0065					
27	.1323	.0255	.0319	.0061					
28	.1298	.0245	.0307	.0058					
29	.1275	.0237	.0297	.0055					

Table 1.1.18 Decimal Equivalents

From minutes and seconds into decimal parts of a degree				From decimal parts of a degree into minutes and seconds (exact values)				Common fractions										
								8 ths	16 ths	32 nds	64 ths	Exact decimal values						
0'	0°.0000	0"	0°.0000	0°.00	0'	0°.50	30'						.01 5625					
1	.0167	1	.0003	1	0' 36"	1	30' 36"						.03 125					
2	.0333	2	.0006	2	1' 12"	2	31' 12"						.04 6875					
3	.05	3	.0008	3	1' 48"	3	31' 48"						.06 25					
4	.0667	4	.0011	4	2' 24"	4	32' 24"		1	2	4	5	.07 8125					
5'	.0833	5"	.0014	0°.05	3'	0°.55	33'					3	6	.09 375				
6	.10	6	.0017	6	3' 36"	6	33' 36"						7	.10 9375				
7	.1167	7	.0019	7	4' 12"	7	34' 12"	1	2	4	8		8	.12 5				
8	.1333	8	.0022	8	4' 48"	8	34' 48"						9	.14 0625				
9	.15	9	.0025	9	5' 24"	9	35' 24"						5	10	.15 625			
10'	0°.1667	10"	0°.0028	0°.10	6'	0°.60	36'						11	.17 1875				
1	.1833	1	.0031	1	6' 36"	1	36' 36"						3	6	12	.18 75		
2	.20	2	.0033	2	7' 12"	2	37' 12"						6	12	13	.20 3125		
3	.2167	3	.0036	3	7' 48"	3	37' 48"						7	14	14	.21 875		
4	.2333	4	.0039	4	8' 24"	4	38' 24"							15	15	.23 4375		
15'	.25	15"	.0042	0°.15	9'	0°.65	39'	2	4	8	16		16	.25				
6	.2667	6	.0044	6	9' 36"	6	39' 36"						8	16	17	.26 5625		
7	.2833	7	.0047	7	10' 12"	7	40' 12"						9	18	18	.28 125		
8	.30	8	.005	8	10' 48"	8	40' 48"							19	19	.29 6875		
9	.3167	9	.0053	9	11' 24"	9	41' 24"			5	10	20		20	.31 25			
20'	0°.3333	20"	0°.0056	0°.20	12'	0°.70	42'							21	.32 8125			
1	.35	1	.0058	1	12' 36"	1	42' 36"						11	22	22	.34 375		
2	.3667	2	.0061	2	13' 12"	2	43' 12"							23	.35 9375			
3	.3833	3	.0064	3	13' 48"	3	43' 48"	3	6	12	24		24	.37 5				
4	.40	4	.0067	4	14' 24"	4	44' 24"							25	.39 0625			
25'	.4167	25"	.0069	0°.25	15'	0°.75	45'						13	26	.40 625			
6	.4333	6	.0072	6	15' 36"	6	45' 36"							27	.42 1875			
7	.45	7	.0075	7	16' 12"	7	46' 12"						7	14	28	.43 75		
8	.4667	8	.0078	8	16' 48"	8	46' 48"							29	.45 3125			
9	.4833	9	.0081	9	17' 24"	9	47' 24"							15	30	.46 875		
30'	0°.50	30"	0°.0083	0°.30	18'	0°.80	48'							31	.48 4375			
1	.5167	1	.0086	1	18' 36"	1	48' 36"	4	8	16	32		32	.50				
2	.5333	2	.0089	2	19' 12"	2	49' 12"							33	.51 5625			
3	.55	3	.0092	3	19' 48"	3	49' 48"							17	34	.53 125		
4	.5667	4	.0094	4	20' 24"	4	50' 24"							35	.54 6875			
35'	.5833	35"	.0097	0°.35	21'	0°.85	51'			9	18		36	.56 25				
6	.60	6	.01	6	21' 36"	6	51' 36"							37	.57 8125			
7	.6167	7	.0103	7	22' 12"	7	52' 12"							19	38	.59 375		
8	.6333	8	.0106	8	22' 48"	8	52' 48"								39	.60 9375		
9	.65	9	.0108	9	23' 24"	9	53' 24"	5	10	20	40		40	.62 5				
40'	0°.6667	40"	0°.0111	0°.40	24'	0°.90	54'							41	.64 0625			
1	.6833	1	.0114	1	24' 36"	1	54' 36"							21	42	.65 625		
2	.70	2	.0117	2	25' 12"	2	55' 12"								43	.67 1875		
3	.7167	3	.0119	3	25' 48"	3	55' 48"							11	22	44	.68 75	
4	.7333	4	.0122	4	26' 24"	4	56' 24"								45	.70 3125		
45'	.75	45"	.0125	0°.45	27'	0°.95	57'							23	46	.71 875		
6	.7667	6	.0128	6	27' 36"	6	57' 36"								47	.73 4375		
7	.7833	7	.0131	7	28' 12"	7	58' 12"								48	.75		
8	.80	8	.0133	8	28' 48"	8	58' 48"	6	12	24	48		49	.76 5625				
9	.8167	9	.0136	9	29' 24"	9	59' 24"							25	50	.78 125		
50'	0°.8333	50"	0°.0139	0°.50	30'	1°.00	60'								51	.79 6875		
1	.85	1	.0142											13	26	52	.81 25	
2	.8667	2	.0144		0°.000	0".0									53	.82 8125		
3	.8833	3	.0147		1	3".6								27	54	.84 375		
4	.90	4	.015		2	7".2									55	.85 9375		
55'	.9167	55"	.0153		3	10".8								7	14	28	56	.87 5
6	.9333	6	.0156		4	14".4									57	.89 0625		
7	.95	7	.0158		0°.005	18"									29	58	.90 625	
8	.9667	8	.0161		6	21".6									59	.92 1875		
9	.9833	9	.0164		7	25".2								15	30	60	.93 75	
60'	1.00	60"	0°.0167		8	28".8									61	.95 3125		
					9	32".4									31	62	.96 875	
					0°.010	36"										63	.98 4375	

## 1.2 MEASURING UNITS

by David T. Goldman

REFERENCES: "International Critical Tables," McGraw-Hill. "Smithsonian Physical Tables," Smithsonian Institution. "Landolt-Börnstein: Zahlenwerte und Funktionen aus Physik, Chemie, Astronomie, Geophysik und Technik," Springer. "Handbook of Chemistry and Physics," Chemical Rubber Co. "Units and Systems of Weights and Measures; Their Origin, Development, and Present Status," NBS LC 1035 (1976). "Weights and Measures Standards of the United States, a Brief History," NBS Spec. Pub. 447 (1976). "Standard Time," Code of Federal Regulations, Title 49. "Fluid Meters, Their Theory and Application," 6th ed., chaps. 1-2, ASME, 1971. H. E. Huntley, "Dimensional Analysis," Richard & Co., New York, 1951. "U.S. Standard Atmosphere, 1962," Government Printing Office. Public Law 89-387. "Uniform Time Act of 1966." Public Law 94-168. "Metric Conversion Act of 1975." ASTM E380-91a, "Use of the International Standards of Units (SI) (the Modernized Metric System)." The International System of Units," NIST Spec. Pub. 330. "Guidelines for Use of the Modernized Metric System," NBS LC 1120. "NBS Time and Frequency Dissemination Services," NBS Spec. Pub. 432. "Factors for High Precision Conversion," NBS LC 1071. American Society of Mechanical Engineers SI Series, ASME SI 1-9. Jespersen and Fitz-Randolph, "From Sundials to Atomic Clocks: Understanding Time and Frequency," NBS, Monograph 155. ANSI/IEEE Std 268-1992, "American National Standard for Metric Practice."

### U.S. CUSTOMARY SYSTEM (USCS)

The USCS, often called the "inch-pound system," is the system of units most commonly used for measures of weight and length (Table 1.2.1). The units are identical for practical purposes with the corresponding English units, but the capacity measures differ from those used in the British Commonwealth, the U.S. gallon being defined as 231 cu in and the bushel as 2,150.42 cu in, whereas the corresponding British Imperial units are, respectively, 277.42 cu in and 2,219.36 cu in (1 Imp gal = 1.2 U.S. gal, approx; 1 Imp bu = 1.03 U.S. bu, approx).

**Table 1.2.1 U.S. Customary Units**

Units of length	
12 inches	= 1 foot
3 feet	= 1 yard
5½ yards = 16½ feet	= 1 rod, pole, or perch
40 poles = 220 yards	= 1 furlong
8 furlongs = 1,760 yards = 5,280 feet	= 1 mile
3 miles	= 1 league
4 inches	= 1 hand
9 inches	= 1 span
Nautical units	
6,076.11549 feet	= 1 international nautical mile
6 feet	= 1 fathom
120 fathoms	= 1 cable length
1 nautical mile per hr	= 1 knot
Surveyor's or Gunter's units	
7.92 inches	= 1 link
100 links = 66 ft = 4 rods	= 1 chain
80 chains	= 1 mile
33⅓ inches	= 1 vara (Texas)
Units of area	
144 square inches	= 1 square foot
9 square feet	= 1 square yard
30¼ square yards	= 1 square rod, pole, or perch

160 square rods = 10 square chains = 43,560 square feet = 5,645 sq varas (Texas)	}	= 1 acre
640 acres = 1 square mile =		{ 1 "section" of U.S. government-surveyed land
1 circular inch = area of circle 1 inch in diameter	}	= 0.7854 sq in
1 square inch		= 1.2732 circular inches
1 circular mil		= area of circle 0.001 in in diam
1,000,000 cir mils		= 1 circular inch

### Units of volume

1,728 cubic inches	= 1 cubic foot
231 cubic inches	= 1 gallon
27 cubic feet	= 1 cubic yard
1 cord of wood	= 128 cubic feet
1 perch of masonry	= 16½ to 25 cu ft

### Liquid or fluid measurements

4 gills	= 1 pint
2 pints	= 1 quart
4 quarts	= 1 gallon
7.4805 gallons	= 1 cubic foot

(There is no standard liquid barrel; by trade custom, 1 bbl of petroleum oil, unrefined = 42 gal. The capacity of the common steel barrel used for refined petroleum products and other liquids is 55 gal.)

### Apothecaries' liquid measurements

60 minims	= 1 liquid dram or drachm
8 drams	= 1 liquid ounce
16 ounces	= 1 pint

### Water measurements

The miner's inch is a unit of water volume flow no longer used by the Bureau of Reclamation. It is used within particular water districts where its value is defined by statute. Specifically, within many of the states of the West the miner's inch is ½ cubic foot per second. In others it is equal to ¼ cubic foot per second, while in the state of Colorado, 38.4 miner's inch is equal to 1 cubic-foot per second. In SI units, these correspond to .32 × 10<sup>-6</sup> m<sup>3</sup>/s, .409 × 10<sup>-6</sup> m<sup>3</sup>/s, and .427 × 10<sup>-6</sup> m<sup>3</sup>/s, respectively.

### Dry measures

2 pints	= 1 quart
8 quarts	= 1 peck
4 pecks	= 1 bushel
1 std bbl for fruits and vegetables = 7,056 cu in or 105 dry qt, struck measure	

### Shipping measures

1 Register ton	= 100 cu ft
1 U.S. shipping ton	= 40 cu ft
	= 32.14 U.S. bu or 31.14 Imp bu
1 British shipping ton	= 42 cu ft
	= 32.70 Imp bu or 33.75 U.S. bu

### Board measurements

(Based on nominal not actual dimensions; see Table 12.2.8)

1 board foot =	{ 144 cu in = volume of board 1 ft sq and 1 in thick
----------------	---

The international log rule, based upon ¼ in kerf, is expressed by the formula

$$X = 0.904762(0.22 D^2 - 0.71 D)$$

where  $X$  is the number of board feet in a 4-ft section of a log and  $D$  is the top diam in in. In computing the number of board feet in a log, the taper is taken at ½ in per 4 ft linear, and separate computation is made for each 4-ft section.



THE INTERNATIONAL SYSTEM OF UNITS (SI) 1-17

Weights (The grain is the same in all systems.)	
Avoirdupois weights	
16 drams = 437.5 grains	= 1 ounce
16 ounces = 7,000 grains	= 1 pound
100 pounds	= 1 cental
2,000 pounds	= 1 short ton
2,240 pounds	= 1 long ton
1 std lime bbl, small	= 180 lb net
1 std lime bbl, large	= 280 lb net
Also (in Great Britain):	
14 pounds	= 1 stone
2 stone = 28 pounds	= 1 quarter
4 quarters = 112 pounds	= 1 hundredweight (cwt)
20 hundredweight	= 1 long ton
Troy weights	
24 grains	= 1 pennyweight (dwt)
20 pennyweights = 480 grains	= 1 ounce
12 ounces = 5,760 grains	= 1 pound
1 assay ton = 29,167 milligrams, or as many milligrams as there are troy ounces in a ton of 2,000 lb avoirdupois. Consequently, the number of milligrams of precious metal yielded by an assay ton of ore gives directly the number of troy ounces that would be obtained from a ton of 2,000 lb avoirdupois.	
Apothecaries' weights	
20 grains	= 1 scruple ℥
3 scruples = 60 grains	= 1 dram ʒ
8 drams	= 1 ounce ʒ
12 ounces = 5,760 grains	= 1 pound
Weight for precious stones	
1 carat = 200 milligrams	
(Used by almost all important nations)	
Circular measures	
60 seconds	= 1 minute
60 minutes	= 1 degree
90 degrees	= 1 quadrant
360 degrees	= circumference
57.2957795 degrees	= 1 radian (or angle having
(= 57°17'44.806")	arc of length equal to radius)

**METRIC SYSTEM**

In the United States the name “metric system” of length and mass units is commonly taken to refer to a system that was developed in France about 1800. The unit of length was equal to 1/10,000,000 of a quarter meridian (north pole to equator) and named the **metre**. A cube 1/10th metre on a side was the **litre**, the unit of volume. The mass of water filling this cube was the **kilogram**, or standard of mass; i.e., 1 litre of water = 1 kilogram of mass. Metal bars and weights were constructed conforming to these prescriptions for the metre and kilogram. One bar and one weight were selected to be the primary representations. The kilogram and the metre are now defined independently, and the litre, although for many years defined as the volume of a kilogram of water at the temperature of its maximum density, 4°C, and under a pressure of 76 cm of mercury, is now equal to 1 cubic decimeter.

