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11.1 COOLING

TABLE 11.1 Cooling Mixtures

The table below gives the lowest temperature that can be obtained from a mixture of the inorganic salt with finely shaved dry ice. With the organic substances, dry ice (−78°C) in small lumps can be added to the solvent until a slight excess of dry ice remains or liquid nitrogen (−196°C) can be poured into the solvent until a slush is formed that consists of the solid-liquid mixture at its melting point.

Substance	Quantity of substance, g	Quantity of water, mL	Temperature, °C
Ammonium nitrate	100	94	−4.0
Sodium nitrate	75	100	−5.3
Sodium thiosulfate 5-water	110	100	−8.0
Sodium chloride	36	100	−10.0
Sodium nitrate	50	100	−17.8
Sodium bromide	66	100	−28
Magnesium chloride	85	100	−34
Calcium chloride 6-water	100	81	−40.3
	100	70	−55

Substance	Temperature, °C	Substance	Temperature, °C
Ethylene glycol	−13	Acetone	−77
1,2-Dichlorobenzene	−17	Ethyl acetate	−84
Carbon tetrachloride	−22.9	2-Butanone	−87
Bromobenzene	−31	Hexane	−95
Methoxybenzene	−37	Methanol	−98
Bis(2-ethoxyethyl) ether	−44	Carbon disulfide	−112
Chlorobenzene	−45	Bromoethane	−119
N-Methylaniline	−57	Pentane	−130
p-Cymene	−68	2-Methylbutane	−160

TABLE 11.2 Molecular Lowering of the Melting or Freezing Point

Cryoscopic constants.

The cryoscopic constant K_f gives the depression of the melting point ΔT (in degrees Celsius) produced when 1 mol of solute is dissolved in 1000 g of a solvent. It is applicable only to dilute solutions for which the number of moles of solute is negligible in comparison with the number of moles of solvent. It is often used for molecular weight determinations.

$$M_2 = \frac{1000 w_2 K_f}{w_1 \, \Delta T}$$

where w_1 is the weight of the solvent and w_2 is the weight of the solute whose molecular weight is M_2.

Compound	K_f	Compound	K_f
Acetamide	4.04	Diphenylamine	8.60
Acetic acid	3.90	Diphenyl ether	7.88
Acetone	2.40	1,2-Ethanediamine	2.43
Ammonia	0.957	Ethoxybenzene	7.15
Aniline	5.87	Formamide	3.85
Antimony(III) chloride	17.95	Formic acid	2.77
Benzene	5.12	Glycerol	3.3 to 3.7
Benzonitrile	5.34	Hexamethylphosphoramide	6.93
Benzophenone	9.8		
Bicyclohexane	14.52	*N*-Methylacetamide	6.65
Biphenyl	8.0	2-Methyl-2-butanol	10.4
Borneol	35.8	Methylcyclohexane	14.13
Bornylamine	40.6	Methyl *cis*-9-octadecenoate	3.4
Butanedinitrile	18.26	2-Methyl-2-propanol	8.37
Camphene	31.08	Naphthalene	6.94
Camphoquinone	45.7	Nitrobenzene	6.852
D-(+)-Camphor	39.7	Octadecanoic acid	4.50
Carbon tetrachloride	29.8	2-Oxohexamethyleneimine	7.30
o-Cresol	5.60	Phenol	7.40
p-Cresol	6.96	Pyridine	4.75
Cyclohexane	20.0	Quinoline	1.95
Cyclohexanol	39.3	Succinonitrile	18.26
Cyclohexylcyclohexane	14.52	Sulfuric acid	1.86
Cyclopentadecanone	21.3	1,1,2,2-Tetrabromoethane	21.7
cis-Decahydronaphthalene	19.47	1,1,2,2-Tetrachloro-	
trans-Decahydronaphthalene	20.81	1,2-difluoroethane	37.7
Dibenz[*de*,*kl*]anthracene	25.7	Tetramethylene sulfone	64.1
Dibenzyl ether	6.27	*p*-Toluidine	5.372
1,2-Dibromoethane	12.5	Tribromomethane	14.4
Diethyl ether	1.79	1,3,3-Trimethyl-2-oxabicyclo-	
1,2-Dimethoxybenzene	6.38	[2.2.2.]octane	6.7
N,*N*-Dimethylacetamide	4.46	Triphenylmethane	12.45
2,2-Dimethyl-1-propanol	11.0	Water	1.86
Dimethyl sulfoxide	4.07	*p*-Xylene	4.3
1,4-Dioxane	4.63		

