Table A.2 Standard enthalpy of devaluation and standard chemical exergy of chemical elements. Reproduced from Ref [6.31], by permission. ($T^0 = 298.15$ K, $P^0 = 1.013\,25$ bar.)

		Enthalpy of devaluation		Chemical exergy			
Chemical element	Standard state of the element	Reference substance	Standard enthalpy of devaluation, h_d^0/[kJ/kmol]	Reference substance	Concentration of reference substance in standard environment		Standard chemical exergy, $\bar{e}^0$/[kJ/kmol]
1	2	3	4	5	6		7
Ag	s	AgCl, s	46 260	$AgCl_2^-$, i	2.7×10^{-9}	(w)	73 700
Al	s	Al_2SiO_5, s sillimanite	927 800	Al_2SiO_5, s sillimanite	2×10^{-5}	(c)	887 890
Ar	g	Ar, g	0	Ar, g	0.907	(a)	11 690
As	s	—	—	$HAsO_4^{2-}$, i	1.5×10^{-8}	(w)	477 040
Au	s	Au, s	0	$AuCl_2^-$, i	5.8×10^{-11}	(w)	18 900
B	s	—	—	$H_2BO_3^-$, i	4.6×10^{-6}	(w)	615 920
Ba	s, II	$BaSO_4$, s, barite	741 640	Ba^{2+}, i	5×10^{-8}	(w)	760 050
Bi	s	Bi_2O_3, s	288 680	Bi_2O_3, s	7×10^{-10}	(c)	271 370
Br_2	l	—	—	Br^-, i	6.5×10^{-5}	(w)	91 770
C	s, graphite	CO_2, g	393 780	CO_2, g	0.03	(a)	410 820
Ca	s, II	$CaCO_3$, s, calcite	813 910	Ca^{2+}, i	4×10^{-4}	(w)	717 400
Cd	s, α	$CdCO_3$, s	354 410	Cd^{2+}, i	5×10^{-11}	(w)	290 920
Cl_2	g	NaCl, s	161 710	Cl^-, i	19×10^{-3}	(w)	117 520
Co	s, III	Co_3O_4, s	293 080	Co^{2+}, i	9×10^{-11}	(w)	260 520
Cr	s	Cr_2O_3, s	564 590	Cr_2O_3, s	4×10^{-7}	(c)	538 610
Cs	s	CsCl, s	352 480	Cs^+, i	2×10^{-9}	(w)	408 530
Cu	s	$CuCO_3$, s	201 590	Cu^{2+}, i	5×10^{-9}	(w)	134 400
D_2	g	D_2O, g	249 370	D_2O, g	0.00014	(a)	266 220
F_2	g	CaF_2, s	401 500	F^-, i	1.4×10^{-6}	(w)	448 820
Fe	s	Fe_2O_3, s, hematite	411 350	Fe_2O_3, s	2.7×10^{-4}	(c)	377 740

Table A.3 Standard enthalpy of devaluation and standard chemical exergy of inorganic substances. Reproduced from Ref [6.31], by permission. ($T^0 = 298.15$ K, $P^0 = 1.013\,25$ bar.)