In 1866, the U.S. Congress formally recognized metric units as a legal system, thereby making their use permissible in the United States. In 1893, the Office of Weights and Measures (now the National Bureau of Standards), by executive order, fixed the values of the U.S. yard and pound in terms of the meter and kilogram, respectively, as 1 yard = 3,600/3,937 m; and 1 lb = 0.453 592 4277 kg. By agreement in 1959 among the **national standards laboratories of the English-speaking nations**, the relations in use now are: 1 yd = 0.9144 m, whence 1 in =

25.4 mm exactly; and 1 lb = 0.453 592 37 kg, or 1 lb = 453.59 g (nearly).

**THE INTERNATIONAL SYSTEM OF UNITS (SI)**

In October 1960, the Eleventh General (International) Conference on Weights and Measures redefined some of the original metric units and expanded the system to include other physical and engineering units. This expanded system is called, in French, **Le Système International d’Unités** (abbreviated **SI**), and in English, **The International System of Units**.

The **Metric Conversion Act of 1975** codifies the voluntary conversion of the U.S. to the SI system. It is expected that in time all units in the United States will be in SI form. For this reason, additional tables of units, prefixes, equivalents, and conversion factors are included below (Tables 1.2.2 and 1.2.3).

SI consists of **seven base units**, **two supplementary units**, a series of **derived units** consistent with the base and supplementary units, and a series of approved prefixes for the formation of multiples and submultiples of the various units (see Tables 1.2.2 and 1.2.3). Multiple and submultiple prefixes in steps of 1,000 are recommended. (See ASTM E380-91a for further details.)

**Base and supplementary units** are defined [NIST Spec. Pub. 330 (1991)] as:

**Metre** The metre is defined as the length of path traveled by light in a vacuum during a time interval 1/299 792 458 of a second.

**Kilogram** The kilogram is the unit of mass; it is equal to the mass of the international prototype of the kilogram.

**Second** The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium 133 atom.

**Ampere** The ampere is that constant current which, if maintained in two straight parallel conductors of infinite length, of negligible cross section, and placed 1 metre apart in vacuum, would produce between these conductors a force equal to  $2 \times 10^{-7}$  newton per metre of length.

**Kelvin** The kelvin, unit of thermodynamic temperature, is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water.

**Mole** The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon 12. (When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.)

**Candela** The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency  $540 \times 10^{12}$  hertz and that has a radiant intensity in that direction of  $\frac{1}{683}$  watt per steradian.

**Radian** The unit of measure of a plane angle with its vertex at the center of a circle and subtended by an arc equal in length to the radius.

**Steradian** The unit of measure of a solid angle with its vertex at the center of a sphere and enclosing an area of the spherical surface equal to that of a square with sides equal in length to the radius.

**SI conversion factors** are listed in Table 1.2.4 alphabetically (adapted from ASTM E380-91a, “Standard Practice for Use of the International System of Units (SI) (the Modernized Metric System).” Conversion factors are written as a number greater than one and less than ten with six or fewer decimal places. This number is followed by the letter E (for exponent), a plus or minus symbol, and two digits which indicate the power of 10 by which the number must be multiplied to obtain the correct value. For example:

$$3.523\ 907\ E - 02 \text{ is } 3.523\ 907 \times 10^{-2} \text{ or } 0.035\ 239\ 07$$

An asterisk (\*) after the sixth decimal place indicates that the conversion factor is exact and that all subsequent digits are zero. All other conversion factors have been rounded off.

1-18 MEASURING UNITS

**Table 1.2.2 SI Units**

Quantity	Unit	SI symbol	Formula
Base units*			
Length	metre	m	
Mass	kilogram	kg	
Time	second	s	
Electric current	ampere	A	
Thermodynamic temperature	kelvin	K	
Amount of substance	mole	mol	
Luminous intensity	candela	cd	
Supplementary units*			
Plane angle	radian	rad	
Solid angle	steradian	sr	
Derived units*			
Acceleration	metre per second squared		m/s <sup>2</sup>
Activity (of a radioactive source)	disintegration per second		(disintegration)/s
Angular acceleration	radian per second squared		rad/s <sup>2</sup>
Angular velocity	radian per second		rad/s
Area	square metre		m <sup>2</sup>
Density	kilogram per cubic metre		kg/m <sup>3</sup>
Electric capacitance	farad	F	A · s/V
Electrical conductance	siemens	S	A/V
Electric field strength	volt per metre		V/m
Electric inductance	henry	H	V · s/A
Electric potential difference	volt	V	W/A
Electric resistance	ohm	Ω	V/A
Electromotive force	volt	V	W/A
Energy	joule	J	N · m
Entropy	joule per kelvin		J/K
Force	newton	N	kg · m/s <sup>2</sup>
Frequency	hertz	Hz	1/s
Illuminance	lux	lx	lm/m <sup>2</sup>
Luminance	candela per square metre		cd/m <sup>2</sup>
Luminous flux	lumen	lm	cd · sr
Magnetic field strength	ampere per metre		A/m
Magnetic flux	weber	Wb	V · s
Magnetic flux density	tesla	T	Wb/m <sup>2</sup>
Magnetic potential difference	ampere	A	
Power	watt	W	J/s
Pressure	pascal	Pa	N/m <sup>2</sup>
Quantity of electricity	coulomb	C	A · s
Quantity of heat	joule	J	N · m
Radiant intensity	watt per steradian		W/sr
Specific heat capacity	joule per kilogram-kelvin		J/(kg · K)
Stress	pascal	Pa	N/m <sup>2</sup>
Thermal conductivity	watt per metre-kelvin		W/(m · K)
Velocity	metre per second		m/s
Viscosity, dynamic	pascal-second		Pa · s
Viscosity, kinematic	square metre per second		m <sup>2</sup> /s
Voltage	volt	V	W/A
Volume	cubic metre		m <sup>3</sup>
Wave number	reciprocal metre		1/m
Work	joule	J	N · m
Units in use with the SI†			
Time	minute	min	1 min = 60 s
	hour	h	1 h = 60 min = 3,600 s
	day	d	1 d = 24 h = 86,400 s
Plane angle	degree	°	1° = π/180 rad
	minute‡	'	1' = (1/60)° = (π/10,800) rad
	second‡	"	1" = (1/60)' = (π/648,000) rad
Volume	litre	L	1 L = 1 dm <sup>3</sup> = 10 <sup>-3</sup> m <sup>3</sup>
Mass	metric ton	t	1 t = 10 <sup>3</sup> kg
	unified atomic mass unit§	u	1 u = 1.660 57 × 10 <sup>-27</sup> kg
Energy	electronvolt§	eV	1 eV = 1.602 19 × 10 <sup>-19</sup> J

\* ASTM E380-91a.

† These units are not part of SI, but their use is both so widespread and important that the International Committee for Weights and Measures in 1969 recognized their continued use with the SI (see NIST Spec. Pub. 330).

‡ Use discouraged, except for special fields such as cartography.

§ Values in SI units obtained experimentally. These units are to be used in specialized fields only.

**Table 1.2.3 SI Prefixes\***

Multiplication factors	Prefix	SI symbol
1 000 000 000 000 000 000 000 000 = 10 <sup>24</sup>	yotta	Y
1 000 000 000 000 000 000 000 = 10 <sup>21</sup>	zeta	Z
1 000 000 000 000 000 000 = 10 <sup>18</sup>	exa	E
1 000 000 000 000 000 = 10 <sup>15</sup>	peta	P
1 000 000 000 000 = 10 <sup>12</sup>	tera	T
1 000 000 000 = 10 <sup>9</sup>	giga	G
1 000 000 = 10 <sup>6</sup>	mega	M
1 000 = 10 <sup>3</sup>	kilo	k
100 = 10 <sup>2</sup>	hecto†	h
10 = 10 <sup>1</sup>	deka†	da
0.1 = 10 <sup>-1</sup>	deci†	d
0.01 = 10 <sup>-2</sup>	centi†	c
0.001 = 10 <sup>-3</sup>	milli	m
0.000 001 = 10 <sup>-6</sup>	micro	μ
0.000 000 001 = 10 <sup>-9</sup>	nano	n
0.000 000 000 001 = 10 <sup>-12</sup>	pico	p
0.000 000 000 000 001 = 10 <sup>-15</sup>	femto	f
0.000 000 000 000 000 001 = 10 <sup>-18</sup>	atto	a
0.000 000 000 000 000 000 001 = 10 <sup>-21</sup>	zepto	z
0.000 000 000 000 000 000 000 001 = 10 <sup>-24</sup>	yocto	y

\* ANSI/IEEE Std 268-1992.  
 † To be avoided where practical.

**Table 1.2.4 SI Conversion Factors**

To convert from	to	Multiply by
abampere	ampere (A)	1.000 000*E+01
abcoulomb	coulomb (C)	1.000 000*E+01
abfarad	farad (F)	1.000 000*E+09
abhenry	henry (H)	1.000 000*E-09
abmho	siemens (S)	1.000 000*E+09
abohm	ohm (Ω)	1.000 000*E-09
abvolt	volt (V)	1.000 000*E-08
acre-foot (U.S. survey) <sup>a</sup>	metre <sup>3</sup> (m <sup>3</sup> )	1.233 489 E+03
acre (U.S. survey) <sup>a</sup>	metre <sup>2</sup> (m <sup>2</sup> )	4.046 873 E+03
ampere, international U.S. (A <sub>INT-US</sub> ) <sup>b</sup>	ampere (A)	9.998 43 E-01
ampere, U.S. legal 1948 (A <sub>US-48</sub> )	ampere (A)	1.000 008 E+00
ampere-hour	coulomb (C)	3.600 000*E+03
angstrom	metre (m)	1.000 000*E-10
are	metre <sup>2</sup> (m <sup>2</sup> )	1.000 000*E+02
astronomical unit	metre (m)	1.495 98 E+11
atmosphere (normal)	pascal (Pa)	1.013 25 E+05
atmosphere (technical = 1 kg <sub>f</sub> /cm <sup>2</sup> )	pascal (Pa)	9.806 650*E+04
bar	pascal (Pa)	1.000 000*E+05
barn	metre <sup>2</sup> (m <sup>2</sup> )	1.000 000*E-28
barrel (for crude petroleum, 42 gal)	metre <sup>3</sup> (m <sup>3</sup> )	1.589 873 E-01
board foot	metre <sup>3</sup> (m <sup>3</sup> )	2.359 737 E-03
British thermal unit (International Table) <sup>c</sup>	joule (J)	1.055 056 E+03
British thermal unit (mean)	joule (J)	1.055 87 E+03
British thermal unit (thermochemical)	joule (J)	1.054 350 E+03
British thermal unit (39°F)	joule (J)	1.059 67 E+03
British thermal unit (59°F)	joule (J)	1.054 80 E+03
British thermal unit (60°F)	joule (J)	1.054 68 E+03
Btu (thermochemical)/foot <sup>2</sup> -second	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	1.134 893 E+04
Btu (thermochemical)/foot <sup>2</sup> -minute	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	1.891 489 E+02
Btu (thermochemical)/foot <sup>2</sup> -hour	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	3.152 481 E+00
Btu (thermochemical)/inch <sup>2</sup> -second	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	1.634 246 E+06
Btu (thermochemical) · in/s · ft <sup>2</sup> · °F (k, thermal conductivity)	watt/metre-kelvin (W/m · K)	5.188 732 E+02
Btu (International Table) · in/s · ft <sup>2</sup> · °F (k, thermal conductivity)	watt/metre-kelvin (W/m · K)	5.192 204 E+02
Btu (thermochemical) · in/h · ft <sup>2</sup> · °F (k, thermal conductivity)	watt/metre-kelvin (W/m · K)	1.441 314 E-01
Btu (International Table) · in/h · ft <sup>2</sup> · °F (k, thermal conductivity)	watt/metre-kelvin (W/m · K)	1.442 279 E-01
Btu (International Table)/ft <sup>2</sup>	joule/metre <sup>2</sup> (J/m <sup>2</sup> )	1.135 653 E+04
Btu (thermochemical)/ft <sup>2</sup>	joule/metre <sup>2</sup> (J/m <sup>2</sup> )	1.134 893 E+04
Btu (International Table)/h · ft <sup>2</sup> · °F (C, thermal conductance)	watt/metre <sup>2</sup> -kelvin (W/m <sup>2</sup> · K)	5.678 263 E+00
Btu (thermochemical)/h · ft <sup>2</sup> · °F (C, thermal conductance)	watt/metre <sup>2</sup> -kelvin (W/m <sup>2</sup> · K)	5.674 466 E+00
Btu (International Table)/pound-mass	joule/kilogram (J/kg)	2.326 000*E+03

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Table 1.2.4 SI Conversion Factors (Continued)