TABLE 11.3 Drying Agents

Drying agent	Most useful for	Residual water, mg H_2O per liter of dry air (25°C)	Grams water removed per gram of desiccant	Regeneration, °C
Al_2O_3	Hydrocarbons	0.002–0.005	0.2	175 (24 h)
$Ba(ClO_4)_2$[a]	Inert gas streams	0.6–0.8	0.17	140
BaO	Basic gases: hydrocarbons, aldehydes, alcohols	0.0007–0.003	0.12	1000
CaC_2[b]	Ethers		0.56	Impossible
$CaCl_2$[c]	Inert organics	0.1–0.2	0.15 (1 H_2O) 0.30 (2 H_2O)	250
CaH_2[d]	Hydrocarbons, ethers, amines, esters, higher alcohols	1×10^{-5}	0.85	Impossible
CaO	Ethers, esters, alcohols, amines	0.01–0.003	0.31	Difficult, 1000
$CaSO_4$	Most organic substances	0.005–0.07	0.07	225
Dow Desiccant 812[e]	Most materials	(5–200 ppm)		No
K_2CO_3	Most materials except acids and phenols		0.16	158
KOH	Amines	0.01–0.9		Impossible
$LiAlH_4$[f]	Hydrocarbons		1.9	Impossible
$Mg(ClO_4)_2$[a]	Gas streams	0.0005–0.002	0.24	250 (high vacuum)
MgO	All but acidic compounds	0.008	0.45	800
$MgSO_4$	Most organic compounds	1–12	0.15–0.75	Not feasible
Molecular sieves: 4X	Molecules with effective diameter >4Å	0.001	0.18	250
5X	Molecules with effective diameter >5Å	0.001	0.18	250
9.5% Na-Pb alloy[d]	Hydrocarbons, ethers	(For solvents only)	0.08	Impossible
Na_2SO_4	Ketones, acids, alkyl and aryl halides	12	1.25	150
P_2O_5	Gas streams; not suitable for alcohols, amines, ketones, or amines	2×10^{-5}	0.5	Not feasible
Silica gel	Most organic amines	0.002–0.07	0.2	200–350
Sulfuric acid	Air and inert gas streams	0.003–0.008	Indefinite	Not feasible

[a] May form explosive mixtures when contacting organic material. [b] Explosive C_2H_2 formed. [c] Slow in drying action.
[d] H_2 formed. [e] Used as column drying of organic liquids. [f] Strong reductant.

A saturated aqueous solution in contact with an excess of a definite solid phase at a given temperature will maintain constant humidity in an enclosed space. Table 11.4 gives a number of salts suitable for this purpose. The aqueous tension (vapor pressure, in millimeters of Hg) of a solution at a given temperature is found by multiplying the decimal fraction of the humidity by the aqueous tension at 100 percent humidity for the specific temperature. For example, the aqueous tension of a saturated solution of NaCl at 20°C is $0.757 \times 17.54 = 13.28$ mmHg and at 80°C it is $0.764 \times 355.1 = 271.3$ mmHg.

TABLE 11.4 Solutions for Maintaining Constant Humidity

Solid Phase	% Humidity at Specified Temperatures (°C)						
	10	20	25	30	40	60	80
$K_2Cr_2O_7$			98.0				
K_2SO_4	98	97	97	96	96	96	
KNO_3	95	93	92.5	91	88	82	
KCl	88	85.0	84.3	84	81.7	80.7	79.5
KBr		84	80.7		79.6	79.0	79.3
NaCl	76	75.7	75.3	74.9	74.7	74.9	76.4
$NaNO_3$			73.8	72.8	71.5	67.5	65.5
$NaNO_2$		66	65	63.0	61.5	59.3	58.9
$NaBr \cdot 2H_2O$		57.9	57.7		52.4	49.9	50.0
$Na_2Cr_2O_7 \cdot 2H_2O$	58	55	54		53.6	55.2	56.0
$Mg(NO_3)_2 \cdot 6H_2O$	57	55	52.9	52	49	43	
$K_2CO_3 \cdot 2H_2O$	47	44	42.8		42		
$MgCl_2 \cdot 6H_2O$	34	33	33.0	33	32	30	
$KF \cdot 2H_2O$				27.4	22.8	21.0	22.8
$KC_2H_3O_2 \cdot 1.5H_2O$	24	23	22.5	22	20		
$LiCl \cdot H_2O$	13	12	10.2	12	11	11	
KOH	13	9	8	7	6	5	
100% Humidity: Aqueous Tension (mm Hg)	9.21	17.54	23.76	31.82	55.32	149.4	355.1

TABLE 11.5 Concentrations of Solutions of H_2SO_4, NaOH, and $CaCl_2$ Giving Specified Vapor Pressures and Percent Humidities at 25°C

Percent humidity	Aqueous tension, mmHg	H_2SO_4		NaOH		$CaCl_2$	
		Molality	Weight %	Molality	Weight %	Molality	Weight %
100	23.76	0.00	0.00	0.00	0.00	0.00	0.00
95	22.57	1.263	11.02	1.465	5.54	0.927	9.33
90	21.38	2.224	17.91	2.726	9.83	1.584	14.95
85	20.19	3.025	22.88	3.840	13.32	2.118	19.03
80	19.00	3.730	26.79	4.798	16.10	2.579	22.25
75	17.82	4.398	30.14	5.710	18.60	2.995	24.95
70	16.63	5.042	33.09	6.565	20.80	3.400	27.40
65	15.44	5.686	35.80	7.384	22.80	3.796	29.64
60	14.25	6.341	38.35	8.183	24.66	4.188	31.73
55	13.07	7.013	40.75	8.974	26.42	4.581	33.71
50	11.88	7.722	43.10	9.792	28.15	4.990	35.64
45	10.69	8.482	45.41	10.64	29.86	5.431	37.61
40	9.50	9.304	47.71	11.54	31.58	5.912	39.62
35	8.31	10.21	50.04	12.53	33.38	6.478	41.83
30	7.13	11.25	52.45	13.63	35.29	7.183	44.36
25	5.94	12.47	55.01	14.96	37.45		
20	4.75	13.94	57.76	16.67	40.00		
15	3.56	15.81	60.80	19.10	43.32		
10	2.38	18.48	64.45	23.05	47.97		
5	1.19	23.17	69.44				

Concentrations are expressed in percentage of anhydrous solute by weight.
Source: Stokes and Robinson, *Ind. Eng. Chem.* **41:**2013 (1949).

