

ضمیمه

APPENDIX

A

جدول ها

Tables

Table A-1 | تابع خطا. The error function.

$\frac{x}{2\sqrt{\alpha\tau}}$	$\operatorname{erf} \frac{x}{2\sqrt{\alpha\tau}}$	$\frac{x}{2\sqrt{\alpha\tau}}$	$\operatorname{erf} \frac{x}{2\sqrt{\alpha\tau}}$	$\frac{x}{2\sqrt{\alpha\tau}}$	$\operatorname{erf} \frac{x}{2\sqrt{\alpha\tau}}$
0.00	0.00000	0.76	0.71754	1.52	0.96841
0.02	0.02256	0.78	0.73001	1.54	0.97059
0.04	0.04511	0.80	0.74210	1.56	0.97263
0.06	0.06762	0.82	0.75381	1.58	0.97455
0.08	0.09008	0.84	0.76514	1.60	0.97636
0.10	0.11246	0.86	0.77610	1.62	0.97804
0.12	0.13476	0.88	0.78669	1.64	0.97962
0.14	0.15695	0.90	0.79691	1.66	0.98110
0.16	0.17901	0.92	0.80677	1.68	0.98249
0.18	0.20094	0.94	0.81627	1.70	0.98379
0.20	0.22270	0.96	0.82542	1.72	0.98500
0.22	0.24430	0.98	0.83423	1.74	0.98613
0.24	0.26570	1.00	0.84270	1.76	0.98719
0.26	0.28690	1.02	0.85084	1.78	0.98817
0.28	0.30788	1.04	0.85865	1.80	0.98909
0.30	0.32863	1.06	0.86614	1.82	0.98994
0.32	0.34913	1.08	0.87333	1.84	0.99074
0.34	0.36936	1.10	0.88020	1.86	0.99147
0.36	0.38933	1.12	0.88079	1.88	0.99216
0.38	0.40901	1.14	0.89308	1.90	0.99279
0.40	0.42839	1.16	0.89910	1.92	0.99338
0.42	0.44749	1.18	0.90484	1.94	0.99392
0.44	0.46622	1.20	0.91031	1.96	0.99443
0.46	0.48466	1.22	0.91553	1.98	0.99489
0.48	0.50275	1.24	0.92050	2.00	0.995322
0.50	0.52050	1.26	0.92524	2.10	0.997020
0.52	0.53790	1.28	0.92973	2.20	0.998137
0.54	0.55494	1.30	0.93401	2.30	0.998857
0.56	0.57162	1.32	0.93806	2.40	0.999311
0.58	0.58792	1.34	0.94191	2.50	0.999593
0.60	0.60386	1.36	0.94556	2.60	0.999764
0.62	0.61941	1.38	0.94902	2.70	0.999866
0.64	0.63459	1.40	0.95228	2.80	0.999925
0.66	0.64938	1.42	0.95538	2.90	0.999959
0.68	0.66278	1.44	0.95830	3.00	0.999978
0.70	0.67780	1.46	0.96105	3.20	0.999994
0.72	0.69143	1.48	0.96365	3.40	0.999998
0.74	0.70468	1.50	0.96610	3.60	1.000000

Table A-2 | Property values for metals.† | **خواص فیزیکی فلزات**

Metal	Properties at 20°C						ضریب هدایت Thermal conductivity k , W/m . °C							
	ρ kg/m ³	c_p kJ/kg . °C	k W/m . °C	$\alpha \times 10^5$ m ² /s	-100°C -148°F	0°C 32°F	100°C 212°F	200°C 392°F	300°C 572°F	400°C 752°F	600°C 1112°F	800°C 1472°F	1000°C 1832°F	1200°C 2192°F
Aluminum:														
Pure	2,707	0.896	204	8.418	215	202	206	215	228	249				
Al-Cu (Duralumin), 94-96% Al, 3-5% Cu, trace Mg	2,787	0.883	164	6.676	126	159	182	194						
Al-Si (Silumin, copper-bearing), 86.5% Al, 1% Cu	2,659	0.867	137	5.933	119	137	144	152	161					
Al-Si (Alusil), 78-80% Al, 20-22% Si	2,627	0.854	161	7.172	144	157	168	175	178					
Al-Mg-Si, 97% Al, 1% Mg, 1% Si, 1% Mn	2,707 11,373	0.892 0.130	177 35	7.311 2.343	36.9	175 35.1	189 33.4	204 31.5	29.8					
Lead	7,897	0.452	73	2.034	87	73	67	62	55	48	40	36	35	36
Iron:	7,849	0.46	59	1.626		59	57	52	48	45	36	33	33	33
Wrought iron, 0.5% C														
Steel														
(C max \approx 1.5%):														
Carbon steel	7,833	0.465	54	1.474		55	52	48	45	42	35	31	29	31
C \approx 0.5%	7,801	0.473	43	1.172		43	43	42	40	36	33	29	28	29
1.0%	7,753	0.486	36	0.970		36	36	36	35	33	31	28	28	29
1.5%														

Table A-2 | Property values for metals[†] (Continued).

خواص فیزیکی فلزات (ادامه)

Metal	Properties at 20°C				Thermal conductivity k , W/m · °C									
	ρ kg/m ³	c_p kJ/kg · °C	k W/m · °C	$\alpha \times 10^5$ m ² /s	-100°C -148°F	0°C 32°F	100°C 212°F	200°C 392°F	300°C 572°F	400°C 752°F	600°C 1112°F	800°C 1472°F	1000°C 1832°F	1200°C 2192°F
Nickel steel														
Ni ≈ 0%	7,897	0.452	73	2.026		73	67	62	55	48	40	36	35	36
20%	7,933	0.46	19	0.526		62	55	52	47	42	36	33	33	
40%	8,169	0.46	10	0.279		40	38	36	36	33	29	29	29	
80%	8,618	0.46	35	0.872		22	22	22	22	24	24	26	29	
Invar 36% Ni	8,137	0.46	10.7	0.286		22	22	22	22	24	24	26	29	
Chrome steel														
Cr = 0%	7,897	0.452	73	2.026	87	73	67	62	55	48	40	36	35	36
1%	7,865	0.46	61	1.665		62	55	52	47	42	36	33	33	
5%	7,833	0.46	40	1.110		40	38	36	36	33	29	29	29	
20%	7,689	0.46	22	0.635		22	22	22	22	24	24	26	29	
Cr-Ni (chrome-nickel): 15% Cr, 10% Ni	7,865	0.46	19	0.527										
18% Cr, 8% Ni														
(V2A)	7,817	0.46	16.3	0.444		16.3	17	17	19	19	22	27	31	
20% Cr, 15% Ni	7,833	0.46	15.1	0.415										
25% Cr, 20% Ni	7,865	0.46	12.8	0.361										
Tungsten steel														
W = 0%	7,897	0.452	73	2.026										
1%	7,913	0.448	66	1.858										
5%	8,073	0.435	54	1.525										
10%	8,314	0.419	48	1.391										
Copper:														
Pure	8,954	0.3831	386	11.234	407	386	379	374	369	363	353			
Aluminum bronze 95% Cu, 5% Al	8,666	0.410	83	2.330										

خواص فیزیکی فلزات (ادامه)

Table A-2 | Property values for metals[†] (Continued).