To convert from	to	Multiply by
Btu (thermochemical)/pound-mass	joule/kilogram (J/kg)	2.324 444 E+03
Btu (International Table)/lbm · °F (c, heat capacity)	joule/kilogram-kelvin (J/kg · K)	4.186 800*E+03
Btu (thermochemical)/lbm · °F (c, heat capacity)	joule/kilogram-kelvin (J/kg · K)	4.184 000 E+03
Btu (International Table)/s · ft <sup>2</sup> · °F	watt/metre <sup>2</sup> -kelvin (W/m <sup>2</sup> · K)	2.044 175 E+04
Btu (thermochemical)/s · ft <sup>2</sup> · °F	watt/metre <sup>2</sup> -kelvin (W/m <sup>2</sup> · K)	2.042 808 E+04
Btu (International Table)/hour	watt (W)	2.930 711 E-01
Btu (thermochemical)/second	watt (W)	1.054 350 E+03
Btu (thermochemical)/minute	watt (W)	1.757 250 E+01
Btu (thermochemical)/hour	watt (W)	2.928 751 E-01
bushel (U.S.)	metre <sup>3</sup> (m <sup>3</sup> )	3.523 907 E-02
calorie (International Table)	joule (J)	4.186 800*E+00
calorie (mean)	joule (J)	4.190 02 E+00
calorie (thermochemical)	joule (J)	4.184 000*E+00
calorie (15°C)	joule (J)	4.185 80 E+00
calorie (20°C)	joule (J)	4.181 90 E+00
calorie (kilogram, International Table)	joule (J)	4.186 800*E+03
calorie (kilogram, mean)	joule (J)	4.190 02 E+03
calorie (kilogram, thermochemical)	joule (J)	4.184 000*E+03
calorie (thermochemical)/centimetre <sup>2</sup> -minute	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	6.973 333 E+02
cal (thermochemical)/cm <sup>2</sup>	joule/metre <sup>2</sup> (J/m <sup>2</sup> )	4.184 000*E+04
cal (thermochemical)/cm <sup>2</sup> · s	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	4.184 000*E+04
cal (thermochemical)/cm · s · °C	watt/metre-kelvin (W/m · K)	4.184 000*E+02
cal (International Table)/g	joule/kilogram (J/kg)	4.186 800*E+03
cal (International Table)/g · °C	joule/kilogram-kelvin (J/kg · K)	4.186 800*E+03
cal (thermochemical)/g	joule/kilogram (J/kg)	4.184 000*E+03
cal (thermochemical)/g · °C	joule/kilogram-kelvin (J/kg · K)	4.184 000*E+03
calorie (thermochemical)/second	watt (W)	4.184 000*E+00
calorie (thermochemical)/minute	watt (W)	6.973 333 E-02
carat (metric)	kilogram (kg)	2.000 000*E-04
centimetre of mercury (0°C)	pascal (Pa)	1.333 22 E+03
centimetre of water (4°C)	pascal (Pa)	9.806 38 E+01
centipoise	pascal-second (Pa · s)	1.000 000*E-03
centistokes	metre <sup>2</sup> /second (m <sup>2</sup> /s)	1.000 000*E-06
chain (engineer or ramden)	meter (m)	3.048* E+01
chain (surveyor or gunter)	meter (m)	2.011 684 E+01
circular mil	metre <sup>2</sup> (m <sup>2</sup> )	5.067 075 E-10
cord	metre <sup>3</sup> (m <sup>3</sup> )	3.624 556 E+00
coulomb, international U.S. (C <sub>INT-US</sub> ) <sup>b</sup>	coulomb (C)	9.998 43 E-01
coulomb, U.S. legal 1948 (C <sub>US-48</sub> )	coulomb (C)	1.000 008 E+00
cup	metre <sup>3</sup> (m <sup>3</sup> )	2.365 882 E-04
curie	becquerel (Bq)	3.700 000*E+10
day (mean solar)	second (s)	8.640 000 E+04
day (sidereal)	second (s)	8.616 409 E+04
degree (angle)	radian (rad)	1.745 329 E-02
degree Celsius	kelvin (K)	$t_K = t_{°C} + 273.15$
degree centigrade	kelvin (K)	$t_K = t_{°C} + 273.15$
degree Fahrenheit	degree Celsius	$t_{°C} = (t_{°F} - 32)/1.8$
degree Fahrenheit	kelvin (K)	$t_K = (t_{°F} + 459.67)/1.8$
deg F · h · ft <sup>2</sup> /Btu (thermochemical) (R, thermal resistance)	kelvin-metre <sup>2</sup> /watt (K · m <sup>2</sup> /W)	1.762 280 E-01
deg F · h · ft <sup>2</sup> /Btu (International Table) (R, thermal resistance)	kelvin-metre <sup>2</sup> /watt (K · m <sup>2</sup> /W)	1.761 102 E-01
degree Rankine	kelvin (K)	$t_K = t_{°R}/1.8$
dram (avoirdupois)	kilogram (kg)	1.771 845 E-03
dram (troy or apothecary)	kilogram (kg)	3.887 934 E-03
dram (U.S. fluid)	kilogram (kg)	3.696 691 E-06
dyne	newton (N)	1.000 000*E-05
dyne-centimetre	newton-metre (N · m)	1.000 000*E-07
dyne-centimetre <sup>2</sup>	pascal (Pa)	1.000 000*E-01
electron volt	joule (J)	1.602 19 E-19
EMU of capacitance	farad (F)	1.000 000*E+09
EMU of current	ampere (A)	1.000 000*E+01
EMU of electric potential	volt (V)	1.000 000*E-08
EMU of inductance	henry (H)	1.000 000*E-09
EMU of resistance	ohm (Ω)	1.000 000*E-09
ESU of capacitance	farad (F)	1.112 650 E-12
ESU of current	ampere (A)	3.335 6 E-10
ESU of electric potential	volt (V)	2.997 9 E+02
ESU of inductance	henry (H)	8.987 554 E+11

Table 1.2.4 SI Conversion Factors (Continued)

To convert from	to	Multiply by
ESU of resistance	ohm ( $\Omega$ )	8.987 554 E+11
erg	joule (J)	1.000 000*E-07
erg/centimetre <sup>2</sup> -second	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	1.000 000*E-03
erg/second	watt (W)	1.000 000*E-07
farad, international U.S. (F <sub>INT-US</sub> )	farad (F)	9.995 05 E-01
faraday (based on carbon 12)	coulomb (C)	9.648 70 E+04
faraday (chemical)	coulomb (C)	9.649 57 E+04
faraday (physical)	coulomb (C)	9.652 19 E+04
fathom (U.S. survey) <sup>a</sup>	metre (m)	1.828 804 E+00
fermi (femtometer)	metre (m)	1.000 000*E-15
fluid ounce (U.S.)	metre <sup>3</sup> (m <sup>3</sup> )	2.957 353 E-05
foot	metre (m)	3.048 000*E-01
foot (U.S. survey) <sup>a</sup>	metre (m)	3.048 006 E-01
foot <sup>3</sup> /minute	metre <sup>3</sup> /second (m <sup>3</sup> /s)	4.719 474 E-04
foot <sup>3</sup> /second	metre <sup>3</sup> /second (m <sup>3</sup> /s)	2.831 685 E-02
foot <sup>3</sup> (volume and section modulus)	metre <sup>3</sup> (m <sup>3</sup> )	2.831 685 E-02
foot <sup>2</sup>	metre <sup>2</sup> (m <sup>2</sup> )	9.290 304*E-02
foot <sup>4</sup> (moment of section) <sup>d</sup>	metre <sup>4</sup> (m <sup>4</sup> )	8.630 975 E-03
foot/hour	metre/second (m/s)	8.466 667 E-05
foot/minute	metre/second (m/s)	5.080 000*E-03
foot/second	metre/second (m/s)	3.048 000*E-01
foot <sup>2</sup> /second	metre <sup>2</sup> /second (m <sup>2</sup> /s)	9.290 304*E-02
foot of water (39.2°F)	pascal (Pa)	2.988 98 E+03
footcandle	lumen/metre <sup>2</sup> (lm/m <sup>2</sup> )	1.076 391 E+01
footcandle	lux (lx)	1.076 391 E+01
footlambert	candela/metre <sup>2</sup> (cd/m <sup>2</sup> )	3.426 259 E+00
foot-pound-force	joule (J)	1.355 818 E+00
foot-pound-force/hour	watt (W)	3.766 161 E-04
foot-pound-force/minute	watt (W)	2.259 697 E-02
foot-pound-force/second	watt (W)	1.355 818 E+00
foot-poundal	joule (J)	4.214 011 E-02
ft <sup>2</sup> /h (thermal diffusivity)	metre <sup>2</sup> /second (m <sup>2</sup> /s)	2.580 640*E-05
foot/second <sup>2</sup>	metre/second <sup>2</sup> (m/s <sup>2</sup> )	3.048 000*E-01
free fall, standard	metre/second <sup>2</sup> (m/s <sup>2</sup> )	9.806 650*E+00
furlong	metre (m)	2.011 68 *E+02
gal	metre/second <sup>2</sup> (m/s <sup>2</sup> )	1.000 000*E-02
gallon (Canadian liquid)	metre <sup>3</sup> (m <sup>3</sup> )	4.546 090 E-03
gallon (U.K. liquid)	metre <sup>3</sup> (m <sup>3</sup> )	4.546 092 E-03
gallon (U.S. dry)	metre <sup>3</sup> (m <sup>3</sup> )	4.404 884 E-03
gallon (U.S. liquid)	metre <sup>3</sup> (m <sup>3</sup> )	3.785 412 E-03
gallon (U.S. liquid)/day	metre <sup>3</sup> /second (m <sup>3</sup> /s)	4.381 264 E-08
gallon (U.S. liquid)/minute	metre <sup>3</sup> /second (m <sup>3</sup> /s)	6.309 020 E-05
gamma	tesla (T)	1.000 000*E-09
gauss	tesla (T)	1.000 000*E-04
gilbert	ampere-turn	7.957 747 E-01
gill (U.K.)	metre <sup>3</sup> (m <sup>3</sup> )	1.420 654 E-04
gill (U.S.)	metre <sup>3</sup> (m <sup>3</sup> )	1.182 941 E-04
grade	degree (angular)	9.000 000*E-01
grade	radian (rad)	1.570 796 E-02
grain (1/7,000 lbm avoirdupois)	kilogram (kg)	6.479 891*E-05
gram	kilogram (kg)	1.000 000*E-03
gram/centimetre <sup>3</sup>	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	1.000 000*E+03
gram-force/centimetre <sup>2</sup>	pascal (Pa)	9.806 650*E+01
hectare	metre <sup>2</sup> (m <sup>2</sup> )	1.000 000*E+04
henry, international U.S. (H <sub>INT-US</sub> )	henry (H)	1.000 495 E+00
hogshead (U.S.)	metre <sup>3</sup> (m <sup>3</sup> )	2.384 809 E-01
horsepower (550 ft·lbf/s)	watt (W)	7.456 999 E+02
horsepower (boiler)	watt (W)	9.809 50 E+03
horsepower (electric)	watt (W)	7.460 000*E+02
horsepower (metric)	watt (W)	7.354 99 E+02
horsepower (water)	watt (W)	7.460 43 E+02
horsepower (U.K.)	watt (W)	7.457 0 E+02
hour (mean solar)	second (s)	3.600 000 E+03
hour (sidereal)	second (s)	3.590 170 E+03
hundredweight (long)	kilogram (kg)	5.080 235 E+01
hundredweight (short)	kilogram (kg)	4.535 924 E+01
inch	metre (m)	2.540 000*E-02
inch <sup>2</sup>	metre <sup>2</sup> (m <sup>2</sup> )	6.451 600*E-04
inch <sup>3</sup> (volume and section modulus)	metre <sup>3</sup> (m <sup>3</sup> )	1.638 706 E-05
inch <sup>3</sup> /minute	metre <sup>3</sup> /second (m <sup>3</sup> /s)	2.731 177 E-07
inch <sup>4</sup> (moment of section) <sup>d</sup>	metre <sup>4</sup> (m <sup>4</sup> )	4.162 314 E-07
inch/second	metre/second (m/s)	2.540 000*E-02
inch of mercury (32°F)	pascal (Pa)	3.386 389 E+03

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**Table 1.2.4 SI Conversion Factors (Continued)**