TABLE 11.6 Relative Humidity from Wet and Dry Bulb Thermometer Readings

Dry bulb temperature, °C	Wet bulb depression, °C											
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
	Relative humidity, %											
−10	83	67	51	35	19							
−5	88	76	64	52	41	29	18	7				
0	91	81	72	64	55	46	38	29	21	13	5	
2	91	84	76	68	60	52	44	37	29	22	14	7
4	92	85	78	71	63	57	49	43	36	29	22	16
6	93	86	79	73	66	60	54	48	41	35	29	24
8	93	87	81	75	69	63	57	51	46	40	35	29
10	94	88	82	77	71	66	60	55	50	44	39	34
12	94	89	83	78	73	68	63	58	53	48	43	39
14	95	90	85	79	75	70	65	60	56	51	47	42
16	95	90	85	81	76	71	67	63	58	54	50	46
18	95	91	86	82	77	73	69	65	61	57	53	49
20	96	91	87	83	78	74	70	66	63	59	55	51
22	96	92	87	83	80	76	72	68	64	61	57	54
24	96	92	88	84	80	77	73	69	66	62	59	56
26	96	92	88	85	81	78	74	71	67	64	61	58
28	96	93	89	85	82	78	75	72	69	65	62	59
30	96	93	89	86	83	79	76	73	70	67	64	61
35	97	94	90	87	84	81	78	75	72	69	67	64
40	97	94	91	88	85	82	80	77	74	72	69	67

Dry bulb temperature, °C	Wet bulb depression, °C											
	6.5	7.0	7.5	8.0	8.5	9.0	10.0	11.0	12.0	13.0	14.0	15.0
	Relative humidity, %											
4	9											
6	17	11	5									
8	24	19	14	8								
10	29	24	20	15	10	6						
12	34	29	25	21	16	12	5					
14	38	34	30	26	22	18	10					
16	42	38	34	30	26	23	15	8				
18	45	41	38	34	30	27	20	14	7			
20	48	44	41	37	34	31	24	18	12	6		
22	50	47	44	40	37	34	28	22	17	11	6	
24	53	49	46	43	40	37	31	26	20	15	10	5
26	54	51	49	46	43	40	34	29	24	19	14	10
28	56	53	51	48	45	42	37	32	27	22	18	13
30	58	55	52	50	47	44	39	35	30	25	21	17
32	60	57	54	51	49	46	41	37	32	28	24	20
34	61	58	56	53	51	48	43	39	35	30	26	23
36	62	59	57	54	52	50	45	41	37	33	29	25
38	63	61	58	56	54	51	47	43	39	35	31	27
40	64	62	59	57	54	53	48	44	40	36	33	29

TABLE 11.7 Relative Humidity from Dew Point Readings

Depression of dew point, °C	Dew point reading, °C				
	−10	0	10	20	30
	Relative humidity, %				
0.5	96	96	96	96	97
1.0	92	93	94	94	94
1.5	89	89	90	91	92
2.0	86	87	88	88	89
3.0	79	81	82	83	84
4.0	73	75	77	78	80
5.0	68	70	72	74	75
6.0	63	66	68	70	71
7.0	59	61	63	66	68
8.0	54	57	60	62	64
9.0	51	53	56	58	61
10.0	47	50	53	55	57
11.0	44	47	49	52	
12.0	41	44	47	49	
13.0	38	41	44	46	
14.0	35	38	41	44	
15.0	33	36	39	42	
16.0	31	34	37	39	
18.0	27	30	33	35	
20.0	24	26	29	32	
22.0	21	23	26		
24.0	18	21	23		
26.0	16	18	21		
28.0	14	16	19		
30.0	12	14	17		

