Copper—*continued.*

$Cu_2O + FeS = Cu_2S + FeO$
42 23·8 20·2 66·4 = + 20·8

When heated in presence of silica, Fe_2SiO_4 is formed

$3Cu_2O + FeS = 6Cu + FeO + SO_2$
3 × 42 23·8 66·4 71 = − 12·4

$CuS + 2CuO = 3Cu + SO_2$
10·2 2 × 37·2 71 = − 13·6

$Cu_2S + 2CuO = 4Cu + SO_2$
20·2 2 × 37·2 71 = − 23·6

$Cu_2S + 2Cu_2O = 6Cu + SO_2$
20·2 2 × 42 71 = − 33·2

$2CuO + SO_2 = Cu_2O + SO_3$
2 × 37·2 71 42 91·8 = − 11·6

$CuO + SO_3 = CuSO_4$
37·2 91·8 182·6 = + 53·6

$Cu_2S + CuSO_4 = 3Cu + 2SO_2$
20·2 182·6 2 × 71 = − 60·8

$Cu_2S + 2CuSO_4 = 2Cu_2O + 3SO_2$
20·2 2 × 182·6 2 × 42 3 × 71 = − 88·4

$Cu_2S + 4CuSO_4 = 6CuO + 5SO_2$
20·2 4 × 182·6 6 × 37·2 5 × 71 = − 172·4

$2CuO + C = 2Cu + CO_2$
2 × 37·2 97 = + 22·6

$Cu_2O + C = 2Cu + CO$
42 29 = − 13·0

$CuO + CO = Cu + CO_2$
37·2 29 97 = + 30·8

$Cu_2O + CO = 2Cu + CO_2$
42 29 97 = + 26·0

III.

Lead.

$PbS + 3O = PbO + SO_2$
17·8 51 71 = + 104·2

$PbSO_4 + PbS = 2SO_2 + 2Pb$
216·2 17·8 2 × 71 = − 92·0

$PbSO_4 + 2C = 2CO_2 + PbS$
216·2 2 × 97 17·8 = − 4·4

$2PbO + PbS = 3Pb + SO_2$
2 × 51 17·8 71 = − 48·8

Lead—*continued.*

$PbS + Fe = Pb + FeS$
17·8 23·8 = + 6·0

$2PbO + C = 2Pb + CO_2$
2 × 51 97 = − 5·0

$PbO + CO = Pb + CO_2$
51 29 97 = + 17·0

$PbS + 3PbSO_4 = 4PbO + 4SO_2$
17·8 3 × 216·2 4 × 51 4 × 71 = − 180·4

IV.

Antimony.

$Sb_2S_3 + 3H_2 = 3H_2S + 2Sb$
34 3 × 4·6 = − 20·2

$Sb_2S_3 + 3Fe = 2Sb + 3FeS$
34 3 × 23·8 = + 37·4

$Sb_2O_3 + 3CO = 2Sb + 3CO_2$
166 3 × 29 3 × 97 = + 38

$2Sb_2O_3 + 3C = 4Sb + 3CO_2$
2 × 166 3 × 97 = + 59

V.

Iron.