Substance	State*	Relative molecular mass	Standard enthalpy of devaluation, $\bar{h}^0$/[kJ/kmol]	Standard chemical exergy, $\bar{e}^0$/[kJ/kmol]
1	2	3	4	5
Ag	s	107.870	46 260	73 730
Ag_2CO_3	s	275.749	− 20 180	121 940
AgCl	s	143.323	0	23 420
AgF	s	126.868	43 950	120 810
$AgNO_3$	s	169.875	− 76 960	46 580
Ag_2O	s	231.739	61 910	64 540
Ag_2O_2	s	247.739	67 620	179 036
Ag_2S	s, α	247.804	785 280	714 060
Ag_2SO_4	s	311.802	103 250	144 220
Al	s	26.981 5	927 800	887 890
Al_4C_3	s	143.959	4 763 080	4 661 880
$AlCl_3$	s	133.340 5	474 510	426 940
Al_2O_3	s, corundum	101.961 2	184 690	204 270
$Al_2O_3 \cdot H_2O$	s	119.976 5	125 520	199 450
$Al_2O_3 \cdot 3H_2O$	s, gibbsite	156.007 2	12 160	209 210
Al_2S_3	s	150.155	3 520 230	3 079 540
$Al_2(SO_4)_3$	s	342.148	592 060	502 100
Al_2SiO_5	s, andalusite	162.046	28 030	45 940
Al_2SiO_5	s, cyanite	162.046	25 940	49 200
Al_2SiO_5	s, sillimanite	162.046	0	15 400
Ar	g	39.948	0	11 690
Au	s	196.967	0	18 920
AuCl	s	232.42	46 100	63 410
$AuCl_3$	s	303.326	124 070	152 110
AuF_3	s	253.962	253 490	437 260
Au_2O_3	s	441.932	− 80 810	121 550
Ba	s, II	137.34	741 640	760 050
$BaCO_3$	s, II, witherite	197.35	− 84 190	37 170
$BaCl_2$	s	208.25	42 710	63 610
BaF_2	s	175.34	− 58 050	61 470
BaO	s	153.34	183 120	244 880
BaO_2	s	169.34	111 530	175 770
$Ba(OH)_2$	s	171.36	36 590	145 520
BaS	s	169.40	1 022 420	896 670
$BaSO_3$	s	217.40	282 750	257 450
$BaSO_4$	s, barite	233.40	0	13 470
Bi	s	208.980	288 680	271 370
BiO	s	224.979	81 240	92 440
Bi_2O_3	s	465.958	0	52 260
Bi_2S_3	s	514.152	2 567 720	2 165 480
C	s, graphite	12.011 15	393 780	410 820
C	s, diamond	12.011 15	395 680	413 690
CCl_4	l	153.823	584 270	583 180
CO	g	28.010 5	283 150	275 430
CO_2	g	44.009 5	0	20 140

CS_2	l	76.139	1 932 410	1 673 670
Ca	s, II	40.08	813 930	717 400
CaC_2	s	64.10	1 538 670	1 471 210
$CaCO_3$	s, calcite	100.09	0	5 050
$CaCO_3$	s, aragonite	100.09	−170	6 100
$CaCl_2$	s	110.99	180 130	84 910
$CaCl_2 \cdot H_2O$	s	129.00	107 700	63 610
$CaFe_2O_4$	s	215.77	104 600	56 480
$Ca_2Fe_2O_5$	s	271.85	324 680	213 620
$Ca(NO_3)_2$	s	164.089 8	−123 290	−11 970
$Ca(NO_3)_2 \cdot 2H_2O$	s	200.120 5	−241 790	−17 020
$Ca(NO_3)_2 \cdot H_2O$	s	218.135 8	−289 290	−8 740
$Ca(NO_3)_2 \cdot 4H_2O$	s	236.151 2	−349 290	−8 870
CaO	s	56.08	177 940	119 620
$CaO \cdot Al_2O_3$	s	158.04	388 690	326 780
$2CaO \cdot Al_2O_3$	s	214.12	105 760	339 540
$4CaO \cdot Al_2O_3$	s	326.28	—	485 420
$12CaO \cdot 7Al_2O_3$	s	1 386.68	3 362 640	2 211 220
$Ca(OH)_2$	s	74.09	68 660	62 500
$Ca_3(PO_4)_2$	s, α	310.18	0	31 910
CaS	s	72.14	1 055 750	838 880
$CaSO_4$	s, anhydrite	136.14	104 950	4 300
$CaSO_4 \cdot \frac{1}{2}H_2O$	s, α	145.15	83 260	4 350
$CaSO_4 \cdot \frac{1}{2}H_2O$	s, β	145.15	85 350	5 310
$CaSO_4 \cdot 2H_2O$	s, gypsum	172.17	0	2 760
$CaSiO_3$	s	116.16	93 780	27 590
Ca_2SiO_4	s	172.24	235 290	116 680
Ca_3SiO_5	s	228.32	419 240	250 770
Cd	s, α	112.40	354 410	290 920
$CdCO_3$	s	172.41	0	36 960
$CdCl_2$	s	183.31	126 750	65 810
CdO	s	128.40	99 600	65 980
$Cd(OH)_2$	s	146.41	38 480	61 370
CdS	s	144.46	934 550	749 050
$CdSO_4$	s	208.46	152 200	81 290
$CdSO_4 \cdot H_2O$	s	226.48	88 520	63 070
Cl_2	g	70.906	161 710	117 520
Cl	g	35.453	201 850	163 940
Co	s, III	58.933 2	293 080	260 520
Co_3C	s	188.810 75	1 312 790	1 222 110
$CoCO_3$	s	118.942 6	−36 200	29 630
$CoCl_2$	s	129.839	129 060	103 800
CoO	s	74.932 6	53 600	51 070
Co_3O_4	s	240.797 2	0	37 560
$Co(OH)_2$	s	92.947 9	−14 230	47 120
$Co(OH)_3$	s	109.955 3	−83 310	27 240
CoS	s	90.997	933 090	765 580
Co_2S_3	s	214.058	2 590 640	2 108 250
$CoSO_4$	s	154.995	148 900	103 220
Cr	s	51.996	564 590	539 260
Cr_3C_2	s	180.010	2 393 410	2 348 290
Cr_4C	s	219.995	2 583 480	2 494 900
Cr_7C_3	s	400.005	4 955 530	4 819 010
$CrCl_2$	s	122.902	330 400	306 000
$CrCl_3$	s	158.355	243 610	221 120