11.3 BOILING POINTS AND HEATING BATHS

TABLE 11.8 Organic Solvents Arranged by Boiling Points

Name	BP, °C	Name	BP, °C
Ethylene oxide	10.6	1-Propanol	97.2
Chloroethane	12.3	Heptane	98.4
Furan	31.4	1-Chloro-3-methylbutane	99
Methyl formate	31.5	Ethyl propionate	99.1
Diethyl ether	34.6	2-Butanol	99.6
Propylene oxide	34.5	Formic acid	100.8
Pentane	36.1	Methylcyclohexane	100.9
Bromoethane	38.4	1,4-Dioxane	101.2
Dichloromethane	39.8	Nitromethane	101.2
Dimethoxymethane	42.3	Propyl acetate	101.5
Carbon disulfide	46.3	2-Pentanone	101.7
1-Isopropoxy-2-propanol	47.9	3-Pentanone	102.0
Ethyl formate	54.2	2-Methyl-2-butanol	102.0
Acetone	56.2	1,1-Diethoxyethane	102.7
Methyl acetate	56.3	Butyl formate	106.6
1,1-Dichloroethane	57.3	2-Methyl-1-propanol	107.9
Dichloroethylene	60.6	Toluene	110.6
Chloroform	61.2	*sec*-Butyl acetate	112.3
Methanol	64.7	1,1,2-Trichloroethane	113.5
Tetrahydrofuran	66.0	Nitroethane	114.1
Diisopropyl ether	68.0	Pyridine	115.2
Hexane	68.7	3-Pentanol	115.6
1-Chloro-2-methylpropane	68.9	4-Methyl-2-pentanone	115.7
1,1,1-Trichloroethane	74.0	1-Chloro-2,3-epoxypropane	116.1
1,3-Dioxolane	74–75		
Carbon tetrachloride	76.7	1-Butanol	117.7
Ethyl acetate	77.1	Acetic acid	117.9
1-Chlorobutane	77.9	Isobutyl acetate	118.0
Ethanol	78.3	2-Pentanol	119.3
2-Butanone	79.6	1-Bromo-3-methylbutane	119.7
2-Methyltetrahydrofuran	80.0	1-Methoxy-2-propanol	120.1
Benzene	80.1	2-Nitropropane	120.3
Cyclohexane	80.7	Tetrachloroethylene	121.1
Propyl formate	80.9	Ethyl butyrate	121.6
Acetonitrile	81.6	3-Hexanone	123
2-Propanol	82.4	2,4-Dimethyl-3-pentanone	124
1,1,-Dimethylethanol	82.4	2-Methoxyethanol	124.6
Cyclohexene	83.0	Octane	125.7
Diisopropylamine	83.5	Butyl acetate	126.1
1,2-Dichloroethane	83.7	Diethyl carbonate	126.8
Thiophene	84.2	2-Hexanone	127.2
Trichloroethylene	87.2	1-Chloro-2-propanol	127.4
Isopropyl acetate	88.2	2-Chloroethanol	128.6
1-Bromo-2-methylpropane	91.5	3-Methyl-1-penten-2-one	129.5
2,5-Dimethylfuran	93–94	1-Nitropropane	131.2
Ethyl chloroformate	94	Chlorobenzene	131.7
Allyl alcohol	96.6	1,2-Dibromoethane	131.7
1,2-Dichloropropane	96.8	4-Methyl-2-pentanol	131.7

TABLE 11.8 Organic Solvents Arranged by Boiling Points (*Continued*)

Name	BP, °C	Name	BP, °C
3-Methyl-1-butanol	132.0	2-Octanol	179
Cyclohexylamine	134.8	1,2-Dichlorobenzene	180.4
2-Ethoxyethanol	134.8	Ethyl acetoacetate	180.8
Ethylbenzene	136.2	Phenol	181.8
1-Pentanol	138	2-Ethyl-1-hexanol	184.3
p-Xylene	138.4	Aniline	184.4
m-Xylene	139.1	Benzyl ethyl ether	185.0
Acetic anhydride	140.0	Diethyl oxalate	185.4
2,4-Pentanedione	140.6	1,2-Propanediol	188
Isopentyl acetate	142	Bis(2-ethoxyethyl) ether	188.4
Dibutyl ether	142.4	Dimethyl sulfoxide	189.0
4-Heptanone	143.7	1,2-Ethanediol diacetate	190.2
o-Xylene	144.4	Benzonitrile	191.0
2-Methoxyethyl acetate	144.5	2,5-Hexanedione	191.4
1,1,2,2-Tetrachloroethane	146.3	2-(2-Methoxyethoxy)-ethanol	194.1
3-Heptanone	147.8		
Tribromomethane	149.6	*N*,*N*-Dimethylaniline	194.2
Nonane	150.8	1-Octanol	195.2
2-Heptanone	151	1,2-Ethanediol	197.3
Isopropylbenzene	152.4	Diethyl malonate	199.3
N,*N*-Dimethylformamide	153.0	Methyl benzoate	199.5
Methoxybenzene	153.8	*o*-Toluidine	200.4
Ethyl lactate	154.5	*p*-Toluidine	200.6
Cyclohexanone	155.7	2-(2-Ethoxyethoxy)-ethanol	202
Bromobenzene	156.2		
1,2,3-Trichloropropane	156.9	Acetophenone	202.1
1-Hexanol	157.5	1,2-Dibutoxyethane	203.6
Propylbenzene	159.2	1-Phenylethanol	203.9
Cyclohexanol	161.1	*m*-Toluidine	203.4
Bis(2-methoxyethyl)ether	160	Benzyl alcohol	205.5
Isopentyl propionate	160.2	Camphor	207
2-Heptanol	160.4	1,3-Butanediol	207.5
Pentachloroethane	160.5	1,2,3,4-Tetrahydro-naphthalene	207.6
2-Furaldehyde	161.8		
2,6-Dimethyl-4-heptanone	168.1	γ-Valerolactone	207–208
4-Hydroxy-4-methyl-2-pentanone	169.2	*o*-Chloroaniline	208.8
		Nitrobenzene	210.8
2-Furanmethanol	170.0	Ethyl benzoate	212.4
Ethoxybenzene	170	3,5,5-Trimethylcyclo-hex-2-en-1-one	215.2
2-Butoxyethanol	170.2		
Diisopentyl ether	173.4	Naphthalene	217.7
Decane	174.2	2-(2-Ethoxyethoxy)ethyl acetate	218.5
1,3-Dichloro-2-propanol	174.3		
Cyclohexyl acetate	174–175	Acetamide	221.2
1-Heptanol	175.8	Methyl salicylate	223.0
Furfuryl acetate	175–177	Diethyl maleate	225.3
1,3,3-Trimethyl-2-oxabicyclo-[2.2.2]octane	177.4	1,4-Butanediol	230
		Propyl benzoate	231.2
		1-Decanol	230.2
4-Isopropyl-1-methylbenzene	177.1	Phenylacetonitrile	233.5
		Quinoline	237
Isopentyl butyrate	178.6	Tributyl borate	238.5
Bis(2-chloroethyl) ether	178.8	Propylene carbonate	240