Metal	Properties at 20°C				Thermal conductivity k , W/m · °C									
	ρ , kg/m ³	c_p kJ/kg · °C	k W/m · °C	$\alpha \times 10^5$ m ² /s	-100°C -148°F	0°C 32°F	100°C 212°F	200°C 392°F	300°C 572°F	400°C 752°F	600°C 1112°F	800°C 1472°F	1000°C 1832°F	1200°C 2192°F
Bronze 75% Cu, 25% Sn	8,666	0.343	26	0.859										
Red brass 85% Cu, 9% Sn, 6% Zn	8,714	0.385	61	1.804		59	71							
Brass 70% Cu, 30% Zn	8,522	0.385	111	3.412			128	144	147					
German silver 62% Cu, 15% Ni, 22% Zn	8,618	0.394	24.9	0.733			31	40	45	48				
Constantan 60% Cu, 40% Ni	8,922	0.410	22.7	0.612			22.2	26						
Magnesium: Pure	1,746	1.013	171	9.708		171	168	163	157					
Mg-Al (electro- lytic) 6–8% Al, 1–2% Zn	1,810	1.00	66	3.605		52	62	74	83					
Molybdenum	10,220	0.251	123	4.790		125	118	114	111	109	106	102	99	92
Nickel: Pure (99.9%)	8,906	0.4459	90	2.266		93	83	73	64	59				
Ni-Cr 90% Ni, 10% Cr	8,666	0.444	17	0.444		17.1	18.9	20.9	22.8	24.6				
80% Ni, 20% Cr	8,314	0.444	12.6	0.343		12.3	13.8	15.6	17.1	18.0				
Silver: Purest	10,524	0.2340	419	17.004		417	415	412						
Pure (99.9%)	10,525	0.2340	407	16.563		410	415	374	362	360				
Tin, pure	7,304	0.2265	64	3.884		65.9	59	57						
Tungsten	19,350	0.1344	163	6.271		166	151	142	133	126	112			
Zinc, pure	7,144	0.3843	112.2	4.106		112	109	106	100	93	76			

[†] Adapted to SI units from E. R. G. Eckert and R. M. Drake, *Heat and Mass Transfer*, 2nd ed. New York: McGraw-Hill, 1959.

Table A-3 | Properties of nonmetals.† خواص فیزیکی غیرفلزات

Substance	Temperature °C	k W/m · °C	ρ kg/m ³	c kJ/kg · °C	$\alpha \times 10^7$ m ² /s
Structural and heat-resistant materials مواد ساختمانی و مقاوم در مقابل حرارت					
Acoustic tile	30	0.06	290	1.3	1.6
Aluminum oxide, sapphire	30	46	3970	0.76	150
Aluminum oxide, polycrystalline	30	36	3970	0.76	120
Asphalt	20–55	0.74–0.76			
Bakelite	30	0.23	1200	1.6	1.2
Brick:					
Building brick, common	20	0.69	1600	0.84	5.2
Face		1.32	2000		
Carborundum brick	600 1400	18.5 11.1			
Chrome brick	200 550 900	2.32 2.47 1.99	3000	0.84	9.2 9.8 7.9
Diatomaceous earth, molded and fired	200 870	0.24 0.31			
Fireclay brick	500	1.04	2000	0.96	5.4
Burnt 2426°F	800 1100	1.07 1.09			
Burnt 2642°F	500 800 1100	1.28 1.37 1.40	2300	0.96	5.8
Missouri	200 600 1400	1.00 1.47 1.77	2600	0.96	4.0
Magnesite	200 650 1200	3.81 2.77 1.90		1.13	
Cement, portland Mortar	23	0.29 1.16	1500		
Coal, anthracite	30	0.26	1300	1.25	1.6
Concrete, cinder Stone, 1-2-4 mix	20	0.76 1.37	1900–2300	0.88	8.2–6.8
Glass, window Corosilicate	20 30–75	0.78 (avg) 1.09	2700 2200	0.84	3.4
Graphite, pyrolytic parallel to layers perpendicular to layers	30 30	1900 5.6	2200 2200	0.71 0.71	12,200 36
Gypsum board	30	0.16			
Lexan	30	0.2	1200	1.3	1.3
Nylon	30	0.16	1100	1.6	0.9
Particle board, low density high density	30 30	0.079 0.17	590 1000	1.3 1.3	1.0 1.3
Phenolic	30	0.03	1400	1.6	0.13
Plaster, gypsum Metal lath Wood lath	20 20 20	0.48 0.47 0.28	1440	0.84	4.0