To convert from	to	Multiply by
inch of mercury (60°F)	pascal (Pa)	3.376 85 E+03
inch of water (39.2°F)	pascal (Pa)	2.490 82 E+02
inch of water (60°F)	pascal (Pa)	2.488 4 E+02
inch/second <sup>2</sup>	metre/second <sup>2</sup> (m/s <sup>2</sup> )	2.540 000*E-02
joule, international U.S. (J <sub>INT-US</sub> ) <sup>b</sup>	joule (J)	1.000 182 E+00
joule, U.S. legal 1948 (J <sub>US-48</sub> )	joule (J)	1.000 017 E+00
kayser	1/metre (1/m)	1.000 000*E+02
kelvin	degree Celsius	$t_c = t_k - 273.15$
kilocalorie (thermochemical)/minute	watt (W)	6.973 333 E+01
kilocalorie (thermochemical)/second	watt (W)	4.184 000*E+03
kilogram-force (kgf)	newton (N)	9.806 650*E+00
kilogram-force-metre	newton-metre (N · m)	9.806 650*E+00
kilogram-force-second <sup>2</sup> /metre (mass)	kilogram (kg)	9.806 650*E+00
kilogram-force/centimetre <sup>2</sup>	pascal (Pa)	9.806 650*E+04
kilogram-force/metre <sup>3</sup>	pascal (Pa)	9.806 650*E+00
kilogram-force/millimetre <sup>2</sup>	pascal (Pa)	9.806 650*E+06
kilogram-mass	kilogram (kg)	1.000 000*E+00
kilometre/hour	metre/second (m/s)	2.777 778 E-01
kilopond	newton (N)	9.806 650*E+00
kilowatt hour	joule (J)	3.600 000*E+06
kilowatt hour, international U.S. (kWh <sub>INT-US</sub> ) <sup>b</sup>	joule (J)	3.600 655 E+06
kilowatt hour, U.S. legal 1948 (kWh <sub>US-48</sub> )	joule (J)	3.600 061 E+06
kip (1,000 lbf)	newton (N)	4.448 222 E+03
kip/inch <sup>2</sup> (ksi)	pascal (Pa)	6.894 757 E+06
knot (international)	metre/second (m/s)	5.144 444 E-01
lambert	candela/metre <sup>2</sup> (cd/m <sup>2</sup> )	3.183 099 E+03
langley	joule/metre <sup>2</sup> (J/m <sup>2</sup> )	4.184 000*E+04
league, nautical (international and U.S.)	metre (m)	5.556 000*E+03
league (U.S. survey) <sup>a</sup>	metre (m)	4.828 042 E+03
league, nautical (U.K.)	metre (m)	5.559 552*E+03
light year	metre (m)	9.460 55 E+15
link (engineer or ramden)	metre (m)	3.048* E-01
link (surveyor or gunter)	metre (m)	2.011 68* E-01
litre <sup>c</sup>	metre <sup>3</sup> (m <sup>3</sup> )	1.000 000*E-03
lux	lumen/metre <sup>2</sup> (lm/m <sup>2</sup> )	1.000 000*E+00
maxwell	weber (Wb)	1.000 000*E-08
mho	siemens (S)	1.000 000*E+00
microinch	metre (m)	2.540 000*E-08
micron (micrometre)	metre (m)	1.000 000*E-06
mil	metre (m)	2.540 000*E-05
mile, nautical (international and U.S.)	metre (m)	1.852 000*E+03
mile, nautical (U.K.)	metre (m)	1.853 184*E+03
mile (international)	metre (m)	1.609 344*E+03
mile (U.S. survey) <sup>a</sup>	metre (m)	1.609 347 E+03
mile <sup>2</sup> (international)	metre <sup>2</sup> (m <sup>2</sup> )	2.589 988 E+06
mile <sup>2</sup> (U.S. survey) <sup>a</sup>	metre <sup>2</sup> (m <sup>2</sup> )	2.589 998 E+06
mile/hour (international)	metre/second (m/s)	4.470 400*E-01
mile/hour (international)	kilometre/hour	1.609 344*E+00
millimetre of mercury (0°C)	pascal (Pa)	1.333 224 E+02
minute (angle)	radian (rad)	2.908 882 E-04
minute (mean solar)	second (s)	6.000 000 E+01
minute (sidereal)	second (s)	5.983 617 E+01
month (mean calendar)	second (s)	2.268 000 E+06
oersted	ampere/metre (A/m)	7.957 747 E+01
ohm, international U.S. (Ω <sub>INT-US</sub> )	ohm (Ω)	1.000 495 E+00
ohm-centimetre	ohm-metre (Ω · m)	1.000 000*E-02
ounce-force (avoirdupois)	newton (N)	2.780 139 E-01
ounce-force-inch	newton-metre (N · m)	7.061 552 E-03
ounce-mass (avoirdupois)	kilogram (kg)	2.834 952 E-02
ounce-mass (troy or apothecary)	kilogram (kg)	3.110 348 E-02
ounce-mass/yard <sup>2</sup>	kilogram/metre <sup>2</sup> (kg/m <sup>2</sup> )	3.390 575 E-02
ounce (avoirdupois)(mass)/inch <sup>3</sup>	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	1.729 994 E+03
ounce (U.K. fluid)	metre <sup>3</sup> (m <sup>3</sup> )	2.841 307 E-05
ounce (U.S. fluid)	metre <sup>3</sup> (m <sup>3</sup> )	2.957 353 E-05
parsec	metre (m)	3.083 74 E+16
peck (U.S.)	metre <sup>3</sup> (m <sup>3</sup> )	8.809 768 E-03
pennyweight	kilogram (kg)	1.555 174 E-03
perm (0°C)	kilogram/pascal-second-metre <sup>2</sup> (kg/Pa · s · m <sup>2</sup> )	5.721 35 E-11
perm (23°C)	kilogram/pascal-second-metre <sup>2</sup> (kg/Pa · s · m <sup>2</sup> )	5.745 25 E-11

Table 1.2.4 SI Conversion Factors (Continued)

To convert from	to	Multiply by
perm-inch (0°C)	kilogram/pascal-second-metre (kg/Pa · s · m)	1.453 22 E-12
perm-inch (23°C)	kilogram/pascal-second-metre (kg/Pa · s · m)	1.459 29 E-12
phot	lumen/metre <sup>2</sup> (lm/m <sup>2</sup> )	1.000 000*E+04
pica (printer's)	metre (m)	4.217 518 E-03
pint (U.S. dry)	metre <sup>3</sup> (m <sup>3</sup> )	5.506 105 E-04
pint (U.S. liquid)	metre <sup>3</sup> (m <sup>3</sup> )	4.731 765 E-04
point (printer's)	metre	3.514 598*E-04
poise (absolute viscosity)	pascal-second (Pa · s)	1.000 000*E-01
poundal	newton (N)	1.382 550 E-01
poundal-foot <sup>2</sup>	pascal (Pa)	1.488 164 E+00
poundal-second/foot <sup>2</sup>	pascal-second (Pa · s)	1.488 164 E+00
pound-force (lbf avoirdupois)	newton (N)	4.448 222 E+00
pound-force-inch	newton-metre (N · m)	1.129 848 E-01
pound-force-foot	newton-metre (N · m)	1.355 818 E+00
pound-force-foot/inch	newton-metre/metre (N · m/m)	5.337 866 E+01
pound-force-inch/inch	newton-metre/metre (N · m/m)	4.448 222 E+00
pound-force/inch	newton-metre (N/m)	1.751 268 E+02
pound-force/foot	newton/metre (N/m)	1.459 390 E+01
pound-force/foot <sup>2</sup>	pascal (Pa)	4.788 026 E+01
pound-force/inch <sup>2</sup> (psi)	pascal (Pa)	6.894 757 E+03
pound-force-second/foot <sup>2</sup>	pascal-second (Pa · s)	4.788 026 E+01
pound-mass (lbm avoirdupois)	kilogram (kg)	4.535 924 E-01
pound-mass (troy or apothecary)	kilogram (kg)	3.732 417 E-01
pound-mass-foot <sup>2</sup> (moment of inertia)	kilogram-metre <sup>2</sup> (kg · m <sup>2</sup> )	4.214 011 E-02
pound-mass-inch <sup>2</sup> (moment of inertia)	kilogram-metre <sup>2</sup> (kg · m <sup>2</sup> )	2.926 397 E-04
pound-mass-foot <sup>2</sup>	kilogram/metre <sup>2</sup> (kg/m <sup>2</sup> )	4.882 428 E+00
pound-mass/second	kilogram/second (kg/s)	4.535 924 E-01
pound-mass/minute	kilogram/second (kg/s)	7.559 873 E-03
pound-mass/foot <sup>3</sup>	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	1.601 846 E+01
pound-mass/inch <sup>3</sup>	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	2.767 990 E+04
pound-mass/gallon (U.K. liquid)	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	9.977 633 E+01
pound-mass/gallon (U.S. liquid)	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	1.198 264 E+02
pound-mass/foot-second	pascal-second (Pa · s)	1.488 164 E+00
quart (U.S. dry)	metre <sup>3</sup> (m <sup>3</sup> )	1.101 221 E-03
quart (U.S. liquid)	metre <sup>3</sup> (m <sup>3</sup> )	9.463 529 E-04
rad (radiation dose absorbed)	gray (Gy)	1.000 000*E-02
rem (dose equivalent)	sievert (Sv)	1.000 000*E-02
rhe	metre <sup>2</sup> /newton-second (m <sup>2</sup> /N · s)	1.000 000*E+01
rod (U.S. survey) <sup>a</sup>	metre (m)	5.029 210 E+00
roentgen	coulomb/kilogram (C/kg)	2.579 760*E-04
second (angle)	radian (rad)	4.848 137 E-06
second (sidereal)	second (s)	9.972 696 E-01
section (U.S. survey) <sup>a</sup>	metre <sup>2</sup> (m <sup>2</sup> )	2.589 998 E+06
shake	second (s)	1.000 000*E-08
slug	kilogram (kg)	1.459 390 E+01
slug/foot <sup>3</sup>	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	5.153 788 E+02
slug/foot-second	pascal-second (Pa · s)	4.788 026 E+01
statampere	ampere (A)	3.335 640 E-10
statcoulomb	coulomb (C)	3.335 640 E-10
statfarad	farad (F)	1.112 650 E-12
stathenry	henry (H)	8.987 554 E+11
statmho	siemens (S)	1.112 650 E-12
statohm	ohm (Ω)	8.987 554 E+11
statvolt	volt (V)	2.997 925 E+02
stere	metre <sup>3</sup> (m <sup>3</sup> )	1.000 000*E+00
stilb	candela/metre <sup>2</sup> (cd/m <sup>2</sup> )	1.000 000*E+04
stokes (kinematic viscosity)	metre <sup>2</sup> /second (m <sup>2</sup> /s)	1.000 000*E-04
tablespoon	metre <sup>3</sup> (m <sup>3</sup> )	1.478 676 E-05
teaspoon	metre <sup>3</sup> (m <sup>3</sup> )	4.928 922 E-06
ton (assay)	kilogram (kg)	2.916 667 E-02
ton (long, 2,240 lbm)	kilogram (kg)	1.016 047 E+03
ton (metric)	kilogram (kg)	1.000 000*E+03
ton (nuclear equivalent of TNT)	joule (J)	4.20 E+09
ton (register)	metre <sup>3</sup> (m <sup>3</sup> )	2.831 685 E+00
ton (short, 2,000 lbm)	kilogram (kg)	9.071 847 E+02
ton (short, mass)/hour	kilogram/second (kg/s)	2.519 958 E-01
ton (long, mass)/yard <sup>3</sup>	kilogram/metre <sup>3</sup> (kg/m <sup>3</sup> )	1.328 939 E+03
tonne	kilogram (kg)	1.000 000*E+03
torr (mm Hg, 0°C)	pascal (Pa)	1.333 22 E+02
township (U.S. survey) <sup>a</sup>	metre <sup>2</sup> (m <sup>2</sup> )	9.323 994 E+07
unit pole	weber (Wb)	1.256 637 E-07

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**Table 1.2.4 SI Conversion Factors (Continued)**

To convert from	to	Multiply by
volt, international U.S. ( $V_{INT-US}$ ) <sup>b</sup>	volt (V)	1.000 338 E+00
volt, U.S. legal 1948 ( $V_{US-48}$ )	volt (V)	1.000 008 E+00
watt, international U.S. ( $W_{INT-US}$ ) <sup>b</sup>	watt (W)	1.000 182 E+00
watt, U.S. legal 1948 ( $W_{US-48}$ )	watt (W)	1.000 017 E+00
watt/centimetre <sup>2</sup>	watt/metre <sup>2</sup> (W/m <sup>2</sup> )	1.000 000*E+04
watt-hour	joule (J)	3.600 000*E+03
watt-second	joule (J)	1.000 000*E+00
yard	metre (m)	9.144 000*E-01
yard <sup>2</sup>	metre <sup>2</sup> (m <sup>2</sup> )	8.361 274 E-01
yard <sup>3</sup>	metre <sup>3</sup> (m <sup>3</sup> )	7.645 549 E-01
yard <sup>3</sup> /minute	metre <sup>3</sup> /second (m <sup>3</sup> /s)	1.274 258 E-02
year (calendar)	second (s)	3.153 600 E+07
year (sidereal)	second (s)	3.155 815 E+07
year (tropical)	second (s)	3.155 693 E+07

<sup>a</sup> Based on the U.S. survey foot (1 ft = 1,200/3,937 m).

<sup>b</sup> In 1948 a new international agreement was reached on absolute electrical units, which changed the value of the volt used in this country by about 300 parts per million. Again in 1969 a new base of reference was internationally adopted making a further change of 8.4 parts per million. These changes (and also changes in ampere, joule, watt, coulomb) require careful terminology and conversion factors for exact use of old information. Terms used in this guide are:

Volt as used prior to January 1948—volt, international U.S. ( $V_{INT-US}$ )

Volt as used between January 1948 and January 1969—volt, U.S. legal 1948 ( $V_{INT-48}$ )

Volt as used since January 1969—volt (V)

Identical treatment is given the ampere, coulomb, watt, and joule.

<sup>c</sup> This value was adopted in 1956. Some of the older International Tables use the value 1.055 04 E+03. The exact conversion factor is 1.055 055 852 62\*E+03.

<sup>d</sup> Moment of inertia of a plane section about a specified axis.

<sup>e</sup> In 1964, the General Conference on Weights and Measures adopted the name "litre" as a special name for the cubic decimetre. Prior to this decision the litre differed slightly (previous value, 1.000028 dm<sup>3</sup>), and in expression of precision, volume measurement, this fact must be kept in mind.