TABLE 11.8 Organic Solvents Arranged by Boiling Points (*Continued*)

Name	BP, °C	Name	BP, °C
2-Phenoxyethanol	240	Isopentyl salicylate	277–278
Bis(2-hydroxyethyl) ether	245	1-Bromonaphthalene	281.1
Dibutyl oxalate	245.5	Dimethyl *o*-phthalate	283.7
Butyl benzoate	250	2,2′-(Ethylenedioxy)-bisethanol	285
1,2,3-Propanetriol triacetate	258–259	Glycerol	290
1-Chloronaphthalene	259.3	Diethyl *o*-phthalate	295
Isopentyl benzoate	262	Benzyl benzoate	323.5
trans-Ethyl cinnamate	271.0	Dibutyl *o*-phthalate	340.0
Bis[2-(methoxyethoxy)-ethyl]ether	275.3	Dibutyl decanedioate	344–345
1-Methoxy-2-nitrobenzene	277		

TABLE 11.9 Molecular Elevation of the Boiling Point

Ebullioscopic constants.

Molecular weights can be determined with the relation:

$$M = E_b \frac{1000\ w_2}{w_1\ \Delta T_b}$$

where ΔT_b is the elevation of the boiling point brought about by the addition of w_2 grams of solute to w_1 grams of solvent and E_b is the ebullioscopic constant. In the column headed "Barometric correction" is the number of degrees for each millimeter of difference between the barometric reading and 760 mmHg to be subtracted from E_b if the pressure is lower, or added if higher, than 760 mm. In general, the effect is within experimental error if the pressure is within 10 mm of 760 mm.

The ebullioscopic constant, a characteristic property of the solvent, may be calculated from the relation:

$$E_b = \frac{RT_b^2\ M}{\Delta_{vap}H}$$

where R is the molar gas constant, M is the molar mass of the solvent, and $\Delta_{vap}H$ the molar enthalpy (heat) of vaporization of the solvent.

Compound	Barometric correction	E_b, °C kg · mol^{-1}
Acetic acid	0.0008	3.22
Acetic anhydride		3.79
Acetone	0.0004	1.80
Acetonitrile		1.44
Acetophenone		5.81
Aniline	0.0009	3.82
Benzaldehyde		4.24
Benzene	0.0007	2.64
Benzonitrile		4.02
Bromobenzene	0.0016	6.35
Bromoethane		1.73
1-Butanol		2.17
2-Butanone		2.28
cis-2-Butene-1,4-diol		2.73
D-(+)-Camphor	0.0015	4.91
Carbon disulfide	0.0006	2.42
Carbon tetrachloride	0.0013	5.26
Chlorobenzene	0.0011	4.36
1-Chlorobutane		3.13
Chloroethane		1.77
Chloroform	0.0009	3.80
Cyclohexane	0.0007	2.92
Cyclohexanol		3.5
Decane		6.10
1,2-Dibromomethane	0.0016	6.01
1,1-Dichloroethane		3.13
1,2-Dichloroethane		3.27
Dichloromethane		2.42
Diethyl ether	0.0005	2.20
Diethyl sulfide		3.14
Dimethoxymethane		2.12
N,*N*-Dimethylacetamide		3.22
Dimethyl sulfide		1.85
Dimethyl sulfoxide		3.22

TABLE 11.9 Molecular Elevation of the Boiling Point (*Continued*)

Compound	Barometric correction	E_b, °C kg · mol^{-1}
1,4-Dioxane		3.00
Ethanol	0.0003	1.22
Ethoxybenzene		4.90
Ethyl acetate	0.0007	2.82
Ethylene glycol		2.26
Formic acid		2.36
Glycerol		6.52
Heptane	0.0008	3.62
Hexane		2.90
2-Hydroxybenzaldehyde		5.87
Iodoethane		5.27
Iodomethane		4.31
4-Isopropyl-1-methylbenzene		5.92
Methanol	0.0002	0.86
Methoxybenzene		4.20
Methyl acetate	0.0005	2.21
N-Methylaniline		4.3
2-Methyl-2-butanol		2.64
3-Methyl-1-butanol		2.88
3-Methylbutyl acetate		4.83
N-Methylformamide		2.2
Methyl formate		1.66
2-Methyl-1-propanol		2.14
2-Methyl-2-propanol		1.99
Naphthalene	0.0014	5.94
Nitrobenzene		5.24
Nitroethane		2.46
Nitromethane		2.09
Octane		4.39
1-Octanol		5.06
Pentyl acetate		4.71
Phenol	0.0009	3.54
Piperidine		3.21
Propanoic acid		3.27
1-Propanol		1.66
2-Propanol		1.58
Propionitrile		1.97
Pyridine		2.83
Pyrrole		2.33
Pyrrolidine		2.32
Quinoline		5.62
Tetrachloroethylene		6.18
Tetrachloromethane		5.26
1,2,3,4-Tetrahydronaphthalene		5.58
Toluene	0.0008	3.40
p-Toluidine		4.51
Trichloroethylene		4.52
Trichloromethane	0.0009	3.80
1,1,2-Trichloro-1,2,2-trifluoroethane		5.93
Triethylamine		3.57
Water	0.0001	0.512
o-Xylene		4.25