Table A-3 | Properties of nonmetals[†] (Continued). (ادامه) خواص فیزیکی غیرفلزات

Substance	Temperature °C	k W/m · °C	ρ kg/m ³	c kJ/kg · °C	$\alpha \times 10^7$ m ² /s
Structural and heat-resistant materials مواد ساختمانی و مقاوم در مقابل حرارت					
Plexiglass	30	0.2	1200	1.5	1.1
Polyethylene	30	0.33	960	2.1	1.64
Polypropylene	30	0.16	1150	1.9	0.73
Polystyrene	30	0.14	1000	1.3	1.1
Polyvinylchloride	30	0.09	1700	1.1	0.48
Rubber, hard	30	0.15	1200	2.0	0.62
Silicon carbide	30	490	3150	0.68	2290
Stone:					
Granite		1.73–3.98	2640	0.82	8–18
Limestone	100–300	1.26–1.33	2500	0.90	5.6–5.9
Marble		2.07–2.94	2500–2700	0.80	10–13.6
Sandstone	40	1.83	2160–2300	0.71	11.2–11.9
Structural concrete					
low density	30	0.21	670		
light weight	30	0.65	1570		
medium weight	30	0.75	1840		
normal weight	30	2.32	2260		
Teflon	30	0.35	2200	1.05	1.5
Titanium dioxide	30	8.4	4150	0.7	29
Wood (across the grain):					
Balsa, 8.8 lb/ft ³	30	0.055	140		
Cypress	30	0.097	460		
Fir	23	0.11	420	2.72	0.96
Maple or oak	30	0.166	540	2.4	1.28
Yellow pine	23	0.147	640	2.8	0.82
White pine	30	0.112	430		
Insulating materials مواد عایق					
Asbestos:					
Loosely packed	–45	0.149			
	0	0.154	470–570	0.816	3.3–4
	100	0.161			
Asbestos-cement boards	20	0.74			
Sheets	51	0.166			
Felt, 40 laminations/in	38	0.057			
	150	0.069			
	260	0.083			
20 laminations/in	38	0.078			
	150	0.095			
	260	0.112			
Corrugated, 4 plies/in	38	0.087			
	93	0.100			
	150	0.119			
Asbestos cement	—	2.08			
Balsam wood, 2.2 lb/ft ³	32	0.04	35		
Cardboard, corrugated	—	0.064			
Celotex	32	0.048			
Cork, regranulated	32	0.045	45–120	1.88	2–5.3
Ground	32	0.043	150		
Corkboard, 10 lb/ft ³	30	0.043	160		

Table A-3 | Properties of nonmetals[†] (Continued). خواص فیزیکی غیرفلزات (ادامه)

Substance	Temperature °C	k W/m · °C	ρ kg/m ³	c kJ/kg · °C	$\alpha \times 10^7$ m ² /s
Insulating materials مواد عایق					
Diamond, Type IIa, insulator	30	2300	3500	0.509	12,900
Diatomaceous earth (Sil-o-cel)	0	0.061	320		
Felt, hair	30	0.036	130–200		
Wool	30	0.052	330		
Fiber, insulating board	20	0.048	240		
Glass fiber, duct liner	30	0.038	32	0.84	14.1
Glass fiber, loose blown	30	0.043	16	0.84	32
Glass wool, 1.5 lb/ft ³	23	0.038	24	0.7	22.6
Ice	0	2.22	910	1.93	12.6
Insulex, dry	32	0.064 0.144			
Kapok	30	0.035			
Magnesia, 85%	38	0.067	270		
	93	0.071			
	150	0.074			
	204	0.080			
Paper (avg.)	30	0.12	900	1.2	1.1
Polyisocyanurate sheet	30	0.023			
Polystyrene, extruded	30	0.028			
Polyurethane foam	30	0.017			
Rock wool, 10 lb/ft ³	32	0.040	160		
Loosely packed	150	0.067	64		
	260	0.087			
Sawdust	23	0.059			
Silica aerogel	32	0.024	140		
Styrofoam	32	0.033			
Urethane, cerllular	30	0.025			
Wood shavings	23	0.059			

[†] Adapted to SI units from A. I. Brown and S. M. Marco, *Introduction to Heat Transfer*, 3rd ed. New York: McGraw-Hill, 1958. Other properties from various sources.

Table A-4 | Properties of saturated liquids. † خواص فیزیکی مایعات اشباع

$T, ^\circ\text{C}$	ρ kg/m^3	c_p $\text{kJ/kg}\cdot^\circ\text{C}$	$\nu, \text{m}^2/\text{s}$	k $\text{W/m}\cdot^\circ\text{C}$	$\alpha, \text{m}^2/\text{s}$	Pr	β, K^{-1}	
آمونیاک Ammonia, NH₃								
-50	703.69	4.463	0.435×10^{-6}	0.547	1.742×10^{-7}	2.60	2.45×10^{-3}	
-40	691.68	4.467	0.406	0.547	1.775	2.28		
-30	679.34	4.476	0.387	0.549	1.801	2.15		
-20	666.69	4.509	0.381	0.547	1.819	2.09		
-10	653.55	4.564	0.378	0.543	1.825	2.07		
0	640.10	4.635	0.373	0.540	1.819	2.05		
10	626.16	4.714	0.368	0.531	1.801	2.04		
20	611.75	4.798	0.359	0.521	1.775	2.02		
30	596.37	4.890	0.349	0.507	1.742	2.01		
40	580.99	4.999	0.340	0.493	1.701	2.00		
50	564.33	5.116	0.330	0.476	1.654	1.99		
دی اکسید کربن Carbon dioxide, CO₂								
-50	1,156.34	1.84	0.119×10^{-6}	0.0855	0.4021×10^{-7}	2.96	14.00×10^{-3}	
-40	1,117.77	1.88	0.118	0.1011	0.4810	2.46		
-30	1,076.76	1.97	0.117	0.1116	0.5272	2.22		
-20	1,032.39	2.05	0.115	0.1151	0.5445	2.12		
-10	983.38	2.18	0.113	0.1099	0.5133	2.20		
0	926.99	2.47	0.108	0.1045	0.4578	2.38		
10	860.03	3.14	0.101	0.0971	0.3608	2.80		
20	772.57	5.0	0.091	0.0872	0.2219	4.10		
30	597.81	36.4	0.080	0.0703	0.0279	28.7		
دی اکسید گوگرد Sulfur dioxide, SO₂								
-50	1,560.84	1.3595	0.484×10^{-6}	0.242	1.141×10^{-7}	4.24		1.94×10^{-3}
-40	1,536.81	1.3607	0.424	0.235	1.130	3.74		
-30	1,520.64	1.3616	0.371	0.230	1.117	3.31		
-20	1,488.60	1.3624	0.324	0.225	1.107	2.93		
-10	1,463.61	1.3628	0.288	0.218	1.097	2.62		
0	1,438.46	1.3636	0.257	0.211	1.081	2.38		
10	1,412.51	1.3645	0.232	0.204	1.066	2.18		
20	1,386.40	1.3653	0.210	0.199	1.050	2.00		
30	1,359.33	1.3662	0.190	0.192	1.035	1.83		
40	1,329.22	1.3674	0.173	0.185	1.019	1.70		
50	1,299.10	1.3683	0.162	0.177	0.999	1.61		
دی کلرو دی فلورو متان (فرئون ۱۲) Dichlorodifluoromethane (Freon-12), CCl₂F₂								
-50	1,546.75	0.8750	0.310×10^{-6}	0.067	0.501×10^{-7}	6.2	2.63×10^{-3}	
-40	1,518.71	0.8847	0.279	0.069	0.514	5.4		
-30	1,489.56	0.8956	0.253	0.069	0.526	4.8		
-20	1,460.57	0.9073	0.235	0.071	0.539	4.4		
-10	1,429.49	0.9203	0.221	0.073	0.550	4.0		
0	1,397.45	0.9345	0.214×10^{-6}	0.073	0.557×10^{-7}	3.8		
10	1,364.30	0.9496	0.203	0.073	0.560	3.6		
20	1,330.18	0.9659	0.198	0.073	0.560	3.5		
30	1,295.10	0.9835	0.194	0.071	0.560	3.5		
40	1,257.13	1.0019	0.191	0.069	0.555	3.5		
50	1,215.96	1.0216	0.190	0.067	0.545	3.5		