**SYSTEMS OF UNITS**

The principal units of interest to mechanical engineers can be derived from three base units which are considered to be dimensionally independent of each other. The British "gravitational system," in common use in the United States, uses units of **length, force, and time** as base units and is also called the "foot-pound-second system." The metric system, on the other hand, is based on the meter, kilogram, and second, units of **length, mass, and time**, and is often designated as the "MKS system." During the nineteenth century a metric "gravitational system," based on a kilogram-force (also called a "kilopond") came into general use. With the development of the International System of Units (SI), based as it is on the original metric system for mechanical units, and the general requirements by members of the European Community that only SI units be used, it is anticipated that the kilogram-force will fall into disuse to be replaced by the newton, the SI unit of force. Table 1.2.5 gives the base units of four systems with the corresponding derived unit given in parentheses.

In the definitions given below, the "standard kilogram body" refers to the international kilogram prototype, a platinum-iridium cylinder kept in the International Bureau of Weights and Measures in Sèvres, just outside Paris. The "standard pound body" is related to the kilogram by a precise numerical factor: 1 lb = 0.453 592 37 kg. This new "unified" pound has replaced the somewhat smaller Imperial pound of the United Kingdom and the slightly larger pound of the United States (see NBS Spec. Pub. 447). The "standard locality" means sea level, 45° latitude,

or more strictly any locality in which the acceleration due to gravity has the value 9.80 665 m/s<sup>2</sup> = 32.1740 ft/s<sup>2</sup>, which may be called the **standard acceleration** (Table 1.2.6).

The **pound force** is the force required to support the standard pound body against gravity, *in vacuo*, in the standard locality; or, it is the force which, if applied to the standard pound body, supposed free to move, would give that body the "standard acceleration." The word *pound* is used for the unit of both force and mass and consequently is ambiguous. To avoid uncertainty, it is desirable to call the units "pound force" and "pound mass," respectively. The slug has been defined as that mass which will accelerate at 1 ft/s<sup>2</sup> when acted upon by a one pound force. It is therefore equal to 32.1740 pound-mass.

The **kilogram force** is the force required to support the standard kilogram against gravity, *in vacuo*, in the standard locality; or, it is the force which, if applied to the standard kilogram body, supposed free to move, would give that body the "standard acceleration." The word *kilogram* is used for the unit of both force and mass and consequently is ambiguous. It is for this reason that the General Conference on Weights and Measures declared (in 1901) that the kilogram was the unit of mass, a concept incorporated into SI when it was formally approved in 1960.

The **dyne** is the force which, if applied to the standard gram body, would give that body an acceleration of 1 cm/s<sup>2</sup>; i.e., 1 dyne = 1/980.665 of a gram force.

The **newton** is that force which will impart to a 1-kilogram mass an acceleration of 1 m/s<sup>2</sup>.

**Table 1.2.5 Systems of Units**

Quantity	Dimensions of units in terms of L/M/F/T	British "gravitational system"	Metric "gravitational system"	CGS system	SI system
Length	L	1 ft	1 m	1 cm	1 m
Mass	M	(1 slug)		1 g	1 kg
Force	F	1 lb	1 kg	(1 dyne)	(1 N)
Time	T	1 s	1 s	1 s	1 s



**Table 1.2.6 Acceleration of Gravity**

Latitude, deg	<i>g</i>			Latitude, deg	<i>g</i>		
	m/s <sup>2</sup>	ft/s <sup>2</sup>	g/g <sup>0</sup>		m/s <sup>2</sup>	ft/s <sup>2</sup>	g/g <sup>0</sup>
0	9.780	32.088	0.9973	50	9.811	32.187	1.0004
10	9.782	32.093	0.9975	60	9.819	32.215	1.0013
20	9.786	32.108	0.9979	70	9.826	32.238	1.0020
30	9.793	32.130	0.9986	80	9.831	32.253	1.0024
40	9.802	32.158	0.9995	90	9.832	32.258	1.0026

NOTE: Correction for altitude above sea level: -3 mm/s<sup>2</sup> for each 1,000 m; -0.003 ft/s<sup>2</sup> for each 1,000 ft.  
SOURCE: U.S. Coast and Geodetic Survey, 1912.

**TEMPERATURE**

The SI unit for thermodynamic temperature is the **kelvin, K**, which is the fraction 1/273.16 of the thermodynamic temperature of the triple point of water. Thus 273.16 K is the **fixed (base) point on the kelvin scale**.

Another unit used for the measurement of temperature is **degrees Celsius** (formerly **centigrade**), °C. The relation between a thermodynamic temperature *T* and a Celsius temperature *t* is

$$t = T - 273.16 \text{ K}$$

Thus the unit Celsius degree is equal to the unit kelvin, and a difference of temperature would be the same on either scale.

In the USCS temperature is measured in degrees **Fahrenheit, F**. The relation between the Celsius and the Fahrenheit scales is

$$t_C = (t_F - 32)/1.8$$

(For temperature-conversion tables, see Sec. 4.)

**TERRESTRIAL GRAVITY**

**Standard acceleration of gravity** is  $g^0 = 9.80665$  m per sec per sec, or 32.1740 ft per sec per sec. This value  $g^0$  is assumed to be the value of  $g$  at sea level and latitude 45°.

**MOHS SCALE OF HARDNESS**

This scale is an arbitrary one which is used to describe the hardness of several mineral substances on a scale of 1 through 10 (Table 1.2.7). The given number indicates a higher relative hardness compared with that of substances below it; and a lower relative hardness than those above it. For example, an unknown substance is scratched by quartz, but it, in turn, scratches feldspar. The unknown has a hardness of between 6 and 7 on the Mohs scale.

**Table 1.2.7 Mohs Scale of Hardness**

1. Talc	5. Apatite	8. Topaz
2. Gypsum	6. Feldspar	9. Sapphire
3. Calc-spar	7. Quartz	10. Diamond
4. Fluorspar		

**TIME**

**Kinds of Time** Three kinds of time are recognized by astronomers: sidereal, apparent solar, and mean solar time. The **sidereal day** is the interval between two consecutive transits of some fixed celestial object across any given meridian, or it is the interval required by the earth to make one complete revolution on its axis. The interval is constant, but it is inconvenient as a time unit because the noon of the sidereal day occurs at all hours of the day and night. The **apparent solar day** is the interval between two consecutive transits of the sun across any given meridian. On account of the variable distance between the sun and earth, the variable speed of the earth in its orbit, the effect of the moon, etc., this interval is not constant and consequently cannot be kept by any simple mechanisms, such as clocks or watches. To overcome the objection noted above, the **mean solar day** was devised. The mean solar day is

the length of the average apparent solar day. Like the sidereal day it is constant, and like the apparent solar day its noon always occurs at approximately the same time of day. By international agreement, beginning Jan. 1, 1925, the astronomical day, like the civil day, is from midnight to midnight. The hours of the astronomical day run from 0 to 24, and the hours of the civil day usually run from 0 to 12 A.M. and 0 to 12 P.M. In some countries the hours of the civil day also run from 0 to 24.

**The Year** Three different kinds of year are used: the sidereal, the tropical, and the anomalistic. The **sidereal year** is the time taken by the earth to complete one revolution around the sun from a given star to the same star again. Its length is 365 days, 6 hours, 9 minutes, and 9 seconds. The **tropical year** is the time included between two successive passages of the vernal equinox by the sun, and since the equinox moves westward 50.2 seconds of arc a year, the tropical year is shorter by 20 minutes 23 seconds in time than the sidereal year. As the seasons depend upon the earth's position with respect to the equinox, the tropical year is the year of civil reckoning. The **anomalistic year** is the interval between two successive passages of the perihelion, viz., the time of the earth's nearest approach to the sun. The anomalistic year is used only in special calculations in astronomy.

**The Second** Although the second is ordinarily defined as 1/86,400 of the mean solar day, this is not sufficiently precise for many scientific purposes. Scientists have adopted more precise definitions for specific purposes: in 1956, one in terms of the length of the tropical year 1900 and, more recently, in 1967, one in terms of a specific atomic frequency.

**Frequency** is the reciprocal of time for 1 cycle; the unit of frequency is the **hertz (Hz)**, defined as 1 cycle/s.

**The Calendar** The **Gregorian calendar**, now used in most of the civilized world, was adopted in Catholic countries of Europe in 1582 and in Great Britain and her colonies Jan. 1, 1752. The average length of the Gregorian calendar year is  $365\frac{1}{4} - \frac{3}{400}$  days, or 365.2425 days. This is equivalent to 365 days, 5 hours, 49 minutes, 12 seconds. The length of the tropical year is 365.2422 days, or 365 days, 5 hours, 48 minutes, 46 seconds. Thus the Gregorian calendar year is longer than the tropical year by 0.0003 day, or 26 seconds. This difference amounts to 1 day in slightly more than 3,300 years and can properly be neglected.

**Standard Time** Prior to 1883, each city of the United States had its own time, which was determined by the time of passage of the sun across the local meridian. A system of standard time had been used since its first adoption by the railroads in 1883 but was first legalized on Mar. 19, 1918, when Congress directed the Interstate Commerce Commission to establish limits of the standard time zones. Congress took no further steps until the **Uniform Time Act of 1966** was enacted, followed with an amendment in 1972. This legislation, referred to as "the Act," transferred the regulation and enforcement of the law to the Department of Transportation.

By the legislation of 1918, with some modifications by the Act, the contiguous United States is divided into four **time zones**, each of which, theoretically, was to span 15 degrees of longitude. The first, the **Eastern zone**, extends from the Atlantic westward to include most of Michigan and Indiana, the eastern parts of Kentucky and Tennessee, Georgia, and Florida, except the west half of the panhandle. **Eastern standard time** is

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based upon the mean solar time of the 75th meridian west of Greenwich, and is 5 hours slower than **Greenwich Mean Time (GMT)**. (See also discussion of UTC below.) The second or **Central zone** extends westward to include most of North Dakota, about half of South Dakota and Nebraska, most of Kansas, Oklahoma, and all but the two most westerly counties of Texas. **Central standard time** is based upon the mean solar time of the 90th meridian west of Greenwich, and is 6 hours slower than GMT. The third or **Mountain zone** extends westward to include Montana, most of Idaho, one county of Oregon, Utah, and Arizona. **Mountain standard time** is based upon the mean solar time of the 105th meridian west of Greenwich, and is 7 hours slower than GMT. The fourth or **Pacific zone** includes all of the remaining 48 contiguous states. **Pacific standard time** is based on the mean solar time of the 120th meridian west of Greenwich, and is 8 hours slower than GMT. Exact locations of boundaries may be obtained from the Department of Transportation.

In addition to the above four zones there are four others that apply to the noncontiguous states and islands. The most easterly is the **Atlantic zone**, which includes Puerto Rico and the Virgin Islands, where the time is 4 hours slower than GMT. Eastern standard time is used in the Panama Canal strip. To the west of the Pacific time zone there are the **Yukon**, the **Alaska-Hawaii**, and **Bering zones** where the times are, respectively, 9, 10, and 11 hours slower than GMT. The system of standard time has been adopted in all civilized countries and is used by ships on the high seas.

The Act directs that from the first Sunday in April to the last Sunday in October, the time in each zone is to be advanced one hour for advanced time or daylight saving time (DST). However, any state-by-state enactment may exempt the entire state from using advanced time. By this provision Arizona and Hawaii do not observe advanced time (as of 1973). By the 1972 amendment to the Act, a state split by a time-zone boundary may exempt from using advanced time all that part which is in one zone without affecting the rest of the state. By this amendment, 80 counties of Indiana in the Eastern zone are exempt from using advanced time, while 6 counties in the northwest corner and 6 counties in the southwest, which are in Central zone, do observe advanced time.

Pursuant to its assignment of carrying out the Act, the Department of Transportation has stipulated that municipalities located on the boundary between the Eastern and Central zones are in the Central zone; those on the boundary between the Central and Mountain zones are in the Mountain zone (except that Murdo, SD, is in the Central zone); those on the boundary between Mountain and Pacific time zones are in the Mountain zone. In such places, when the time is given, it should be specified as Central, Mountain, etc.

**Standard Time Signals** The National Institute of Standards and Technology broadcasts time signals from station **WWV**, Ft. Collins, CO, and from station **WWVH**, near Kekaha, Kauai, HI. The broadcasts by WWV are on radio carrier frequencies of 2.5, 5, 10, 15, and 20 MHz, while those by WWVH are on radio carrier frequencies of 2.5, 5, 10, and 15 MHz. Effective Jan. 1, 1975, time announcements by both WWV and WWVH are referred to as **Coordinated Universal Time, UTC**, the international coordinated time scale used around the world for most timekeeping purposes. UTC is generated by reference to International Atomic Time (TAI), which is determined by the Bureau International de l'Heure on the basis of atomic clocks operating in various establishments in accordance with the definition of the second. Since the difference between UTC and TAI is defined to be a whole number of seconds, a "leap second" is periodically added to or subtracted from UTC to take into account variations in the rotation of the earth. Time (i.e., clock time) is given in terms of 0 to 24 hours a day, starting with 0000 at midnight at Greenwich zero longitude. The beginning of each 0.8-second-long audio tone marks the end of an announced time interval. For example, at 2:15 P.M., UTC, the voice announcement would be: "At the tone fourteen hours fifteen minutes Coordinated Universal Time," given during the last 7.5 seconds of each minute. The tone markers from both stations are given simultaneously, but owing to propagation interferences may not be received simultaneously.

Beginning 1 minute after the hour, a 600-Hz signal is broadcast for about 45 s. At 2 min after the hour, the standard musical pitch of 440 Hz is broadcast for about 45 s. For the remaining 57 min of the hour, alternating tones of 600 and 500 Hz are broadcast for the first 45 s of each minute (see NIST Spec. Pub. 432). The time signal can also be received via long-distance telephone service from Ft. Collins. In addition to providing the musical pitch, these tone signals may be of use as markers for automated recorders and other such devices.