TABLE 11.10 Substances Which Can Be Used for Heating Baths

Medium	Melting point, °C	Boiling point, °C	Useful range, °C	Flash point, °C	Comments
Water	0	100	0–100	None	Ideal
Silicone oil	−50	—	30–250	315	Somewhat viscous at low temperature
Triethylene glycol	−7	285	0–250	165	Noncorrosive
Glycerol	18	290	−20 to 260	160	Water-soluble, nontoxic
Paraffin	50	—	60–300	199	Flammable
Dibutyl *o*-phthalate	−35	340	150–320	171	Generally used

11.4 SEPARATION METHODS

TABLE 11.11 Solvents of Chromatographic Interest

Solvent	Boiling point, °C	Solvent strength parameter		Viscosity, $mN \cdot s \cdot m^{-2}$ (20°C)	Refractive index (20°C)	UV cutoff, nm
		$e°$ (SiO_2)	$e°$ (Al_2O_3)			
Fluoroalkanes			−0.25		1.25	
Pentane	36	0.0	0.0	$0.24^{15°C}$	1.358	210
Hexane	69	0.0	0.0	0.31	1.375	210
2,2,4-Trimethylpentane	99		0.01	0.50	1.392	215
Decane	174		0.04	0.93	1.412	210
Cyclohexane	81	−0.05	0.04	0.98	1.426	210
Cyclopentane	49		0.05	0.44	1.407	210
Diisobutylene	101		0.06		1.411	
1-Pentene	30		0.08	$0.24^{0°C}$	1.371	
Carbon disulfide	46	0.14	0.15	0.36	1.626	380
Carbon tetrachloride	77	0.14	0.18	0.97	1.466	265
1-Chlorobutane	78		0.26	0.43	1.402	220
1-Chloropentane	98		0.26	0.58	1.412	225
o-Xylene	144		0.26	0.81	1.505	290
Diisopropyl ether	68		0.28	$0.38^{25°C}$	1.369	220
2-Chloropropane	35		0.29	0.33	1.378	225
Toluene	111		0.29	0.59	1.497	286
1-Chloropropane	47		0.30	0.35	1.389	225
Chlorobenzene	132		0.40	0.80	1.525	
Benzene	80	0.25	0.32	0.65	1.501	280
Bromoethane	38		0.37	0.40	1.424	

Diethyl ether	35	0.38	0.38	0.25	1.353	218
Diethyl sulfide	92		0.38	0.45	1.443	290
Chloroform	62	0.26	0.40	0.57	1.443	245
Dichloromethane	41		0.42	0.44	1.425	235
4-Methyl-2-pentanone	116		0.43	$0.42^{15°C}$	1.396	335
Tetrahydrofuran	66		0.45	0.55	1.407	220
1,2-Dichloroethane	84		0.49	0.80	1.445	228
2-Butanone	80		0.51	$0.42^{15°C}$	1.379	330
1-Nitropropane	131		0.53	$0.80^{25°C}$	1.402	380
Acetone	56	0.47	0.56	0.32	1.359	330
1,4-Dioxane	101	0.49	0.56	$1.44^{15°C}$	1.420	215
Ethyl acetate	77	0.38	0.58	0.45	1.372	255
Methyl acetate	56		0.60	$0.48^{15°C}$	1.362	260
1-Pentanol	138		0.61	4.1	1.410	210
Dimethyl sulfoxide	189		0.62	2.47	1.478	265
Aniline	184		0.62	4.40	1.586	
Diethylamine	56		0.63	0.33	1.386	275
Nitromethane	101		0.64	0.67	1.394	380
Acetonitrile	82	0.50	0.65	0.37	1.344	190
Pyridine	115		0.71	0.97	1.510	330
2-Butoxyethanol	170		0.74	$3.15^{25°C}$	1.420	220
1-Propanol	97		0.82	2.25	1.386	210
2-Propanol	82		0.82	2.50	1.377	210
Ethanol	78		0.88	1.20	1.361	210
Methanol	65		0.95	0.59	1.328	210
Ethylene glycol	198		1.11	21.8	1.432	210
Acetic acid	118		large	1.23	1.372	260
Water	100		large	1.00	1.333	191

TABLE 11.12 Solvents Having the Same Refractive Index and the Same Density at 25°C