Table A-4 | Properties of saturated liquids[†] (Continued). (ادامه) خواص فیزیکی مایعات اشباع

$T, ^\circ\text{C}$	ρ kg/m^3	c_p $\text{kJ/kg}\cdot^\circ\text{C}$	$\nu, \text{m}^2/\text{s}$	k $\text{W/m}\cdot^\circ\text{C}$	$\alpha, \text{m}^2/\text{s}$	Pr	β, K^{-1}
گلیسرین Glycerin, $\text{C}_3\text{H}_5(\text{OH})_3$							
0	1,276.03	2.261	0.00831	0.282	0.983×10^{-7}	84.7×10^3	0.50×10^{-3}
10	1,270.11	2.319	0.00300	0.284	0.965	31.0	
20	1,264.02	2.386	0.00118	0.286	0.947	12.5	
30	1,258.09	2.445	0.00050	0.286	0.929	5.38	
40	1,252.01	2.512	0.00022	0.286	0.914	2.45	
50	1,244.96	2.583	0.00015	0.287	0.893	1.63	
اتیلن گلیکول Ethylene glycol, $\text{C}_2\text{H}_4(\text{OH})_2$							
0	1,130.75	2.294	7.53×10^{-6}	0.242	0.934×10^{-7}	615	0.65×10^{-3}
20	1,116.65	2.382	19.18	0.249	0.939	204	
40	1,101.43	2.474	8.69	0.256	0.939	93	
60	1,087.66	2.562	4.75	0.260	0.932	51	
80	1,077.56	2.650	2.98	0.261	0.921	32.4	
100	1,058.50	2.742	2.03	0.263	0.908	22.4	
روغن موتور (مصرف نشده) Engine oil (unused)							
0	899.12	1.796	0.00428	0.147	0.911×10^{-7}	47,100	0.70×10^{-3}
20	888.23	1.880	0.00090	0.145	0.872	10,400	
40	876.05	1.964	0.00024	0.144	0.834	2,870	
60	864.04	2.047	0.839×10^{-4}	0.140	0.800	1,050	
80	852.02	2.131	0.375	0.138	0.769	490	
100	840.01	2.219	0.203	0.137	0.738	276	
120	828.96	2.307	0.124	0.135	0.710	175	
140	816.94	2.395	0.080	0.133	0.686	116	
160	805.89	2.483	0.056	0.132	0.663	84	
جیوه Mercury, Hg							
0	13,628.22	0.1403	0.124×10^{-6}	8.20	42.99×10^{-7}	0.0288	1.82×10^{-4}
20	13,579.04	0.1394	0.114	8.69	46.06	0.0249	
50	13,505.84	0.1386	0.104	9.40	50.22	0.0207	
100	13,384.58	0.1373	0.0928	10.51	57.16	0.0162	
150	13,264.28	0.1365	0.0853	11.49	63.54	0.0134	
200	13,144.94	0.1570	0.0802	12.34	69.08	0.0116	
250	13,025.60	0.1357	0.0765	13.07	74.06	0.0103	
315.5	12,847	0.134	0.0673	14.02	81.5	0.0083	

[†]Adapted to SI units from E. R. G. Eckert and R. M. Drake, *Heat and Mass Transfer*, 2nd ed. New York: McGraw-Hill, 1959.

M=28.97

Table A-5 | Properties of air at atmospheric pressure.† خواص هوا در فشار اتمسفریک

مقادیر μ , k , cp و Pr وابستگی شدید به فشار ندارند و می توانند در محدوده وسیعی از فشارها به کار گرفته شوند

T, K	ρ kg/m ³	c_p kJ/kg · °C	$\mu \times 10^5$ kg/m · s	$\nu \times 10^6$ m ² /s	k W/m · °C	$\alpha \times 10^4$ m ² /s	Pr
100	3.6010	1.0266	0.6924	1.923	0.009246	0.02501	0.770
150	2.3675	1.0099	1.0283	4.343	0.013735	0.05745	0.753
200	1.7684	1.0061	1.3289	7.490	0.01809	0.10165	0.739
250	1.4128	1.0053	1.5990	11.31	0.02227	0.15675	0.722
300	1.1774	1.0057	1.8462	15.69	0.02624	0.22160	0.708
350	0.9980	1.0090	2.075	20.76	0.03003	0.2983	0.697
400	0.8826	1.0140	2.286	25.90	0.03365	0.3760	0.689
450	0.7833	1.0207	2.484	31.71	0.03707	0.4222	0.683
500	0.7048	1.0295	2.671	37.90	0.04038	0.5564	0.680
550	0.6423	1.0392	2.848	44.34	0.04360	0.6532	0.680
600	0.5879	1.0551	3.018	51.34	0.04659	0.7512	0.680
650	0.5430	1.0635	3.177	58.51	0.04953	0.8578	0.682
700	0.5030	1.0752	3.332	66.25	0.05230	0.9672	0.684
750	0.4709	1.0856	3.481	73.91	0.05509	1.0774	0.686
800	0.4405	1.0978	3.625	82.29	0.05779	1.1951	0.689
850	0.4149	1.1095	3.765	90.75	0.06028	1.3097	0.692
900	0.3925	1.1212	3.899	99.3	0.06279	1.4271	0.696
950	0.3716	1.1321	4.023	108.2	0.06525	1.5510	0.699
1000	0.3524	1.1417	4.152	117.8	0.06752	1.6779	0.702
1100	0.3204	1.160	4.44	138.6	0.0732	1.969	0.704
1200	0.2947	1.179	4.69	159.1	0.0782	2.251	0.707
1300	0.2707	1.197	4.93	182.1	0.0837	2.583	0.705
1400	0.2515	1.214	5.17	205.5	0.0891	2.920	0.705
1500	0.2355	1.230	5.40	229.1	0.0946	3.262	0.705
1600	0.2211	1.248	5.63	254.5	0.100	3.609	0.705
1700	0.2082	1.267	5.85	280.5	0.105	3.977	0.705
1800	0.1970	1.287	6.07	308.1	0.111	4.379	0.704
1900	0.1858	1.309	6.29	338.5	0.117	4.811	0.704
2000	0.1762	1.338	6.50	369.0	0.124	5.260	0.702
2100	0.1682	1.372	6.72	399.6	0.131	5.715	0.700
2200	0.1602	1.419	6.93	432.6	0.139	6.120	0.707
2300	0.1538	1.482	7.14	464.0	0.149	6.540	0.710
2400	0.1458	1.574	7.35	504.0	0.161	7.020	0.718
2500	0.1394	1.688	7.57	543.5	0.175	7.441	0.730