DENSITY AND RELATIVE DENSITY

**Density** of a body is its mass per unit volume. With SI units densities are in kilograms per cubic meter. However, giving densities in grams per cubic centimeter has been common. With the USCS, densities are given in pounds per mass cubic foot.

**Table 1.2.8 Relative Densities at 60°/60°F Corresponding to Degrees API and Weights per U.S. Gallon at 60°F**

$$\left( \text{Calculated from the formula, relative density} = \frac{141.5}{131.5 + \text{deg API}} \right)$$

Degrees API	Relative density	Lb per U.S. gallon	Degrees API	Relative density	Lb per U.S. gallon
10	1.0000	8.328	56	0.7547	6.283
11	0.9930	8.270	57	0.7507	6.249
12	0.9861	8.212	58	0.7467	6.216
13	0.9792	8.155	59	0.7428	6.184
14	0.9725	8.099	60	0.7389	6.151
15	0.9659	8.044	61	0.7351	6.119
16	0.9593	7.989	62	0.7313	6.087
17	0.9529	7.935	63	0.7275	6.056
18	0.9465	7.882	64	0.7238	6.025
19	0.9402	7.830	65	0.7201	5.994
20	0.9340	7.778	66	0.7165	5.964
21	0.9279	7.727	67	0.7128	5.934
22	0.9218	7.676	68	0.7093	5.904
23	0.9159	7.627	69	0.7057	5.874
24	0.9100	7.578	70	0.7022	5.845
25	0.9042	7.529	71	0.6988	5.817
26	0.8984	7.481	72	0.6953	5.788
27	0.8927	7.434	73	0.6919	5.759
28	0.8871	7.387	74	0.6886	5.731
29	0.8816	7.341	75	0.6852	5.703
30	0.8762	7.296	76	0.6819	5.676
31	0.8708	7.251	77	0.6787	5.649
32	0.8654	7.206	78	0.6754	5.622
33	0.8602	7.163	79	0.6722	5.595
34	0.8550	7.119	80	0.6690	5.568
35	0.8498	7.076	81	0.6659	5.542
36	0.8448	7.034	82	0.6628	5.516
37	0.8398	6.993	83	0.6597	5.491
38	0.8348	6.951	84	0.6566	5.465
39	0.8299	6.910	85	0.6536	5.440
40	0.8251	6.870	86	0.6506	5.415
41	0.8203	6.830	87	0.6476	5.390
42	0.8155	6.790	88	0.6446	5.365
43	0.8109	6.752	89	0.6417	5.341
44	0.8063	6.713	90	0.6388	5.316
45	0.8017	6.675	91	0.6360	5.293
46	0.7972	6.637	92	0.6331	5.269
47	0.7927	6.600	93	0.6303	5.246
48	0.7883	6.563	94	0.6275	5.222
49	0.7839	6.526	95	0.6247	5.199
50	0.7796	6.490	96	0.6220	5.176
51	0.7753	6.455	97	0.6193	5.154
52	0.7711	6.420	98	0.6166	5.131
53	0.7669	6.385	99	0.6139	5.109
54	0.7628	6.350	100	0.6112	5.086
55	0.7587	6.316			

NOTE: The weights in this table are weights in air at 60°F with humidity 50 percent and pressure 760 mm.

**Table 1.2.9 Relative Densities at 60°/60°F Corresponding to Degrees Baumé for Liquids Lighter than Water and Weights per U.S. Gallon at 60°F**

$$\left( \text{Calculated from the formula, relative density } \frac{60^\circ}{60^\circ} F = \frac{140}{130 + \text{deg Baumé}} \right)$$

Degrees Baumé	Relative density	Lb per gallon	Degrees Baumé	Relative density	Lb per gallon
10.0	1.0000	8.328	56.0	0.7527	6.266
11.0	0.9929	8.269	57.0	0.7487	6.233
12.0	0.9859	8.211	58.0	0.7447	6.199
13.0	0.9790	8.153	59.0	0.7407	6.166
14.0	0.9722	8.096	60.0	0.7368	6.134
15.0	0.9655	8.041	61.0	0.7330	6.102
16.0	0.9589	7.986	62.0	0.7292	6.070
17.0	0.9524	7.931	63.0	0.7254	6.038
18.0	0.9459	7.877	64.0	0.7216	6.007
19.0	0.9396	7.825	65.0	0.7179	5.976
20.0	0.9333	7.772	66.0	0.7143	5.946
21.0	0.9272	7.721	67.0	0.7107	5.916
22.0	0.9211	7.670	68.0	0.7071	5.886
23.0	0.9150	7.620	69.0	0.7035	5.856
24.0	0.9091	7.570	70.0	0.7000	5.827
25.0	0.9032	7.522	71.0	0.6965	5.798
26.0	0.8974	7.473	72.0	0.6931	5.769
27.0	0.8917	7.425	73.0	0.6897	5.741
28.0	0.8861	7.378	74.0	0.6863	5.712
29.0	0.8805	7.332	75.0	0.6829	5.685
30.0	0.8750	7.286	76.0	0.6796	5.657
31.0	0.8696	7.241	77.0	0.6763	5.629
32.0	0.8642	7.196	78.0	0.6731	5.602
33.0	0.8589	7.152	79.0	0.6699	5.576
34.0	0.8537	7.108	80.0	0.6667	5.549
35.0	0.8485	7.065	81.0	0.6635	5.522
36.0	0.8434	7.022	82.0	0.6604	5.497
37.0	0.8383	6.980	83.0	0.6573	5.471
38.0	0.8333	6.939	84.0	0.6542	5.445
39.0	0.8284	6.898	85.0	0.6512	5.420
40.0	0.8235	6.857	86.0	0.6482	5.395
41.0	0.8187	6.817	87.0	0.6452	5.370
42.0	0.8140	6.777	88.0	0.6422	5.345
43.0	0.8092	6.738	89.0	0.6393	5.320
44.0	0.8046	6.699	90.0	0.6364	5.296
45.0	0.8000	6.661	91.0	0.6335	5.272
46.0	0.7955	6.623	92.0	0.6306	5.248
47.0	0.7910	6.586	93.0	0.6278	5.225
48.0	0.7865	6.548	94.0	0.6250	5.201
49.0	0.7821	6.511	95.0	0.6222	5.178
50.0	0.7778	6.476	96.0	0.6195	5.155
51.0	0.7735	6.440	97.0	0.6167	5.132
52.0	0.7692	6.404	98.0	0.6140	5.100
53.0	0.7650	6.369	99.0	0.6114	5.088
54.0	0.7609	6.334	100.0	0.6087	5.066
55.0	0.7568	6.300			

**Relative density** is the ratio of the density of one substance to that of a second (or reference) substance, both at some specified temperature. Use of the earlier term *specific gravity* for this quantity is discouraged. For solids and liquids water is almost universally used as the reference substance. Physicists use a reference temperature of 4°C (= 39.2°F); U.S. engineers commonly use 60°F. With the introduction of SI units, it may be found desirable to use 59°F, since 59°F and 15°C are equivalents.

For gases, relative density is generally the ratio of the density of the gas to that of air, both at the same temperature, pressure, and dryness (as regards water vapor). Because equal numbers of moles of gases occupy

equal volumes, the ratio of the molecular weight of the gas to that of air may be used as the relative density of the gas. When this is done, the molecular weight of air may be taken as 28.9644.

The relative density of liquids is usually measured by means of a **hydrometer**. In addition to a scale reading in relative density as defined above, other arbitrary scales for hydrometers are used in various trades and industries. The most common of these are the **API** and **Baumé**. The API (American Petroleum Institute) scale is approved by the American Petroleum Institute, the ASTM, the U.S. Bureau of Mines, and the National Bureau of Standards and is recommended for exclusive use in the U.S. petroleum industry, superseding the Baumé scale for liquids lighter than water. The relation between **API degrees** and relative density (see Table 1.2.8) is expressed by the following equation:

$$\text{Degrees API} = \frac{141.5}{\text{rel dens } 60^\circ/60^\circ\text{F}} - 131.5$$

The relative densities corresponding to the indications of the **Baumé hydrometer** are given in Tables 1.2.9 and 1.2.10.

**Table 1.2.10 Relative Densities at 60°/60°F Corresponding to Degrees Baumé for Liquids Heavier than Water**

$$\left( \text{Calculated from the formula, relative density } \frac{60^\circ}{60^\circ} F = \frac{145}{145 - \text{deg Baumé}} \right)$$

Degrees Baumé	Relative density	Degrees Baumé	Relative density	Degrees Baumé	Relative density
0	1.0000	24	1.1983	48	1.4948
1	1.0069	25	1.2083	49	1.5104
2	1.0140	26	1.2185	50	1.5263
3	1.0211	27	1.2288	51	1.5426
4	1.0284	28	1.2393	52	1.5591
5	1.0357	29	1.2500	53	1.5761
6	1.0432	30	1.2609	54	1.5934
7	1.0507	31	1.2719	55	1.6111
8	1.0584	32	1.2832	56	1.6292
9	1.0662	33	1.2946	57	1.6477
10	1.0741	34	1.3063	58	1.6667
11	1.0821	35	1.3182	59	1.6860
12	1.0902	36	1.3303	60	1.7059
13	1.0985	37	1.3426	61	1.7262
14	1.1069	38	1.3551	62	1.7470
15	1.1154	39	1.3679	63	1.7683
16	1.1240	40	1.3810	64	1.7901
17	1.1328	41	1.3942	65	1.8125
18	1.1417	42	1.4078	66	1.8354
19	1.1508	43	1.4216	67	1.8590
20	1.1600	44	1.4356	68	1.8831
21	1.1694	45	1.4500	69	1.9079
22	1.1789	46	1.4646	70	1.9333
23	1.1885	47	1.4796		

**CONVERSION AND EQUIVALENCY TABLES**

**Note for Use of Conversion Tables (Tables 1.2.11 through 1.2.34)**

Subscripts after any figure, 0<sub>s</sub>, 9<sub>s</sub>, etc., mean that that figure is to be repeated the indicated number of times.

**1-28 MEASURING UNITS**

**Table 1.2.11 Length Equivalents**

Centimetres	Inches	Feet	Yards	Metres	Chains	Kilometres	Miles
1	0.3937	0.03281	0.01094	0.01	0.0 <sub>5</sub> 4971	10 <sup>-5</sup>	0.0 <sub>5</sub> 6214
2.540	1	0.08333	0.02778	0.0254	0.001263	0.0 <sub>2</sub> 254	0.0 <sub>1</sub> 578
30.48	12	1	0.3333	0.3048	0.01515	0.0 <sub>3</sub> 3048	0.0 <sub>3</sub> 1894
91.44	36	3	1	0.9144	0.04545	0.0 <sub>3</sub> 9144	0.0 <sub>5</sub> 5682
100	39.37	3.281	1.0936	1	0.04971	0.001	0.0 <sub>3</sub> 6214
2012	792	66	22	20.12	1	0.02012	0.0125
100000	39370	3281	1093.6	1000	49.71	1	0.6214
160934	63360	5280	1760	1609	80	1.609	1

(As used by metrology laboratories for precise measurements, including measurements of surface texture)\*

Angstrom units Å	Surface texture (U.S.), microinch $\mu$ in	Light bands, <sup>†</sup> monochromatic helium light count <sup>‡</sup>	Surface texture foreign, $\mu$ m	Precision measurements, § 0.0001 in	Close-tolerance measurements, 0.001 in (mils)	Metric unit, mm	USCS unit, in
1	0.003937	0.0003404	0.0001	0.0 <sub>4</sub> 3937	0.0 <sub>5</sub> 3937	0.0 <sub>6</sub> 1	0.0 <sub>8</sub> 3937
254	1	0.086	0.0254	0.01	0.001	0.0 <sub>2</sub> 254	0.0 <sub>3</sub> 1
2937.5	11.566	1	0.29375	0.11566	0.011566	0.0 <sub>2</sub> 29375	0.0 <sub>4</sub> 11566
10,000	39.37	3.404	1	0.3937	0.03937	0.001	0.0 <sub>4</sub> 3937
25,400	100	8.646	2.54	1	0.1	0.00254	0.0001
254,000	1000	86.46	25.4	10	1	0.0254	0.001
10,000,000	39,370	3404	1000	393.7	39.37	1	0.03937
254,000,000	1,000,000	86,460	25,400	10,000	1000	25.4	1

\* Computed by J. A. Broadston.

<sup>†</sup> One light band equals one-half corresponding wavelength. Visible-light wavelengths range from red at 6,500 Å to violet at 4,100 Å.

<sup>‡</sup> One helium light band = 0.000011661 in = 2937.5 Å; one krypton 86 light band = 0.0000119 in = 3,022.5 Å; one mercury 198 light band = 0.00001075 in = 2,730 Å.

§ The designations "precision measurements," etc., are not necessarily used in all metrology laboratories.

**CONVERSION AND EQUIVALENCY TABLES 1-29**

**Table 1.2.12 Conversion of Lengths\***

	Inches to millimetres	Millimetres to inches	Feet to metres	Metres to feet	Yards to metres	Metres to yards	Miles to kilometres	Kilometres to miles
1	25.40	0.03937	0.3048	3.281	0.9144	1.094	1.609	0.6214
2	50.80	0.07874	0.6096	6.562	1.829	2.187	3.219	1.243
3	76.20	0.1181	0.9144	9.843	2.743	3.281	4.828	1.864
4	101.60	0.1575	1.219	13.12	3.658	4.374	6.437	2.485
5	127.00	0.1969	1.524	16.40	4.572	5.468	6.047	3.107
6	152.40	0.2362	1.829	19.69	5.486	6.562	9.656	3.728
7	177.80	0.2756	2.134	22.97	6.401	7.655	11.27	4.350
8	203.20	0.3150	2.438	26.25	7.315	8.749	12.87	4.971
9	228.60	0.3543	2.743	29.53	8.230	9.843	14.48	5.592

\*EXAMPLE: 1 in = 25.40 mm.