HF	g	20.006 4	52 960	71 840
HNO_3	l	63.012 9	−52 330	45 650
H_2O	l	18.015 34	−44 030	3 120
H_2O	g	18.015 34	0	11 710
H_3PO_4	s	98.001 3	−75 360	98 850
H_2S	g	34.080	946 420	804 770
H_2SO_4	l	98.077	154 720	161 010
He	g	4.002 6	0	30 290
Hg	l	200.59	68 560	122 700
$HgCO_3$	s	260.60	−89 390	193 550
$HgCl_2$	s	271.50	0	63 100
Hg_2Cl_2	s	472.09	33 720	153 740
HgO	s, red	216.59	−22 210	64 240
HgS	s, red	232.65	734 940	679 430
$HgSO_4$	s	296.65	88 500	150 580
Hg_2SO_4	s	497.24	119 210	234 880
K	s	39.102	355 330	371 520
K_2CO_3	s	138.213	−42 450	90 110
KCl	s	74,555	0	21 390
$KClO_4$	s	138.553	2 430	125 900
KF	s	58.100	−6 880	59 760
$KMnO_4$	s	158.038	62 680	148 840
KNO_3	s	101.106 9	−137 380	−15 290
K_2O	s	94.203	348 820	425 540
KOH	s	56.109	50 200	101 320
K_2S	s	110.268	1 016 560	928 230
K_2SO_3	s	158.266	317 780	384 910
K_2SO_4	s, II	174.266	590	38 470
K_2SiO_3	s	154.288	1 308 010	1 565 320
Kr	g	83.80	0	34 280
Li	s	6.939	328 200	396 170
Li_2CO_3	s	73.887	−166 250	77 180
LiCl	s	42.392	0	70 160
$LiNO_3$	s	68.934	−154 450	12 700
Li_2O	s	29.877	60 200	233 460
LiOH	s	23.946	−38 350	75 620
Li_2SO_4	s	109.940	−54 380	76 520
Mg	s	24.312	719 920	626 710
$MgCO_3$	s	84.321	0	13 700
$MgCl_2$	s	95.218	239 370	151 860
$MgFe_2O_4$	s	200.004	76 640	38 230
MgO	s	40.311	117 690	59 170
$Mg(OH)_2$	s	58.327	36 610	33 830
$Mg(NO_3)_2$	s	148.321 8	−69 680	50 950
$Mg(NO_3)_2 \cdot 6H_2O$	s	256.413 8	−440 400	29 400
MgS	s	56.376	1 097 000	875 550
$MgSO_3$	s	104.374	438 730	305 400
$MgSO_4$	s	120.374	165 430	67 480
$MgSiO_3$	s	100.396	81 430	25 060
Mg_2SiO_4	s	140.708	255 810	140 770
Mg_2TiO_4	s	160.52	185 980	92 200
Mn	s, α, IV	54.938 1	521 260	483 240
Mn_3C	s, II	176.825 45	1 953 370	1 856 770
$MnCO_3$	s	114.947 5	19 480	35 360
$MnCl_2$	s	125.844	200 230	159 340