†From Natl. Bur. Stand. (U.S.) Circ. 564, 1955.

Table A-6 | Properties of gases at atmospheric pressure. † خواص گازها در فشار اتمسفریک

مقادیر μ , k , c_p و Pr وابستگی شدیدی به فشار ندارند و می‌توانند در محدوده وسیعی از فشارها به کار گرفته شوند

T , K	ρ kg/m ³	c_p kJ/kg · °C	μ , kg/m · s	ν , m ² /s	k W/m · °C	α , m ² /s	Pr
Helium, M=4							
144	0.3379	5.200	125.5 × 10 ⁻⁷	37.11 × 10 ⁻⁶	0.0928	0.5275 × 10 ⁻⁴	0.70
200	0.2435	5.200	156.6	64.38	0.1177	0.9288	0.694
255	0.1906	5.200	181.7	95.50	0.1357	1.3675	0.70
366	0.13280	5.200	230.5	173.6	0.1691	2.449	0.71
477	0.10204	5.200	275.0	269.3	0.197	3.716	0.72
589	0.08282	5.200	311.3	375.8	0.225	5.215	0.72
700	0.07032	5.200	347.5	494.2	0.251	6.661	0.72
800	0.06023	5.200	381.7	634.1	0.275	8.774	0.72
Hydrogen, M=2.02							
150	0.16371	12.602	5.595 × 10 ⁻⁶	34.18 × 10 ⁻⁶	0.0981	0.475 × 10 ⁻⁴	0.718
200	0.12270	13.540	6.813	55.53	0.1282	0.772	0.719
250	0.09819	14.059	7.919	80.64	0.1561	1.130	0.713
300	0.08185	14.314	8.963	109.5	0.182	1.554	0.706
350	0.07016	14.436	9.954	141.9	0.206	2.031	0.697
400	0.06135	14.491	10.864	177.1	0.228	2.568	0.690
450	0.05462	14.499	11.779	215.6	0.251	3.164	0.682
500	0.04918	14.507	12.636	257.0	0.272	3.817	0.675
550	0.04469	14.532	13.475	301.6	0.292	4.516	0.668
600	0.04085	14.537	14.285	349.7	0.315	5.306	0.664
700	0.03492	14.574	15.89	455.1	0.351	6.903	0.659
800	0.03060	14.675	17.40	569	0.384	8.563	0.664
900	0.02723	14.821	18.78	690	0.412	10.217	0.676
Oxygen, M=32							
150	2.6190	0.9178	11.490 × 10 ⁻⁶	4.387 × 10 ⁻⁶	0.01367	0.05688 × 10 ⁻⁴	0.773
200	1.9559	0.9131	14.850	7.593	0.01824	0.10214	0.745
250	1.5618	0.9157	17.87	11.45	0.02259	0.15794	0.725
300	1.3007	0.9203	20.63	15.86	0.02676	0.22353	0.709
350	1.1133	0.9291	23.16	20.80	0.03070	0.2968	0.702
400	0.9755	0.9420	25.54	26.18	0.03461	0.3768	0.695
450	0.8682	0.9567	27.77	31.99	0.03828	0.4609	0.694
500	0.7801	0.9722	29.91	38.34	0.04173	0.5502	0.697
550	0.7096	0.9881	31.97	45.05	0.04517	0.641	0.700
Nitrogen, M=28.02							
200	1.7108	1.0429	12.947 × 10 ⁻⁶	7.568 × 10 ⁻⁶	0.01824	0.10224 × 10 ⁻⁴	0.747
300	1.1421	1.0408	17.84	15.63	0.02620	0.22044	0.713
400	0.8538	1.0459	21.98	25.74	0.03335	0.3734	0.691
500	0.6824	1.0555	25.70	37.66	0.03984	0.5530	0.684
600	0.5687	1.0756	29.11	51.19	0.04580	0.7486	0.686
700	0.4934	1.0969	32.13	65.13	0.05123	0.9466	0.691
800	0.4277	1.1225	34.84	81.46	0.05609	1.1685	0.700
900	0.3796	1.1464	37.49	91.06	0.06070	1.3946	0.711
1000	0.3412	1.1677	40.00	117.2	0.06475	1.6250	0.724
1100	0.3108	1.1857	42.28	136.0	0.06850	1.8571	0.736
1200	0.2851	1.2037	44.50	156.1	0.07184	2.0932	0.748

خواص گازها در فشار اتمسفریک (ادامه)

Table A-6 | Properties of gases at atmospheric pressure[†] (Continued).