$Fe_2O_3 + 3CO = 2Fe + 3CO_2$
199·4 3 × 29 3 + 97 = + 4·6

$Fe_2O_3 + 3C = 2Fe \times 3CO$
199·4 3 × 29 = − 112·4

$Fe_3O_4 + 4CO = 3Fe + 4CO_2$
265·8 4 × 29 4 × 97 = + 6·2

$Fe_3O_4 + 4C = 3Fe + 4CO$
265·8 4 × 29 = − 149·8

$FeO + CO = Fe + CO_2$
66·4 29 97 = + 1·6

$FeO + C = Fe + CO$
66·4 29 = − 37·4

$2FeO + CO_2 = Fe_2O_3 + CO$
2 × 66·4 97 199·4 29 = + 192·6

$2Fe + 3CO_2 = Fe_2O_3 + 3CO$
3 × 97 199·4 3 × 29 = − 4·6

$4Fe + 3CO_2 = 2Fe_2O_3 + 3C$
3 × 97 2 × 199·4 = + 107·8

Iron—*continued.*

$Fe + CO = FeO + C$
29 66·4 = + 37·4

$4Fe_2O_3 + Fe = 3Fe_3O_4$
4 × 199·4 3 × 265·8 = − 0·2

$2Fe_3O_4 + Si = 6FeO + SiO_2$
2 × 265·8 6 × 66·4 179·6 = + 46·4

$Fe_3O_4 + Mn = 3FeO + MnO$
265·8 3 × 66·4 91·0 = + 24·4

$5Fe_3O_4 + 2P = 15FeO + P_2O_5$
5 × 265·8 15 × 66·4 365·2 = + 31·2

$Fe_3O_4 + C = 3FeO + CO$
265·8 199·2 29·4 = − 37·2

$Fe_3O_4 + 2Si = 3Fe + 2SiO_2$
265·8 2 × 179·6 = + 93·4

$Fe_3O_4 + 4Mn = 3Fe + 4MnO$
265·8 4 × 91·0 = + 98·2

$5Fe_3O_4 + 8P = 15Fe + 4P_2O_5$
5 × 265·8 4 × 365·2 = + 131·8

$Fe_3O_4 + 4C = 3Fe + 4CO$
265·8 4 × 29 = − 149·8

$2FeO + Si = 2Fe + SiO_2$
2 × 66·4 179·8 = + 46·8

$FeO + Mn = Fe + MnO$
66·4 91 = + 24·6

$5FeO + 2P = 5Fe + P_2O_5$
5 × 66·4 365·2 = + 33·2

$3FeO + O = Fe_3O_4$
3 × 66·4 265·8 = + 66·6

$FeO + Fe_2O_3 = Fe_3O_4$
66·4 199·4 265·8 = 0

VI.

Zinc.

$ZnO + C = Zn + CO$
86·4 29 = − 57·4

$ZnO + CO = Zn + CO_2$
86·4 29 97 = − 18·4

VII.

Aluminium.

[1] $Al_2O_3 + 3C = 2Al + 3CO$
391·6 3 × 29 = − 304·6

$Al_2Cl_6 + 6Na = 2Al + 6NaCl$
321·8 6 × 97·3 = + 262·0

VIII.

Silver.

$8NaCl + 4CuSO_4 = 4CuCl_2 + 4Na_2SO_4$
8 × 97·3 4 × 182·6 4 × 51·6 4 × 328·8 = + 12·8

$4CuCl_2 + 4Hg = 2Cu_2Cl_2 + 2Hg_2Cl_2$
4 × 51·6 2 × 71·2 2 × 65·2 = − 66·4

$2Cu_2Cl_2 + Ag\ S = Cu_2S + 2CuCl_2 + 2Ag$
2 × 71·2 3 20·2 2 × 51·6 = − 22·0

$Hg_2Cl_2 + Cu_2S = CuCl_2 + 2Hg + CuS$
65·2 20·2 51·6 10·2 = − 23·6

$2AgCl + 2Hg = 2Ag + Hg_2Cl_2$
2 × 29·2 65·2 = + 6·8

$6FeS + 12NaCl + 27O = 2Fe_2Cl_6 + Fe_2O_3 + 6Na_2SO_4$
6 × 23·8 12 × 97·3 2 × 192·0 199·4 6 × 328·8
= + 1245·8

IX.

Chloridising Roasting.