Common fractions of an inch to millimetres (from 1/64 to 1 in)

64ths	Millimetres	64ths	Millimetres	64th	Millimetres	64ths	Millimetres	64ths	Millimetres	64ths	Millimetres
1	0.397	13	5.159	25	9.922	37	14.684	49	19.447	57	22.622
2	0.794	14	5.556	26	10.319	38	15.081	50	19.844	58	23.019
3	1.191	15	5.953	27	10.716	39	15.478	51	20.241	59	23.416
4	1.588	16	6.350	28	11.112	40	15.875	52	20.638	60	23.812
5	1.984	17	6.747	29	11.509	41	16.272	53	21.034	61	24.209
6	2.381	18	7.144	30	11.906	42	16.669	54	21.431	62	24.606
7	2.778	19	7.541	31	12.303	43	17.066	55	21.828	63	25.003
8	3.175	20	7.938	32	12.700	44	17.462	56	22.225	64	25.400
9	3.572	21	8.334	33	13.097	45	17.859				
10	3.969	22	8.731	34	13.494	46	18.256				
11	4.366	23	9.128	35	13.891	47	18.653				
12	4.762	24	9.525	36	14.288	48	19.050				

Decimals of an inch to millimetres (0.01 to 0.99 in)

	0	1	2	3	4	5	6	7	8	9
.0		0.254	0.508	0.762	1.016	1.270	1.524	1.778	2.032	2.286
.1	2.540	2.794	3.048	3.302	3.556	3.810	4.064	4.318	4.572	4.826
.2	5.080	5.334	5.588	5.842	6.096	6.350	6.604	6.858	7.112	7.366
.3	7.620	7.874	8.128	8.382	8.636	8.890	9.144	9.398	9.652	9.906
.4	10.160	10.414	10.668	10.922	11.176	11.430	11.684	11.938	12.192	12.446
.5	12.700	12.954	13.208	13.462	13.716	13.970	14.224	14.478	14.732	14.986
.6	15.240	15.494	15.748	16.002	16.256	16.510	16.764	17.018	17.272	17.526
.7	17.780	18.034	18.288	18.542	18.796	19.050	19.304	19.558	19.812	20.066
.8	20.320	20.574	20.828	21.082	21.336	21.590	21.844	22.098	22.352	22.606
.9	22.860	23.114	23.368	23.622	23.876	24.130	24.384	24.638	24.892	25.146

Millimetres to decimals of an inch (from 1 to 99 mm)

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0		0.0394	0.0787	0.1181	0.1575	0.1969	0.2362	0.2756	0.3150	0.3543
1	0.3937	0.4331	0.4724	0.5118	0.5512	0.5906	0.6299	0.6693	0.7087	0.7480
2	0.7874	0.8268	0.8661	0.9055	0.9449	0.9843	1.0236	1.0630	1.1024	1.1417
3	1.1811	1.2205	1.2598	1.2992	1.3386	1.3780	1.4173	1.4567	1.4961	1.5354
4	1.5748	1.6142	1.6535	1.6929	1.7323	1.7717	1.8110	1.8504	1.8898	1.9291
5	1.9685	2.0079	2.0472	2.0866	2.1260	2.1654	2.2047	2.2441	2.2835	2.3228
6	2.3622	2.4016	2.4409	2.4803	2.5197	2.5591	2.5984	2.6378	2.6772	2.7165
7	2.7559	2.7953	2.8346	2.8740	2.9134	2.9528	2.9921	3.0315	3.0709	3.1102
8	3.1496	3.1890	3.2283	3.2677	3.3071	3.3465	3.3858	3.4252	3.4646	3.5039
9	3.5433	3.5827	3.6220	3.6614	3.7008	3.7402	3.7795	3.8189	3.8583	3.8976

**1-30 MEASURING UNITS**

**Table 1.2.13 Area Equivalents**

(1 hectare = 100 ares = 10,000 centiares or square metres)

Square metres	Square inches	Square feet	Square yards	Square rods	Square chains	Roods	Acres	Square miles or sections
1	1550	10.76	1.196	0.0395	0.002471	0.0,9884	0.0,2471	0.0,3861
0.0,6452	1	0.006944	0.0,7716	0.0,2551	0.0,1594	0.0,6377	0.0,1594	0.0,2491
0.09290	144	1	0.1111	0.003673	0.0,2296	0.0,9183	0.0,2296	0.0,3587
0.8361	1296	9	1	0.03306	0.002066	0.0,8264	0.0002066	0.0,3228
25.29	39204	272.25	30.25	1	0.0625	0.02500	0.00625	0.0,9766
404.7	627264	4356	484	16	1	0.4	0.1	0.0001562
1012	1568160	10890	1210	40	2.5	1	0.25	0.0,3906
4047	6272640	43560	4840	160	10	4	1	0.001562
2589988		27878400	3097600	102400	6400	2560	640	1

**Table 1.2.14 Conversion of Areas\***

	Sq in to sq cm	Sq cm to sq in	Sq ft to sq m	Sq m to sq ft	Sq yd to sq m	Sq m to sq yd	Acres to hectares	Hectares to acres	Sq mi to sq km	Sq km to sq mi
1	6.452	0.1550	0.0929	10.76	0.8361	1.196	0.4047	2.471	2.590	0.3861
2	12.90	0.3100	0.1858	21.53	1.672	2.392	0.8094	4.942	5.180	0.7722
3	19.35	0.4650	0.2787	32.29	2.508	3.588	1.214	7.413	7.770	1.158
4	25.81	0.6200	0.3716	43.06	3.345	4.784	1.619	9.884	10.360	1.544
5	32.26	0.7750	0.4645	53.82	4.181	5.980	2.023	12.355	12.950	1.931
6	38.71	0.9300	0.5574	64.58	5.017	7.176	2.428	14.826	15.540	2.317
7	45.16	1.085	0.6503	75.35	5.853	8.372	2.833	17.297	18.130	2.703
8	51.61	1.240	0.7432	86.11	6.689	9.568	3.237	19.768	20.720	3.089
9	58.06	1.395	0.8361	96.88	7.525	10.764	3.642	22.239	23.310	3.475

\* EXAMPLE: 1 in<sup>2</sup> = 6.452 cm<sup>2</sup>.

**Table 1.2.15 Volume and Capacity Equivalents**

Cubic inches	Cubic feet	Cubic yards	U.S. Apothecary fluid ounces	U.S. quarts		U.S. gallons	U.S. bushels	Cubic decimetres or litres
				Liquid	Dry			
1	0.0,5787	0.0,2143	0.5541	0.01732	0.01488	0.0,4329	0.0,4650	0.01639
1728	1	0.03704	957.5	29.92	25.71	7.481	0.8036	28.32
46656	27	1	25853	807.9	694.3	202.2	21.70	764.6
1.805	0.001044	0.0,3868	1	0.03125	0.02686	0.007812	0.0,8392	0.02957
57.75	0.03342	0.001238	32	1	0.8594	0.25	0.02686	0.9464
67.20	0.03889	0.001440	37.24	1.164	1	0.2909	0.03125	1.101
231	0.1337	0.004951	128	4	3.437	1	0.1074	3.785
2150	1.244	0.04609	1192	37.24	32	9.309	1	35.24
61.02	0.03531	0.001308	33.81	1.057	0.9081	0.2642	0.02838	1

**Table 1.2.16 Conversion of Volumes or Cubic Measure\***

	Cu in to mL	mL to cu in	Cu ft to cu m	Cu m to cu ft	Cu yd to cu m	Cu m to cu yd	Gallons to cu ft	Cu ft to gallons
1	16.39	0.06102	0.02832	35.31	0.7646	1.308	0.1337	7.481
2	32.77	0.1220	0.05663	70.63	1.529	2.616	0.2674	14.96
3	49.16	0.1831	0.08495	105.9	2.294	3.924	0.4010	22.44
4	65.55	0.2441	0.1133	141.3	3.058	5.232	0.5347	29.92
5	81.94	0.3051	0.1416	176.6	3.823	6.540	0.6684	37.40
6	98.32	0.3661	0.1699	211.9	4.587	7.848	0.8021	44.88
7	114.7	0.4272	0.1982	247.2	5.352	9.156	0.9358	52.36
8	131.1	0.4882	0.2265	282.5	6.116	10.46	1.069	59.84
9	147.5	0.5492	0.2549	317.8	6.881	11.77	1.203	67.32

\* EXAMPLE: 1 in<sup>3</sup> = 16.39 mL.

**CONVERSION AND EQUIVALENCY TABLES 1-31**

**Table 1.2.17 Conversion of Volumes or Capacities\***

	Fluid ounces to mL	mL to fluid ounces	Liquid pints to litres	Litres to liquid pints	Liquid quarts to litres	Litres to liquid quarts	Gallons to litres	Litres to gallons	Bushels to hectolitres	Hectolitres to bushels
1	29.57	0.03381	0.4732	2.113	0.9463	1.057	3.785	0.2642	0.3524	2.838
2	59.15	0.06763	0.9463	4.227	1.893	2.113	7.571	0.5284	0.7048	5.676
3	88.72	0.1014	1.420	6.340	2.839	3.170	11.36	0.7925	1.057	8.513
4	118.3	0.1353	1.893	8.454	3.785	4.227	15.14	1.057	1.410	11.35
5	147.9	0.1691	2.366	10.57	4.732	5.284	18.93	1.321	1.762	14.19
6	177.4	0.2092	2.839	12.68	5.678	6.340	22.71	1.585	2.114	17.03
7	207.0	0.2367	3.312	14.79	6.624	7.397	26.50	1.849	2.467	19.86
8	236.6	0.2705	3.785	16.91	7.571	8.454	30.28	2.113	2.819	22.70
9	266.2	0.3043	4.259	19.02	8.517	9.510	34.07	2.378	3.171	25.54

\* EXAMPLE: 1 fluid oz = 29.57 mL.

**Table 1.2.18 Mass Equivalents**

Kilograms	Grains	Ounces		Pounds		Tons		Metric
		Troy and apoth	Avoirdupois	Troy and apoth	Avoirdupois	Short	Long	
1	15432	32.15	35.27	2.6792	2.205	0.0 <sub>2</sub> 1102	0.0 <sub>2</sub> 9842	0.001
0.0 <sub>6</sub> 480	1	0.0 <sub>2</sub> 2083	0.0 <sub>2</sub> 2286	0.0 <sub>3</sub> 1736	0.0 <sub>3</sub> 1429	0.0 <sub>7</sub> 7143	0.0 <sub>7</sub> 6378	0.0 <sub>6</sub> 480
0.03110	480	1	1.09714	0.08333	0.06857	0.0 <sub>3</sub> 3429	0.0 <sub>3</sub> 3061	0.0 <sub>3</sub> 110
0.02835	437.5	0.9115	1	0.07595	0.0625	0.0 <sub>3</sub> 3125	0.0 <sub>2</sub> 2790	0.0 <sub>2</sub> 835
0.3732	5760	12	13.17	1	0.8229	0.0 <sub>4</sub> 4114	0.0 <sub>3</sub> 3673	0.0 <sub>3</sub> 732
0.4536	7000	14.58	16	1.215	1	0.0005	0.0 <sub>4</sub> 4464	0.0 <sub>4</sub> 536
907.2	140 <sub>6</sub>	29167	320 <sub>3</sub>	2431	2000	1	0.8929	0.9072
1016	15680 <sub>4</sub>	32667	35840	2722	2240	1.12	1	1.016
1000	15432356	32151	35274	2679	2205	1.102	0.9842	1

**Table 1.2.19 Conversion of Masses\***

	Grains to grams	Grams to grains	Ounces (avdp) to grams	Grams to ounces (avdp)	Pounds (avdp) to kilograms	Kilograms to pounds (avdp)	Short tons (2000 lb) to metric tons	Metric tons (1000 kg) to short tons	Long tons (2240 lb) to metric tons	Metric tons to long tons
1	0.06480	15.43	28.35	0.03527	0.4536	2.205	0.907	1.102	1.016	0.984
2	0.1296	30.86	56.70	0.07055	0.9072	4.409	1.814	2.205	2.032	1.968
3	0.1944	46.30	85.05	0.1058	1.361	6.614	2.722	3.307	3.048	2.953
4	0.2592	61.73	113.40	0.1411	1.814	8.818	3.629	4.409	4.064	3.937
5	0.3240	77.16	141.75	0.1764	2.268	11.02	4.536	5.512	5.080	4.921
6	0.3888	92.59	170.10	0.2116	2.722	13.23	5.443	6.614	6.096	5.905
7	0.4536	108.03	198.45	0.2469	3.175	15.43	6.350	7.716	7.112	6.889
8	0.5184	123.46	226.80	0.2822	3.629	17.64	7.257	8.818	8.128	7.874
9	0.5832	138.89	255.15	0.3175	4.082	19.84	8.165	9.921	9.144	8.858

\* EXAMPLE: 1 grain = 0.06480 grams.