مقادیر μ , k , cp و Pr وابستگی شدید به فشار ندارند و می توانند در محدوده وسیعی از فشارها به کار گرفته شوند							
T, K	ρ kg/m^3	c_p $kJ/kg \cdot ^\circ C$	$\mu, kg/m \cdot s$	$\nu, m^2/s$	k $W/m \cdot ^\circ C$	$\alpha, m^2/s$	Pr
Carbon dioxide, M=44.01							
220	2.4733	0.783	11.105×10^{-6}	4.490×10^{-6}	0.010805	0.05920×10^{-4}	0.818
250	2.1657	0.804	12.590	5.813	0.012884	0.07401	0.793
300	1.7973	0.871	14.958	8.321	0.016572	0.10588	0.770
350	1.5362	0.900	17.205	11.19	0.02047	0.14808	0.755
400	1.3424	0.942	19.32	14.39	0.02461	0.19463	0.738
450	1.1918	0.980	21.34	17.90	0.02897	0.24813	0.721
500	1.0732	1.013	23.26	21.67	0.03352	0.3084	0.702
550	0.9739	1.047	25.08	25.74	0.03821	0.3750	0.685
600	0.8938	1.076	26.83	30.02	0.04311	0.4483	0.668
Ammonia, NH₃ M=17.03							
273	0.7929	2.177	9.353×10^{-6}	1.18×10^{-5}	0.0220	0.1308×10^{-4}	0.90
323	0.6487	2.177	11.035	1.70	0.0270	0.1920	0.88
373	0.5590	2.236	12.886	2.30	0.0327	0.2619	0.87
423	0.4934	2.315	14.672	2.97	0.0391	0.3432	0.87
473	0.4405	2.395	16.49	3.74	0.0467	0.4421	0.84
Water vapor, M=18.01							
380	0.5863	2.060	12.71×10^{-6}	2.16×10^{-5}	0.0246	0.2036×10^{-4}	1.060
400	0.5542	2.014	13.44	2.42	0.0261	0.2338	1.040
450	0.4902	1.980	15.25	3.11	0.0299	0.307	1.010
500	0.4405	1.985	17.04	3.86	0.0339	0.387	0.996
550	0.4005	1.997	18.84	4.70	0.0379	0.475	0.991
600	0.3652	2.026	20.67	5.66	0.0422	0.573	0.986
650	0.3380	2.056	22.47	6.64	0.0464	0.666	0.995
700	0.3140	2.085	24.26	7.72	0.0505	0.772	1.000
750	0.2931	2.119	26.04	8.88	0.0549	0.883	1.005
800	0.2739	2.152	27.86	10.20	0.0592	1.001	1.010
850	0.2579	2.186	29.69	11.52	0.0637	1.130	1.019

[†]Adapted to SI units from E. R. G. Eckert and R. M. Drake, *Heat and Mass Transfer*, 2nd ed. New York: McGraw-Hill, 1959.

خواص فیزیکی برخی از فلزات با نقطه ذوب پائین

Table A-7 | Physical properties of some common low-melting-point metals.[†]

Metal	Melting point °C	Normal boiling point °C	Temperature °C	Density, $\rho \times 10^{-3}$ kg/m ³	Viscosity $\mu \times 10^3$ kg/m · s	c_p Heat capacity kJ/kg · °C	k Thermal conductivity W/m · °C	Pr Prandtl number
Bismuth	271	1477	316	10.01	1.62	0.144	16.4	0.014
			760	9.47	0.79	0.165	15.6	0.0084
Lead	327	1737	371	10.5	2.40	0.159	16.1	0.024
			704	10.1	1.37	0.155	14.9	0.016
Lithium	179	1317	204	0.51	0.60	4.19	38.1	0.065
			982	0.44	0.42	4.19		
Mercury	-39	357	10	13.6	1.59	0.138	8.1	0.027
			316	12.8	0.86	0.134	14.0	0.0084
Potassium	63.8	760	149	0.81	0.37	0.796	45.0	0.0066
			704	0.67	0.14	0.754	33.1	0.0031
Sodium	97.8	883	204	0.90	0.43	1.34	80.3	0.0072
			704	0.78	0.18	1.26	59.7	0.0038
Sodium-potassium: 22% Na	19	826	93.3	0.848	0.49	0.946	24.4	0.019
			760	0.69	0.146	0.883		
56% Na	-11	784	93.3	0.89	0.58	1.13	25.6	0.026
			760	0.74	0.16	1.04	28.9	0.058
Lead-bismuth, 44.5% Pb	125	1670	288	10.3	1.76	0.147	10.7	0.024
			649	9.84	1.15			

[†]Adapted to SI units from J. G. Knudsen and D. L. Katz, *Fluid Dynamics and Heat Transfer*, New York: McGraw-Hill, 1958.

ضرایب نفوذ برای گازها و بخارها در هوا در ۲۵ °C - ۱ atm

Table A-8 | Diffusion coefficients of gases and vapors in air at 25°C and 1 atm.[†]

Substance	$D, \text{cm}^2/\text{s}$	$Sc = \frac{\nu}{D}$	Substance	$D, \text{cm}^2/\text{s}$	$Sc = \frac{\nu}{D}$
Ammonia	0.28	0.78	Formic Acid	0.159	0.97
Carbon dioxide	0.164	0.94	Acetic acid	0.133	1.16
Hydrogen	0.410	0.22	Aniline	0.073	2.14
Oxygen	0.206	0.75	Benzene	0.088	1.76
Water	0.256	0.60	Toluene	0.084	1.84
Ethyl ether	0.093	1.66	Ethyl benzene	0.077	2.01
Methanol	0.159	0.97	Propyl benzene	0.059	2.62
Ethyl alcohol	0.119	1.30			

[†]From J. H. Perry (ed.), *Chemical Engineers' Handbook*, 4th ed. New York: McGraw-Hill, 1963.

Table A-9 | Properties of water (saturated liquid).[†] (خواص آب (مایع اشباع)