Solvent 1	Solvent 2	Refractive index		Density, g/mL	
		1	2	1	2
Acetone	Ethanol	1.357	1.359	0.788	0.786
Ethyl formate	Methyl acetate	1.358	1.360	0.916	0.935
Ethanol	Propionitrile	1.359	1.363	0.786	0.777
2,2-Dimethylbutane	2-Methylpentane	1.366	1.369	0.644	0.649
2-Methylpentane	Hexane	1.369	1.372	0.649	0.655
Isopropyl acetate	2-Chloropropane	1.375	1.376	0.868	0.865
3-Butanone	Butyraldehyde	1.377	1.378	0.801	0.799
Butyraldehyde	Butyronitrile	1.378	1.382	0.799	0.786
Dipropyl ether	Butyl ethyl ether	1.379	1.380	0.753	0.746
Propyl acetate	Ethyl propionate	1.382	1.382	0.883	0.888
Propyl acetate	1-Chloropropane	1.382	1.386	0.883	0.890
Butyronitrile	2-Methyl-2-propanol	1.382	1.385	0.786	0.781
Ethyl propionate	1-Chloropropane	1.382	1.386	0.888	0.890
1-Propanol	2-Pentanone	1.383	1.387	0.806	0.804
Isobutyl formate	1-Chloropropane	1.383	1.386	0.881	0.890
1-Chloropropane	Butyl formate	1.386	1.387	0.890	0.888
Butyl formate	Methyl butyrate	1.387	1.391	0.888	0.875
Methyl butyrate	2-Chlorobutane	1.392	1.395	0.875	0.868
Butyl acetate	2-Chlorobutane	1.392	1.395	0.877	0.868
4-Methyl-2-pentanone	Pentanonitrile	1.394	1.395	0.797	0.795
4-Methyl-2-pentanone	1-Butanol	1.394	1.397	0.797	0.812
2-Methyl-1-propanol	Pentanonitrile	1.394	1.395	0.798	0.795
2-Methyl-1-propanol	2-Hexanone	1.394	1.395	0.798	0.810
2-Butanol	2,4-Dimethyl-3-pentanone	1.395	1.399	0.803	0.805
2-Hexanone	1-Butanol	1.395	1.397	0.810	0.812
Pentanonitrile	2,4-Dimethyl-3-pentanone	1.395	1.399	0.795	0.805
2-Chlorobutane	Isobutyl butyrate	1.395	1.399	0.868	0.860
Butyric acid	2-Methoxyethanol	1.396	1.400	0.955	0.960
1-Butanol	3-Methyl-2-pentanone	1.397	1.398	0.812	0.808
1-Chloro-2-methylpropane	Isobutyl butyrate	1.397	1.399	0.872	0.860
1-Chloro-2-methylpropane	Pentyl acetate	1.397	1.400	0.872	0.871
Methyl methacrylate	3-Methyl-2-pentanone	1.398	1.398	0.795	0.808
Triethylamine	2,2,3-Trimethylpentane	1.399	1.401	0.723	0.712
Butylamine	Dodecane	1.399	1.400	0.736	0.746
Isobutyl butyrate	1-Chlorobutane	1.399	1.401	0.860	0.875
1-Nitropropane	Propionic anhydride	1.399	1.400	0.995	1.007
Pentyl acetate	1-Chlorobutane	1.400	1.400	0.871	0.881
Pentyl acetate	Tetrahydrofuran	1.400	1.404	0.871	0.885
Dodecane	Dipropylamine	1.400	1.400	0.746	0.736
1-Chlorobutane	Tetrahydrofuran	1.401	1.404	0.871	0.885
Isopentanoic acid	2-Ethoxyethanol	1.402	1.405	0.923	0.926
Dipropylamine	Cyclopentane	1.403	1.404	0.736	0.740
2-Pentanol	4-Heptanone	1.404	1.405	0.804	0.813
3-Methyl-1-butanol	Hexanonitrile	1.404	1.405	0.805	0.801
3-Methyl-1-butanol	4-Heptanone	1.404	1.405	0.805	0.813
Hexanonitrile	4-Heptanone	1.405	1.405	0.801	0.813
Hexanonitrile	1-Pentanol	1.405	1.408	0.801	0.810
Hexanonitrile	2-Methyl-1-butanol	1.405	1.409	0.801	0.815
4-Heptanone	1-Pentanol	1.405	1.408	0.813	0.810

TABLE 11.12 Solvents Having the Same Refractive Index and the Same Density at 25°C (*Continued*)