$FeSO_4 + 2NaCl = Na_2SO_4 + FeCl_2$
235·6 2 × 97·3 328·8 82 = − 19·4

$CuSO_4 + 2NaCl = Na_2SO_4 + CuCl_2$
182·6 2 × 97·3 328·8 51·6 = + 3·2

$CuCl_2 + Ag_2SO_4 = 2AgCl + CuSO_4$
51·6 167·3 2 × 29·2 182·6 = + 22·1

$2NaCl + 2SO_3 = Na_2SO_4 + SO_2 + 2Cl$
2 × 97·3 2 × 91·8 328·8 71 = + 21·6

$2FeCl_2 + 3CuO = Cu_2Cl_2 + CuCl_2 + Fe_2O_3$
2 × 82 3 × 37·2 71·2 51·6 199·4 = + 46·6

$2FeCl_2 + 3Cu_2O = 2Cu + 2Cu_2Cl_2 + Fe_2O_3$
2 × 82 3 × 42 2 × 71·2 199·4 = + 51·8

$2Fe_2Cl_6 + 6CuO = 6CuCl_2 + 2Fe_2O_3$
2 × 192 6 × 37·2 6 × 51·6 2 × 199·4 = + 101·2

$CuCl_2 + Cu = Cu_2Cl_2$
51·6 71·2 = + 19·6

[1] Fremy, *Encyclopédie Chimique*, Paris, 1890.

X.

Roasting (mainly to Sulphate).

$3FeS + 11O = 2SO_2 + Fe_2O_3 + FeSO_4$
3 × 23·8   2 × 71   199·4   235·6 = + 505·6

$FeS + 3O = FeO + SO_2$
23·8   66·4   71 = + 113·6

$FeS + 3Fe_2O_3 = 7FeO + SO_2$
23·8   3 × 199·4   7 × 66·4   71 = + 85·2

$2CuO + 2SO_2 + O_2 = 2CuSO_4$
2 × 37·2   2 × 71   2 × 182·6 = + 148·8

$Cu_2O + 2SO_3 + O = 2CuSO_4$
42   2 × 91·8   2 × 182·6 = + 137·6

$Cu_2O + 2SO_2 + 3O = 2CuSO_4$
42   2 × 71   2 × 182·6 = + 181·2

$CuO + SO_3 = CuSO_4$
37·2   91·8   182·6 = + 53·6

$FeO + SO_3 = FeSO_4$
66·4   91·8   235·6 = + 77·4

$4FeSO_4 + 2O = Fe_2O_3 + Fe_2(SO_4)_3 + SO_3$
4 × 235·6   199·4   618·4   91·8 = − 32·8

$Fe_2(SO_4)_3 + 3CuO = 3CuSO_4 + Fe_2O_3$
618·4   3 × 37·2   3 × 182·6   199·4 = + 17·2

$Fe_2O_3.3(SO_3) + Cu = 2FeSO_4 + CuSO_4$
618·4   2 × 235·6   182·6 = + 35·4

$Ag_2SO_4 + Cu_2O = 2Ag + CuO + CuSO_4$
167·3   42   37·2   182·6 = + 10·5

$Fe_2(SO_4)_3 + Fe = 3FeSO_4$
618·4   3 × 256·4 = + 88·4

$2Fe_2(SO_4)_3 + Cu_2S = 4FeSO_4 + 2CuSO_4 + S$
2 × 618·4   20·2   4 × 235·6   2 × 182·6 = + 50·6

$Fe_2(SO_4)_3 + Cu_2O + H_2O = 2CuSO_4 + Fe_2O_3SO_2 + H_2$
618·4   42   69   2 × 182·6   339·1 = − 25·1

$Fe_2(SO_4)_3 + CuO = CuSO_4 + Fe_2O_3.2SO_3$
618·4   37·2   182·6   478·8 = + 5·8

$3FeSO_4 + CuO + H_2O = CuSO_4 + FeSO_4 + Fe_2O_3SO_3 + H_2$
3 × 235·6   37·2   69   182·6   235·6   339·1 = + 55·7

$Ag_2S + O_2 = 2Ag + SO_2$
3   71 = + 68

$Ag_2S + H_2O = Ag_2O + SH_2$
3   58·2   7   4·6 = − 49·6

Roasting—*continued.*

$Fe_2(SO_4)_3 + 2Ag = 2FeSO_4 + Ag_2SO_4$
618·4   2 × 235·6   167·3 = + 20·1

$3Ag_2O + Fe_2(SO_4)_3 = 3Ag_2SO_4 + Fe_2O_3$
3 × 7   618·4   3 × 167·3   199·4 = + 61·9