Note: $Gr_x Pr = \left(\frac{g\beta\rho^2 c_p}{\mu k} \right) x^3 \Delta T$

°F	°C	c_p kJ/kg · °C	ρ kg/m ³	μ kg/m · s	k W/m · °C	Pr	$\frac{g\beta\rho^2 c_p}{\mu k}$ 1/m ³ · °C
32	0	4.225	999.8	1.79×10^{-3}	0.566	13.25	
40	4.44	4.208	999.8	1.55	0.575	11.35	1.91×10^9
50	10	4.195	999.2	1.31	0.585	9.40	6.34×10^9
60	15.56	4.186	998.6	1.12	0.595	7.88	1.08×10^{10}
70	21.11	4.179	997.4	9.8×10^{-4}	0.604	6.78	1.46×10^{10}
80	26.67	4.179	995.8	8.6	0.614	5.85	1.91×10^{10}
90	32.22	4.174	994.9	7.65	0.623	5.12	2.48×10^{10}
100	37.78	4.174	993.0	6.82	0.630	4.53	3.3×10^{10}
110	43.33	4.174	990.6	6.16	0.637	4.04	4.19×10^{10}
120	48.89	4.174	988.8	5.62	0.644	3.64	4.89×10^{10}
130	54.44	4.179	985.7	5.13	0.649	3.30	5.66×10^{10}
140	60	4.179	983.3	4.71	0.654	3.01	6.48×10^{10}
150	65.55	4.183	980.3	4.3	0.659	2.73	7.62×10^{10}
160	71.11	4.186	977.3	4.01	0.665	2.53	8.84×10^{10}
170	76.67	4.191	973.7	3.72	0.668	2.33	9.85×10^{10}
180	82.22	4.195	970.2	3.47	0.673	2.16	1.09×10^{11}
190	87.78	4.199	966.7	3.27	0.675	2.03	
200	93.33	4.204	963.2	3.06	0.678	1.90	
220	104.4	4.216	955.1	2.67	0.684	1.66	
240	115.6	4.229	946.7	2.44	0.685	1.51	
260	126.7	4.250	937.2	2.19	0.685	1.36	
280	137.8	4.271	928.1	1.98	0.685	1.24	
300	148.9	4.296	918.0	1.86	0.684	1.17	
350	176.7	4.371	890.4	1.57	0.677	1.02	
400	204.4	4.467	859.4	1.36	0.665	1.00	
450	232.2	4.585	825.7	1.20	0.646	0.85	
500	260	4.731	785.2	1.07	0.616	0.83	
550	287.7	5.024	735.5	9.51×10^{-5}			
600	315.6	5.703	678.7	8.68			

[†]Adapted to SI units from A. I. Brown and S. M. Marco, *Introduction to Heat Transfer*, 3rd ed. New York: McGraw-Hill, 1958.

Table A-10 | Normal total emissivity of various surfaces.† ضریب پخش کلی سطوح گوناگون

Surface	T, °F	Emissivity ϵ
Metals and their oxides		
Aluminum:		
Highly polished plate, 98.3% pure	440–1070	0.039–0.057
Commercial sheet	212	0.09
Heavily oxidized	299–940	0.20–0.31
Al-surfaced roofing	100	0.216
Brass:		
Highly polished:		
73.2% Cu, 26.7% Zn	476–674	0.028–0.031
62.4% Cu, 36.8% Zn, 0.4% Pb, 0.3% Al	494–710	0.033–0.037
82.9% Cu, 17.0% Zn	530	0.030
Hard-rolled, polished, but direction of polishing visible	70	0.038
Dull plate	120–660	0.22
Chromium (see nickel alloys for Ni-Cr steels), polished	100–2000	0.08–0.36
Copper:		
Polished		
	242	0.023
	212	0.052
Plate, heated long time, covered with thick oxide layer	77	0.78
Gold, pure, highly polished	440–1160	0.018–0.035
Iron and steel (not including stainless):		
Steel, polished	212	0.066
Iron, polished	800–1880	0.14–0.38
Cast iron, newly turned	72	0.44
turned and heated	1620–1810	0.60–0.70
Mild steel	450–1950	0.20–0.32
Iron and steel (oxidized surfaces):		
Iron plate, pickled, then rusted red	68	0.61
Iron, dark-gray surface	212	0.31
Rough ingot iron	1700–2040	0.87–0.95
Sheet steel with strong, rough oxide layer	75	0.80
Lead:		
Unoxidized, 99.96% pure	240–440	0.057–0.075
Gray oxidized	75	0.28
Oxidized at 300°F	390	0.63
Magnesium, magnesium oxide	530–1520	0.55–0.20
Molybdenum:		
Filament	1340–4700	0.096–0.202
Massive, polished	212	0.071
Monel metal, oxidized at 1110°F	390–1110	0.41–0.46
Nickel:		
Polished	212	0.072
Nickel oxide	1200–2290	0.59–0.86
Nickel alloys:		
Copper nickel, polished	212	0.059
Nichrome wire, bright	120–1830	0.65–0.79
Nichrome wire, oxidized	120–930	0.95–0.98
Platinum, polished plate, pure	440–1160	0.054–0.104
Silver:		
Polished, pure	440–1160	0.020–0.032
Polished	100–700	0.022–0.031

Table A-10 | Normal total emissivity of various surfaces[†] (Continued).

Surface	T, °F	Emissivity ϵ
فلزات و اکسیدهای آن ها Metals and their oxides		
Stainless steels:		
Polished	212	0.074
Type 301; B	450–1725	0.54–0.63
Tin, bright tinned iron	76	0.043 and 0.064
Tungsten, filament	6000	0.39
Zinc, galvanized sheet iron, fairly bright	82	0.23
مواد نسوز، مصالح ساختمانی، رنگ ها و غیره Refractories, building materials, paints, and miscellaneous		
Alumina (85–99.5%, Al ₂ O ₃ , 0–12% SiO ₂ , 0–1% Ge ₂ O ₃); effect of mean grain size, microns (μm):		
10 μm		0.30–0.18
50 μm		0.39–0.28
100 μm		0.50–0.40
Asbestos, board	74	0.96
Brick:		
Red, rough, but no gross irregularities	70	0.93
Fireclay	1832	0.75
Carbon:		
T-carbon (Gebrüder Siemens) 0.9% ash, started with emissivity of 0.72 at 260°F but on heating changed to values given	260–1160	0.81–0.79
Filament	1900–2560	0.526
Rough plate	212–608	0.77
Lampblack, rough deposit	212–932	0.84–0.78
Concrete tiles	1832	0.63
Enamel, white fused, on iron	66	0.90
Glass:		
Smooth	72	0.94
Pyrex, lead, and soda	500–1000	0.95–0.85
Paints, lacquers, varnishes:		
Snow-white enamel varnish on rough iron plate	73	0.906
Black shiny lacquer, sprayed on iron	76	0.875
Black shiny shellac on tinned iron sheet	70	0.821
Black matte shellac	170–295	0.91
Black or white lacquer	100–200	0.80–0.95
Flat black lacquer	100–200	0.96–0.98
Aluminum paints and lacquers:		
10% Al, 22% lacquer body, on rough or smooth surface	212	0.52
Other Al paints, varying age and Al content	212	0.27–0.67
Porcelain, glazed	72	0.92
Quartz, rough, fused	70	0.93
Roofing paper	69	0.91
Rubber, hard, glossy plate	74	0.94
Water	32–212	9.95–0.963

[†] Courtesy of H. C. Hottel, from W. H. McAdams, *Heat Transmissions*, 3rd ed. New York: McGraw-Hill, 1954.