Substance	State*	Relative molecular mass	Standard enthalpy of devaluation, $\bar{R}_u^o$/[kJ/kmol]	Standard chemical exergy, $\bar{\varepsilon}^o$/[kJ/kmol]
1	2	3	4	5
CrO_3	s	99.994	−14 850	42 910
Cr_2O_3	s	151.990	0	36 510
Cs	s	132.905	352 480	408 530
CsCl	s	168.358	0	62 850
$CsNO_3$	s	194.910	−141 980	22 310
Cs_2O	s	281.809	387 180	544 370
CsOH	s	149.912	66 520	164 090
Cs_2S	s	297.874	1 089 990	1 091 020
Cs_2SO_4	s	361.872	8 590	123 020
Cu	s	63.54	201 590	134 400
$CuCO_3$	s	123.55	0	33 210
CuCl	s	98.99	146 370	77 050
$CuCl_2$	s	134.45	157 310	120 450
$CuFe_2O_4$	s	239.23	36 580	22 790
CuO	s	79.54	46 260	6 590
Cu_2O	s	143.08	236 380	123 500
$Cu(OH)_2$	s	97.55	−5 230	19 770
CuS	s	95.60	877 600	668 020
Cu_2S	s, II	159.14	1 048 210	773 000
$CuSO_4$	s	159.60	155 800	80 940
Cu_2SO_4	s	223.14	377 490	222 450
D_2	g	4.029 46	249 370	266 220
D_2O	g	20.028 86	0	33 450
D_2O	l	20.028 86	−45 430	24 520
F_2	g	37.996 8	401 500	448 820
Fe	s	55.847	411 350	377 740
Fe_3C	s, cementite	179.552	1 648 760	1 558 570
$FeCO_3$	s, siderite	115.856	56 950	120 410
$FeCl_2$	s	126.753	231 840	193 130
$FeCl_3$	s	162.206	248 630	225 600
$FeCr_2O_4$	s	223.837	108 990	133 490
FeO	s	71.846	140 800	133 750
Fe_2O_3	s, hematite	159.692	0	20 370
Fe_3O_4	s, magnetite	231.539	116 170	126 960
$Fe(OH)_3$	s	106.869	−50 450	46 530
FeS	s, α	87.911	1 040 810	879 000
FeS	s, β	87.911	1 046 540	890 180
FeS_2	s, pyrite	119.975	1 682 480	1 447 410
$FeSO_4$	s	151.909	212 740	170 240
FeSi	s	83.933	1 190 140	1 099 080
$FeSiO_3$	s	131,931	115 690	111 260
Fe_2SiO_4	s	203.778	243 670	228 310
$FeTiO_3$	s	151.75	86 870	99 530
H_2	g	2.015 94	242 000	238 490
H	g	1.007 97	360 860	322 410
HCl	g	36.461	109 490	85 950