$Ag_2O + CuSO_4 = CuO + Ag_2SO_4$
7   182·6   37·2   167·3 = + 14·9

$Ag_2O + SO_3 = Ag_2SO_4$
7   91·8   167·3 = + 68·5

$Ag_2SO_4 + 4Fe_3O_4 = 2Ag + 6Fe_2O_3 + SO_2$
167·3   4 × 265·8   6 × 199·4   71 = + 36·9

$Ag_2S + 4SO_3 = Ag_2SO_4 + 4SO_2$
3   4 × 91·8   167·3   4 × 71 = + 81·1

$Ag_2SO_4 + Cu_2O = Ag_2O + 2CuO + SO_2$
167·3   42   7   2 × 37·2   71 = − 46·9

XI.

Precipitation (by a cheaper metal).

$Ag_2SO_4 + Cu = CuSO_4 + 2Ag$
167·3   182·6   = + 15·3

$CuSO_4 + Fe = FeSO_4 + Cu$
182·6   235·6   = + 53·0

See also III. and IV. for cases of precipitation in the dry way of lead and antimony, from their sulphides, by iron.

The table given on the folding plate will enable the student to form other thermal equations for himself.

In calculating the heats of formation of the basic ferric sulphates, it has been necessary to assume that the heat evolved is proportional to the ratio of acid to base. It must be remembered that in the case of the combination of carbon and oxygen such a relationship does not exist.

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TABLE SHOWING HEATS OF FORMATION OF THE PRINCIPAL METALLIC COMPOUNDS.