**Table 1.2.20 Pressure Equivalents**

Pascals N/m <sup>2</sup>	Bars 10 <sup>5</sup> N/m <sup>2</sup>	Poundsf per in <sup>2</sup>	Atmospheres	Columns of mercury at temperature 0°C and g = 9.80665 m/s <sup>2</sup>		Columns of water at temperature 15°C and g = 9.80665 m/s <sup>2</sup>	
				cm	in	cm	in
1	10 <sup>-5</sup>	0.000145	0.00001	0.00075	0.000295	0.01021	0.00402
100000	1	14.504	0.9869	75.01	29.53	1020.7	401.8
6894.8	0.068948	1	0.06805	5.171	2.036	70.37	27.703
101326	1.0132	14.696	1	76.000	29.92	1034	407.1
1333	0.0133	0.1934	0.01316	1	0.3937	13.61	5.357
3386	0.03386	0.4912	0.03342	2.540	1	34.56	13.61
97.98	0.0009798	0.01421	0.000967	0.07349	0.02893	1	0.3937
248.9	0.002489	0.03609	0.002456	0.1867	0.07349	2.540	1

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**Table 1.2.21 Conversion of Pressures\***

	Lb/in <sup>2</sup> to bars	Bars to lb/in <sup>2</sup>	Lb/in <sup>2</sup> to atmospheres	Atmospheres to lb/in <sup>2</sup>	Bars to atmospheres	Atmospheres to bars
1	0.06895	14.504	0.06805	14.696	0.98692	1.01325
2	0.13790	29.008	0.13609	29.392	1.9738	2.0265
3	0.20684	43.511	0.20414	44.098	2.9607	3.0397
4	0.27579	58.015	0.27218	58.784	3.9477	4.0530
5	0.34474	72.519	0.34823	73.480	4.9346	5.0663
6	0.41368	87.023	0.40826	88.176	5.9215	6.0795
7	0.48263	101.53	0.47632	102.87	6.9085	7.0927
8	0.55158	116.03	0.54436	117.57	7.8954	8.1060
9	0.62053	130.53	0.61241	132.26	8.8823	9.1192

\* EXAMPLE: 1 lb/in<sup>2</sup> = 0.06895 bar.

**Table 1.2.22 Velocity Equivalents**

cm/s	m/s	m/min	km/h	ft/s	ft/min	mi/h	Knots
1	0.01	0.6	0.036	0.03281	1.9685	0.02237	0.01944
100	1	60	3.6	3.281	196.85	2.237	1.944
1.667	0.01667	1	0.06	0.05468	3.281	0.03728	0.03240
27.78	0.2778	16.67	1	0.9113	54.68	0.6214	0.53996
30.48	0.3048	18.29	1.097	1	60	0.6818	0.59248
0.5080	0.005080	0.3048	0.01829	0.01667	1	0.01136	0.00987
44.70	0.4470	26.82	1.609	1.467	88	1	0.86898
51.44	0.5144	30.87	1.852	1.688	101.3	1.151	1

**Table 1.2.23 Conversion of Linear and Angular Velocities\***

cm/s to ft/min	ft/min to cm/s	cm/s to mi/h	mi/h to cm/s	ft/s to mi/h	mi/h to ft/s	rad/s to r/min	r/min to rad/s
1	1.97	0.508	0.0224	44.70	0.682	1.47	9.55
2	3.94	1.016	0.0447	89.41	1.364	2.93	19.10
3	5.91	1.524	0.0671	134.1	2.045	4.40	28.65
4	7.87	2.032	0.0895	178.8	2.727	5.87	38.20
5	9.84	2.540	0.1118	223.5	3.409	7.33	47.75
6	11.81	3.048	0.1342	268.2	4.091	8.80	57.30
7	13.78	3.556	0.1566	312.9	4.773	10.27	66.84
8	15.75	4.064	0.1790	357.6	5.455	11.73	76.39
9	17.72	4.572	0.2013	402.3	6.136	13.20	85.94

\* EXAMPLE: 1 cm/s = 1.97 ft/min.

**Table 1.2.24 Acceleration Equivalents**

cm/s <sup>2</sup>	m/s <sup>2</sup>	m/(h·s)	km/(h·s)	ft/(h·s)	ft/s <sup>2</sup>	ft/min <sup>2</sup>	mi/(h·s)	knots/s
1	0.01	36.00	0.036	118.1	0.03281	118.1	0.02237	0.01944
100	1	3600	3.6	11811	3.281	11811	2.237	1.944
0.02778	0.0002778	1	0.001	3.281	0.0009113	3.281	0.0006214	0.0005400
27.78	0.2778	1000	1	3281	0.9113	3281	0.6214	0.5400
0.008467	0.00008467	0.3048	0.0003048	1	0.0002778	1	0.0001894	0.0001646
30.48	0.3048	1097	1.097	3600	1	3600	0.6818	0.4572
0.008467	0.00008467	0.3048	0.0003048	1	0.0002778	1	0.0001894	0.0001646
44.70	0.4470	1609	1.609	5280	1.467	5280	1	0.8690
51.44	0.5144	1852	1.852	6076	1.688	6076	1.151	1



**Table 1.2.25 Conversion of Accelerations\***

	cm/s <sup>2</sup> to ft/min <sup>2</sup>	km/(h · s) to mi/(h · s)	km/(h · s) to knots/s	ft/s <sup>2</sup> to mi/(h · s)	ft/s <sup>2</sup> to knots/s	ft/min <sup>2</sup> to cm/s <sup>2</sup>	mi/(h · s) to m/(h · s)	mi/(h · s) to knots/s	knots/s to mi/(h · s)	knots/s to km/(h · s)
1	118.1	0.6214	0.5400	0.6818	0.4572	0.008467	1.609	0.8690	1.151	1.852
2	236.2	1.243	1.080	1.364	0.9144	0.01693	3.219	1.738	2.302	3.704
3	354.3	1.864	1.620	2.045	1.372	0.02540	4.828	2.607	3.452	5.556
4	472.4	2.485	2.160	2.727	1.829	0.03387	6.437	3.476	4.603	7.408
5	590.6	3.107	2.700	3.409	2.286	0.04233	8.046	4.345	5.754	9.260
6	708.7	3.728	3.240	4.091	2.743	0.05080	9.656	5.214	6.905	11.11
7	826.8	4.350	3.780	4.772	3.200	0.05927	11.27	6.083	8.056	12.96
8	944.9	4.971	4.320	5.454	3.658	0.06774	12.87	6.952	9.206	14.82
9	1063	5.592	4.860	6.136	4.115	0.07620	14.48	7.821	10.36	16.67

\* EXAMPLE: 1 cm/s<sup>2</sup> = 118.1 ft/min<sup>2</sup>.

**Table 1.2.26 Energy or Work Equivalents**

Joules or Newton-metre	Kilogramf- metres	Foot-poundsf	Kilowatt hours	Metric horsepower- hours	Horsepower- hours	Litre- atmospheres	Kilocalories	British thermal units
1	0.10197	0.7376	0.0 <sub>2</sub> 2778	0.0 <sub>6</sub> 3777	0.0 <sub>6</sub> 3725	0.009869	0.0 <sub>2</sub> 2388	0.0 <sub>2</sub> 9478
9.80665	1	7.233	0.0 <sub>2</sub> 2724	0.0 <sub>5</sub> 37037	0.0 <sub>5</sub> 3653	0.09678	0.002342	0.009295
1.356	0.1383	1	0.0 <sub>6</sub> 3766	0.0 <sub>6</sub> 51206	0.0 <sub>6</sub> 50505	0.01338	0.0 <sub>3</sub> 3238	0.001285
3.600 × 10 <sup>6</sup>	3.671 × 10 <sup>5</sup>	2.655 × 10 <sup>6</sup>	1	1.3596	1.341	35528	859.9	3412
2.648 × 10 <sup>6</sup>	270000	1.9529 × 10 <sup>6</sup>	0.7355	1	0.9863	26131	632.4	2510
2.6845 × 10 <sup>6</sup>	2.7375 × 10 <sup>5</sup>	1.98 × 10 <sup>6</sup>	0.7457	1.0139	1	26493	641.2	2544
101.33	10.333	74.74	0.0 <sub>2</sub> 2815	0.0 <sub>3</sub> 3827	0.0 <sub>3</sub> 3775	1	0.02420	0.09604
4186.8	426.9	3088	0.001163	0.001581	0.001560	41.32	1	3.968
1055	107.6	778.2	0.0 <sub>3</sub> 2931	0.0 <sub>3</sub> 3985	0.0 <sub>3</sub> 3930	10.41	0.25200	1

**Table 1.2.27 Conversion of Energy, Work, Heat\***

	Ft · lbf to joules	Joules to ft · lbf	Ft · lbf to Btu	Btu to ft · lbf	Kilogramf- metres to kilocalories	Kilocalories to kilogramf- metres	Joules to calories	Calories to joules
1	1.3558	0.7376	0.001285	778.2	0.002342	426.9	0.2388	4.187
2	2.7116	1.4751	0.002570	1,556	0.004685	853.9	0.4777	8.374
3	4.0674	2.2127	0.003855	2,334	0.007027	1,281	0.7165	12.56
4	5.4232	2.9503	0.005140	3,113	0.009369	1,708	0.9554	16.75
5	6.7790	3.6879	0.006425	3,891	0.01172	2,135	1.194	20.93
6	8.1348	4.4254	0.007710	4,669	0.01405	2,562	1.433	25.12
7	9.4906	5.1630	0.008995	5,447	0.01640	2,989	1.672	29.31
8	10.8464	5.9006	0.01028	6,225	0.01874	3,415	1.911	33.49
9	12.2022	6.6381	0.01156	7,003	0.02108	3,842	2.150	37.68

\* EXAMPLE: 1 ft · lbf = 1.3558 J.

**Table 1.2.28 Power Equivalents**

Horsepower	Kilowatts	Metric horsepower	Kgf · m per s	Ft · lbf per s	Kilocalories per s	Btu per s
1	0.7457	1.014	76.04	550	0.1781	0.7068
1.341	1	1.360	102.0	737.6	0.2388	0.9478
0.9863	0.7355	1	75	542.5	0.1757	0.6971
0.01315	0.009807	0.01333	1	7.233	0.002342	0.009295
0.00182	0.001356	0.00184	0.1383	1	0.0 <sub>3</sub> 3238	0.001285
5.615	4.187	5.692	426.9	3088	1	3.968
1.415	1.055	1.434	107.6	778.2	0.2520	1

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**Table 1.2.29 Conversion of Power\***

	Horsepower to kilowatts	Kilowatts to horsepower	Metric horsepower to kilowatts	Kilowatts to metric horsepower	Horsepower to metric horsepower	Metric horsepower to horsepower
1	0.7457	1.341	0.7355	1.360	1.014	0.9863
2	1.491	2.682	1.471	2.719	2.028	1.973
3	2.237	4.023	2.206	4.079	3.042	2.959
4	2.983	5.364	2.942	5.438	4.055	3.945
5	3.729	6.705	3.677	6.798	5.069	4.932
6	4.474	8.046	4.412	8.158	6.083	5.918
7	5.220	9.387	5.147	9.520	7.097	6.904
8	5.966	10.73	5.883	10.88	8.111	7.891
9	6.711	12.07	6.618	12.24	9.125	8.877

\* EXAMPLE: 1 hp = 0.7457 kW.

**Table 1.2.30 Density Equivalents\***

Grams per mL	Lb per cu in	Lb per cu ft	Short tons (2,000 lb) per cu yd	Lb per U.S. gal
1	0.03613	62.43	0.8428	8.345
27.68	1	1728	23.33	231
0.01602	0.035787	1	0.0135	0.1337
1.187	0.04287	74.7	1	9.902
0.1198	0.004329	7.481	0.1010	1

\* EXAMPLE: 1 g per mL = 62.43 lb per cu ft.

**Table 1.2.31 Conversion of Density**

Grams per mL to lb per cu ft	Lb per cu ft to grams per mL	Grams per mL to short tons per cu yd	Short tons per cu yd to grams per mL
62.43	0.01602	0.8428	1.187
187.28	0.04805	2.5283	3.560
312.14	0.08009	4.2139	5.933
437.00	0.11213	5.8995	8.306
561.85	0.14416	7.5850	10.679

**Table 1.2.32 Thermal Conductivity**

Calories per cm <sup>2</sup> · s · °C	Watts per cm <sup>2</sup> · °C	Calories per cm <sup>2</sup> · h · °C	Btu · ft per ft <sup>2</sup> · h · °F	Btu · in per ft <sup>2</sup> · day · °F
1	4.1868	3,600	241.9	69,670
0.2388	1	860	57.79	16,641
0.0002778	0.001163	1	0.0672	19.35
0.004134	0.01731	14.88	1	288
0.00001435	0.00006009	0.05167	0.00347	1

**Table 1.2.33 Thermal Conductance**

Calories per cm <sup>2</sup> · s · °C	Watts per cm <sup>2</sup> · °C	Calories per cm <sup>2</sup> · h · °C	Btu per ft <sup>2</sup> · h · °F	Btu per ft <sup>2</sup> · day · °F
1	4.1868	3,600	7,373	176,962
0.2388	1	860	1,761	42,267
0.0002778	0.001163	1	2.048	49.16
0.0001356	0.0005678	0.4882	1	24
0.000005651	0.00002366	0.02034	0.04167	1

**Table 1.2.34 Heat Flow**

Calories per cm <sup>2</sup> · s	Watts per cm <sup>2</sup>	Calories per cm <sup>2</sup> · h	Btu per ft <sup>2</sup> · h	Btu per ft <sup>2</sup> · day
1	4.1868	3,600	13,272	318,531
0.2388	1	860	3,170	76,081
0.0002778	0.001163	1	3.687	88.48
0.00007535	0.0003154	0.2712	1	24
0.000003139	0.00001314	0.01130	0.04167	1