Appendix B: Ideal gas properties

Ideal-gas properties of air

T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/kg · K	T K	h kJ/kg	P_r	u kJ/kg	v_r	s° kJ/kg · K
200	199.97	0.3363	142.56	1707.0	1.29559	580	586.04	14.38	419.55	115.7	2.37348
210	209.97	0.3987	149.69	1512.0	1.34444	590	596.52	15.31	427.15	110.6	2.39140
220	219.97	0.4690	156.82	1346.0	1.39105	600	607.02	16.28	434.78	105.8	2.40902
230	230.02	0.5477	164.00	1205.0	1.43557	610	617.53	17.30	442.42	101.2	2.42644
240	240.02	0.6355	171.13	1084.0	1.47824	620	628.07	18.36	450.09	96.92	2.44356
250	250.05	0.7329	178.28	979.0	1.51917	630	638.63	19.84	457.78	92.84	2.46048
260	260.09	0.8405	185.45	887.8	1.55848	640	649.22	20.64	465.50	88.99	2.47716
270	270.11	0.9590	192.60	808.0	1.59634	650	659.84	21.86	473.25	85.34	2.49364
280	280.13	1.0889	199.75	738.0	1.63279	660	670.47	23.13	481.01	81.89	2.50985
285	285.14	1.1584	203.33	706.1	1.65055	670	681.14	24.46	488.81	78.61	2.52589
290	290.16	1.2311	206.91	676.1	1.66802	680	691.82	25.85	496.62	75.50	2.54175
295	295.17	1.3068	210.49	647.9	1.68515	690	702.52	27.29	504.45	72.56	2.55731
298	298.18	1.3543	212.64	631.9	1.69528	700	713.27	28.80	512.33	69.76	2.57277
300	300.19	1.3860	214.07	621.2	1.70203	710	724.04	30.38	520.23	67.07	2.58810
305	305.22	1.4686	217.67	596.0	1.71865	720	734.82	32.02	528.14	64.53	2.60319
310	310.24	1.5546	221.25	572.3	1.73498	730	745.62	33.72	536.07	62.13	2.61803
315	315.27	1.6442	224.85	549.8	1.75106	740	756.44	35.50	544.02	59.82	2.63280
320	320.29	1.7375	228.42	528.6	1.76690	750	767.29	37.35	551.99	57.63	2.64737
325	325.31	1.8345	232.02	508.4	1.78249	760	778.18	39.27	560.01	55.54	2.66176
330	330.34	1.9352	235.61	489.4	1.79783	780	800.03	43.35	576.12	51.64	2.69013
340	340.42	2.149	242.82	454.1	1.82790	800	821.95	47.75	592.30	48.08	2.71787
350	350.49	2.379	250.02	422.2	1.85708	820	843.98	52.59	608.59	44.84	2.74504
360	360.58	2.626	257.24	393.4	1.88543	840	866.08	57.60	624.95	41.85	2.77170
370	370.67	2.892	264.46	367.2	1.91313	860	888.27	63.09	641.40	39.12	2.79783
380	380.77	3.176	271.69	343.4	1.94001	880	910.56	68.98	657.95	36.61	2.82344
390	390.88	3.481	278.93	321.5	1.96633	900	932.93	75.29	674.58	34.31	2.84856
400	400.98	3.806	286.16	301.6	1.99194	920	955.38	82.05	691.28	32.18	2.87324
410	411.12	4.153	293.43	283.3	2.01699	940	977.92	89.28	708.08	30.22	2.89748
420	421.26	4.522	300.69	266.6	2.04142	960	1000.55	97.00	725.02	28.40	2.92128
430	431.43	4.915	307.99	251.1	2.06533	980	1023.25	105.2	741.98	26.73	2.94468
440	441.61	5.332	315.30	236.8	2.08870	1000	1046.04	114.0	758.94	25.17	2.96770
450	451.80	5.775	322.62	223.6	2.11161	1020	1068.89	123.4	776.10	23.72	2.99034
460	462.02	6.245	329.97	211.4	2.13407	1040	1091.85	133.3	793.36	23.29	3.01260
470	472.24	6.742	337.32	200.1	2.15604	1060	1114.86	143.9	810.62	21.14	3.03449
480	482.49	7.268	344.70	189.5	2.17760	1080	1137.89	155.2	827.88	19.98	3.05608
490	492.74	7.824	352.08	179.7	2.19876	1100	1161.07	167.1	845.33	18.896	3.07732
500	503.02	8.411	359.49	170.6	2.21952	1120	1184.28	179.7	862.79	17.886	3.09825
510	513.32	9.031	366.92	162.1	2.23993	1140	1207.57	193.1	880.35	16.946	3.11883
520	523.63	9.684	374.36	154.1	2.25997	1160	1230.92	207.2	897.91	16.064	3.13916
530	533.98	10.37	381.84	146.7	2.27967	1180	1254.34	222.2	915.57	15.241	3.15916
540	544.35	11.10	389.34	139.7	2.29906	1200	1277.79	238.0	933.33	14.470	3.17888
550	555.74	11.86	396.86	133.1	2.31809	1220	1301.31	254.7	951.09	13.747	3.19834
560	565.17	12.66	404.42	127.0	2.33685	1240	1324.93	272.3	968.95	13.069	3.21751
570	575.59	13.50	411.97	121.2	2.35531						