Metal.	Oxides.		Sulphide.		Sulphates.		Selenides and Tellurides.		Fluorides.		Chlorides.		Bromides (from Liquid Bromine).		Iodides (from Solid Iodine).		Cyanides.*		Carbonates.	
	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.	Solid.	Dissolved.
Aluminium	$Al_2O_33H_2O$ 391·6	..	Al_2S_3 124·4	...	...	...	...	...	...	...	Al_2Cl_6 321·8	475·6	Al_2Br_6 239·4	410·0	Al_2I_6 140·2	319·6	...	...	...	...
Ammonium	...	...	...	...	$(NH_4)_2SO_4$ 282·2	279·6	...	...	NH_4F 87·7	85·6	NH_4Cl 76·7	72·7	NH_4Br 71·2	66·9	NH_4I 50·6	47·1	NH_4CN † 40·5	36·1	...	...
Antimony	Sb_2O_3 166	...	Sb_2S_3 34	...	...	...	...	...	Sb_2F_6 277·6	...	$SbCl_3$ 91·4 $SbCl_5$ (liquid) 104·9	...	$SbBr_3$ 76·9	...	SbI_3 29·2	...	...	...	...	...
Arsenic	As_2O_3 154·7 As_2O_5 219·4	147·1 225·4	...	...	...	...	...	...	...	...	$AsCl_3$ 71·5	...	$AsBr_3$ 44·9	...	AsI_3 12·7	...	...	...	...	...
Barium	BaO 124·2	158·7	BaS 98·3	109·8	$BaSO_4$ 338·1	...	$BaSe$ 69·9	...	BaF_2 224	221·5	$BaCl_2$ 194·7	...	$BaBr_2$ 170	...	...	...	...	...	...	...
Bismuth	Bi_2O_3 137·8 $Bi(OH)_3$ 171·7	...	...	...	...	...	...	...	...	...	$BiCl_3$ 90·8 $BiOCl$ 88·2	...	...	...	...	...	...	...	...	...
Cadmium	$Cd(OH)_2$ 66·4	...	CdS 34	...	$CdSO_4$ 221·2	...	$CdSe$ 23·7 $CdTe$ 20	...	...	...	$CdCl_2$ 93·2	96·2	$CdBr_2$ 75·2	75·6	CdI_2 48·8	47·8	$Cd(CN)_2$ 40	...	$CdCO_3$ 84·9	...
Calcium	CaO 132	150·1	CaS 92	98	$CaSO_4$ 318·4	...	$CaSe$ 70·2	...	CaF_2 219·8	...	$CaCl_2$ 169·8	187·2	$CaBr_2$ 143·6	168	CaI_2 107·8	135·4	...	$Ca(CN)_2(Aq)$ 115·4	$CaCO_3$ 172·4	...
Cobalt	$Co(OH)_2$ 64	...	$CoS(Aq)$ 19·7	...	$CoSO_4(Aq)$ 230·5	...	$CoSe$ 13·9 $CoTe$ 15·2	...	...	...	$CoCl_2$ 76·4	94·8	...	...	...	...	...	...	...	...
Copper	Cu_2O 42 CuO 37·2	...	Cu_2S 20·2 CuS 10·2	...	$CuSO_4$ 182·6	198·4	Cu_2Se 9·6 Cu_2Te 14·2	...	...	...	Cu_2Cl_2 71·2 $CuCl_2$ 51·6	62·7	Cu_2Br_2 50 $CuBr_2$ 34·8	43	Cu_2I_2 32·5	...	...	...	...	...
Gold	...	Au_2O_3Aq 13·2	...	...	...	...	...	...	...	...	$AuCl_3$ 22·8 $AuCl$ 5·8	27·3	$AuBr_3$ 12·1 $AuBr$ −1	8·4	AuI −5·5	...	...	...	...	...
Iron	FeO ‡ 66·4 $Fe(OH)_2$ ‡ 68·3 $Fe_2(OH)_6$ ‡ 198·2 Fe_2O_3 ‡ 199·4 Fe_3O_4 ‡ 265·8	...	FeS 23·8	...	$FeSO_4(Aq)$ 235·6 $Fe_2(SO_4)_3(Aq)$ 618·4	...	$FeSe$ 15·6 $FeTe$ 15·6	...	...	...	$FeCl_2$ 82 Fe_2Cl_6 192	100 255·4	$FeBr_2(Aq)$ 80·8 $FeBr_3(Aq)$ 96·8	...	$FeI_2(Aq)$ 46·4	...	..	...	...	...
Lead	PbO 51	...	PbS 17·8	...	$PbSO_4$ 216·2	...	$PbSe$ 17 $PbTe$ 11·4	...	PbF_2 92·4	...	$PbCl_2$ 85·2	78·4	$PbBr_2$ 69	59	PbI_2 42·0	...	...	...	$PbCO_3$ 69·4	...
Magnesium	MgO 143·9	148·8	MgS 79·6	...	$MgSO_4$ 302·3	322·6	...	...	MgF_2 212·8	...	$MgCl_2$ 151	187	...	...	...	..	...	...	$MgCO_3$ 170·6	...
Manganese	MnO 91 MnO_2 116·2	...	MnS 45·2	...	$MnSO_4$ 249·9	..	$MnSe$ 22·4	...	...	...	$MnCl_2$ 112	128	...	...	...	...	...	...	$MnCO_3$ 113·9	...
Mercury	Hg_2O 24·8 HgO 22	...	HgS 8·2	...	$HgSO_4$ 165·1 Hg_2SO_4 175	...	$HgSe$ 6·3	...	...	...	Hg_2Cl_2 65·2 $HgCl_2$ 54·5	51·2	Hg_2Br_2 50·9 $HgBr_2$ 41·9	...	Hg_2I_2 31·1 HgI_2 25·6	...	$Hg(CN)_2$ 10·3	7·3	...	...
Nickel	NiO 61	...	NiS 19·4	...	$NiSO_4(Aq)$ 229·4	...	$NiSe$ 14·8 $NiTe$ 15	...	...	...	$NiCl_2$ 74·6	97·3	...	...	...	...	...	...	...	...
Palladium	$Pd(OH)_2$ 20	...	...	...	...	...	...	...	...	...	$PdCl_2$ 40·4	...	$PdBr_2$ 24·8	...	PdI_2 13·4	...	$Pd(CN)_2$ 23·6	...	...	...
Platinum	PtO 15·0	...	...	...	...	...	...	...	...	...	$PtCl_4$ 59·8 $PtH_2Cl_6(Aq)$ 163·2	79·4	$PtH_2Br_6(Aq)$ 113·8	...	...	...	...	...	...	...
Potassium	K_2O 97·2	164·6	K_2S 101·2	112·4	K_2SO_4 344·6	338·2	K_2Se 90·6	99·2	KF 111·1	108·1	KCl 105	100·8	KBr 96·4	91	KI 80	74·7	KCN 67·6	64·7	K_2CO_3 180·8	...
Silver	Ag_2O 7	...	Ag_2S 3	...	Ag_2SO_4 167·3	162·8	Ag_2Se 2	...	AgF 30·9	25·7	$AgCl$ 29·4	...	$AgBr$ 22·7	...	AgI 13·8	...	$AgCN$ 3·6	...	Ag_2CO_3 23·4	...
Sodium	Na_2O 100·2	155·2	Na_2S 88·4	103·2	Na_2SO_4 328·8	329	Na_2Se 71·2	89·8	NaF 110·8	110·6	$NaCl$ 97·3	96·2	$NaBr$ 86·7	86·4	NaI 68·8	70·1	$NaCN$ 60·4	59·9	Na_2CO_3 175·7	...
Tin	SnO 66·2 SnO_2 137·2	...	...	...	...	...	...	...	...	...	$SnCl_2$ 80·4 $SnCl_4$ (liquid) 127·3	81·2 157·2	$SnBr_2$ 63 $SnBr_4$ 98·4	118	...	...	...	...	...	...
Zinc	ZnO 86·4	...	ZnS 43	...	$ZnSO_4$ 230	248·5	$ZnSe$ 40·4 $ZnTe$ 37·2	34	...	...	$ZnCl_2$ 97·2	112·8	$ZnBr_2$ 78·2	93·2	ZnI_2 49·2	60·6	$Zn(CN)_2$ 53·4	...	$ZnCO_3$ 97·2	...