Table A-11 | Steel-pipe dimensions.

ابعاد لوله‌های فولادی

Nominal pipe size, in	OD, in	Schedule no.	Wall Thickness, in	ID, in	Metal sectional area, in ²	Inside cross-sectional area, ft ²
1/8	0.405	40	0.068	0.269	0.072	0.00040
		80	0.095	0.215	0.093	0.00025
1/4	0.540	40	0.088	0.364	0.125	0.00072
		80	0.119	0.302	0.157	0.00050
3/8	0.675	40	0.091	0.493	0.167	0.00133
		80	0.126	0.423	0.217	0.00098
1/2	0.840	40	0.109	0.622	0.250	0.00211
		80	0.147	0.546	0.320	0.00163
3/4	1.050	40	0.113	0.824	0.333	0.00371
		80	0.154	0.742	0.433	0.00300
1	1.315	40	0.133	1.049	0.494	0.00600
		80	0.179	0.957	0.639	0.00499
1 1/2	1.900	40	0.145	1.610	0.799	0.01414
		80	0.200	1.500	1.068	0.01225
		160	0.281	1.338	1.429	0.00976
2	2.375	40	0.154	2.067	1.075	0.02330
		80	0.218	1.939	1.477	0.02050
3	3.500	40	0.216	3.068	2.228	0.05130
		80	0.300	2.900	3.016	0.04587
4	4.500	40	0.237	4.026	3.173	0.08840
		80	0.337	3.826	4.407	0.7986
5	5.563	40	0.258	5.047	4.304	0.1390
		80	0.375	4.813	6.122	0.1263
		120	0.500	4.563	7.953	0.1136
		160	0.625	4.313	9.696	0.1015
6	6.625	40	0.280	6.065	5.584	0.2006
		80	0.432	5.761	8.405	0.1810
10	10.75	40	0.365	10.020	11.90	0.5475
		80	0.500	9.750	16.10	0.5185

Table A-12 | Conversion factors. (See also inside cover.) **ضرایب تبدیل واحد**

<p>Length:</p> <p>12 in = 1 ft</p> <p>2.54 cm = 1 in</p> <p>1 $\mu\text{m} = 10^{-6} \text{ m} = 10^{-4} \text{ cm}$</p> <p>Mass:</p> <p>1 kg = 2.205 lb_m</p> <p>1 slug = 32.16 lb_m</p> <p>454 g = 1 lb_m</p> <p>Force:</p> <p>1 dyn = $2.248 \times 10^{-6} \text{ lb}_f$</p> <p>1 lb_f = 4.448 N</p> <p>$10^5 \text{ dyn} = 1 \text{ N}$</p>	<p>Energy:</p> <p>1 ft · lb_f = 1.356 J</p> <p>1 kWh = 3413 Btu</p> <p>1 hp · h = 2545 Btu</p> <p>1 Btu = 252 cal</p> <p>1 Btu = 778 ft · lb_f</p> <p>Pressure:</p> <p>1 atm = $14.696 \text{ lb}_f/\text{in}^2 = 2116 \text{ lb}_f/\text{ft}^2$</p> <p>1 atm = $1.01325 \times 10^5 \text{ Pa}$</p> <p>1 in Hg = $70.73 \text{ lb}_f/\text{ft}^2$</p> <p>Viscosity:</p> <p>1 centipoise = $2.42 \text{ lb}_m/\text{h} \cdot \text{ft}$</p> <p>1 lb_f · s/ft² = $32.16 \text{ lb}_m/\text{s} \cdot \text{ft}$</p> <p>Thermal conductivity:</p> <p>1 cal/s · cm · °C = $242 \text{ Btu}/\text{h} \cdot \text{ft} \cdot \text{°F}$</p> <p>1 W/cm · °C = $57.79 \text{ Btu}/\text{h} \cdot \text{ft} \cdot \text{°F}$</p>
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Useful conversion to SI units**تبدیلات مفید در سیستم SI**

<p>Length:</p> <p>1 in = 0.0254 m</p> <p>1 ft = 0.3048 m</p> <p>1 mi = 1.60934 km</p> <p>Area:</p> <p>1 in² = 645.16 mm²</p> <p>1 ft² = 0.092903 m²</p> <p>1 mi² = 2.58999 km²</p> <p>Pressure:</p> <p>1 N/m² = 1 Pa</p> <p>1 atm = $1.01325 \times 10^5 \text{ Pa}$</p> <p>1 lb_f/in² = 6894.76 Pa</p> <p>Energy:</p> <p>1 erg = 10^{-7} J</p> <p>1 Btu = 1055.04 J</p> <p>1 ft · lb_f = 1.35582 J</p> <p>1 cal (15°C) = 4.1855 J</p> <p>Power:</p> <p>1 hp = 745.7 W</p> <p>1 Btu/h = 0.293 W</p> <p>Heat flux:</p> <p>1 Btu/h · ft² = $3.15372 \text{ W}/\text{m}^2$</p> <p>1 Btu/h · ft = 0.96128 W/m</p> <p>Thermal conductivity:</p> <p>1 Btu/h · ft · °F = $1.7307 \text{ W}/\text{m} \cdot \text{°C}$</p> <p>Heat-transfer coefficient:</p> <p>1 Btu/h · ft² · °F = $5.6782 \text{ W}/\text{m}^2 \cdot \text{°C}$</p>	<p>Volume:</p> <p>1 in³ = $1.63871 \times 10^{-5} \text{ m}^3$</p> <p>1 ft³ = 0.0283168 m³</p> <p>1 gal = 231 in³ = 0.0037854 m³</p> <p>Mass:</p> <p>1 lb_m = 0.45359237 kg</p> <p>Density:</p> <p>1 lb_m/in³ = $2.76799 \times 10^4 \text{ kg}/\text{m}^3$</p> <p>1 lb_m/ft³ = $16.0185 \times 10^4 \text{ kg}/\text{m}^3$</p> <p>Force:</p> <p>1 dyn = 10^{-5} N</p> <p>1 lb_f = 4.44822 N</p>
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