* From Cyanogen.

† From Nitrogen, Hydrogen, and Cyanogen.

‡ Calculated from Andrews' Value, 265·8 for Fe_3O_4.

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CHAPTER XII.

TYPICAL METALLURGICAL PROCESSES.

Classification of Processes.—The methods that are adopted in extracting metals from their ores may conveniently be grouped in the following manner :—

The thick, black Roman numerals refer to the Thermal Equations, Chapter XI.

A. Dry Processes.

I. α. *By Simple Fusion with Suitable Fluxes.*

(*a*) In blast or reverberatory furnaces.	1. Gold . . . 2. Silver . . 3. Platinum . . 4. Copper . .	This process is only applicable to metals in an uncombined form.
(*b*) In tube-furnace.	5. Bismuth . .	By liquation.

β. *By Simple Heating.*

(*a*) In kilns or reverberatories.	1. Mercury (**I.**) .	From its sulphide, the presence of air being necessary.
(*b*) In retorts.	2. Arsenic . . .	From sulphides of arsenic and iron, air excluded, always with appliances for condensing the volatilised metal.

II. *By Reduction of Oxide by Carbon.*

(*a*) In blast-furnaces or, more rarely, in hearths or crucibles.	1. Copper (**II.**) . 2. Lead (**III.**) . 3. Antimony (**IV.**) . 4. Nickel . .	Usually after previous roasting of sulphide or arsenide ;
	5. Iron (**V.**) . 6. Nickel . 7. Manganese .	Usually with simultaneous carburisation of the liberated metal.
(*b*) In reverberatory furnace.	8. Tin. 9. Bismuth.	