Solvent 1	Solvent 2	Refractive index		Density, g/mL	
		1	2	1	2
2-Ethoxyethanol	Pentanoic acid	1.405	1.406	0.926	0.936
2-Heptanone	1-Pentanol	1.406	1.408	0.811	0.810
2-Heptanone	2-Methyl-1-butanol	1.406	1.409	0.811	0.815
2-Heptanone	Dipentyl ether	1.406	1.410	0.811	0.799
2-Pentanol	3-Isopropyl-2-pentanone	1.407	1.409	0.804	0.808
1-Pentanol	Dipentyl ether	1.408	1.410	0.810	0.799
2-Methyl-1-butanol	Dipentyl ether	1.409	1.410	0.815	0.799
Isopentyl isopentanoate	Allyl alcohol	1.410	1.411	0.853	0.847
Dipentyl ether	2-Octanone	1.410	1.414	0.799	0.814
2,4-Dimethyldioxane	3-Chloropentene	1.412	1.413	0.935	0.932
2,4-Dimethyldioxane	Hexanoic acid	1.412	1.415	0.935	0.923
Diethyl malonate	Ethyl cyanoacetate	1.412	1.415	1.051	1.056
3-Chloropentene	Octanoic acid	1.413	1.415	0.932	0.923
2-Octanone	1-Hexanol	1.414	1.416	0.814	0.814
2-Octanone	Octanonitrile	1.414	1.418	0.814	0.810
3-Octanone	3-Methyl-2-heptanone	1.414	1.416	0.830	0.818
3-Methyl-2-heptanone	1-Hexanol	1.415	1.416	0.818	0.814
3-Methyl-2-heptanone	Octanonitrile	1.415	1.418	0.818	0.810
1-Hexanol	Octanonitrile	1.416	1.418	0.814	0.810
Dibutylamine	Allylamine	1.416	1.419	0.756	0.758
Allylamine	Methylcyclohexane	1.419	1.421	0.758	0.765
Butyrolactone	1,3-Propanediol	1.434	1.438	1.051	1.049
Butyrolactone	Diethyl maleate	1.434	1.438	1.051	1.064
2-Chloromethyl-2-propanol	Diethyl maleate	1.436	1.438	1.059	1.064
N-Methylmorpholine	Dibutyl decanedioate	1.436	1.440	0.924	0.932
1,3-Propanediol	Diethyl maleate	1.438	1.438	1.049	1.064
Methyl salicylate	Diethyl sulfide	1.438	1.442	0.836	0.831
Methyl salicylate	1-Butanethiol	1.438	1.442	0.836	0.837
1-Chlorodecane	Mesityl oxide	1.441	1.442	0.862	0.850
Diethylene glycol	Formamide	1.445	1.446	1.128	1.129
Diethylene glycol	Ethylene glycol diglycidyl ether	1.445	1.447	1.128	1.134
Formamide	Ethylene glycol diglycidyl ether	1.446	1.447	1.129	1.134
2-Methylmorpholine	Cyclohexanone	1.446	1.448	0.951	0.943
2-Methylmorpholine	1-Amino-2-propanol	1.446	1.448	0.951	0.961
Dipropylene glycol monoethyl ether	Tetrahydrofurfuryl alcohol	1.446	1.450	1.043	1.050
1-Amino-2-methyl-2-pentanol	2-Butylcyclohexanone	1.449	1.453	0.904	0.901
2-Propylcyclohexanone	4-Methylcyclohexanol	1.452	1.454	0.923	0.908
Carbon tetrachloride	4,5-Dichloro-1,3-dioxolane-2-one	1.459	1.461	1.584	1.591
N-Butyldiethanolamine	Cyclohexanol	1.461	1.465	0.965	0.968
D-α-Pinene	*trans*-Decahydronaphthalene	1.464	1.468	0.855	0.867
Propylbenzene	*p*-Xylene	1.490	1.493	0.858	0.857
Propylbenzene	Toluene	1.490	1.494	0.858	0.860

TABLE 11.12 Solvents Having the Same Refractive Index and the Same Density at 25°C (*Continued*)

Solvent 1	Solvent 2	Refractive index		Density, g/mL	
		1	2	1	2
Phenyl 1-hydroxyphenyl ether	1,3-Dimorpholyl-2-propanol	1.491	1.493	1.081	1.094
Phenetole	Pyridine	1.505	1.507	0.961	0.978
2-Furanmethanol	Thiophene	1.524	1.526	1.057	1.059
m-Cresol	Benzaldehyde	1.542	1.544	1.037	1.041

TABLE 11.13 McReynolds' Constants for Stationary Phases in Gas Chromatography

Stationary phase	Chemical type	Similar stationary phases	Temp., °C		McReynolds' constants						USP code
			Min	Max	*x'*	*y'*	*z'*	*u'*	*s'*	Σ	
Boiling-point separation of broad molecular weight range of compounds; nonpolar phases											
Squalane	2,6,10,15,19,23-Hexamethyltetracosane		20	150	0	0	0	0	0	0	
Paraffin oil					9	5	2	6	11	33	
Apiezon® L			50	300	32	22	15	32	42	143	
SPB-1	Poly(dimethylsiloxane)	SA-1, DB-1	−60	320	4	58	43	56	38	199	
SP™-2100	Poly(dimethylsiloxane)	DC-200, SE 30, UC W98, DC 200	0	350	17	57	45	67	43	229	G 9
OV-1	Methylsiloxane gum		100	350	16	55	44	65	42	227	G 2
OV-101	Methylsiloxane fluid		20	350	17	57	45	67	43	234	G 1
SPB-5	1% Vinyl, 5% phenyl methyl polysiloxane	SA-5, DB-5	−60	320	19	74	64	93	62	312	
SE-54	1% Vinyl, 5% phenyl methyl polysiloxane	PTE-5	50	300	19	74	64	93	62	312	G 36
SE-52	5% Phenyl methyl polysiloxane		50	300	32	72	65	98	67	334	G 27
OV-73	5.5% Phenyl methyl polysiloxane	SP-400	0	325	40	86	76	114	85	401	G 27
OV-3	Poly(dimethyldiphenylsiloxane); 90%:10%		0	350	44	86	81	124	88	423	
Dexsil® 300	Carborane—methyl silicone		50	450	47	80	103	148	96	474	G 33
Dexsil® 400	Carborane—methylphenyl silicone		50	400	72	108	118	166	123	587	

TABLE 11.13 McReynolds' Constants for Stationary Phases in Gas Chromatography (*Continued*)

Stationary phase	Chemical type	Similar stationary phases	Temp., °C		McReynolds' constants						USP code
			Min	Max	*x*'	*y*'	*z*'	*u*'	*s*'	Σ	
Boiling-point separation of broad molecular weight range of compounds; nonpolar phases (*continued*)											
OV-7	20% Phenyl methyl polysiloxane	DC 550	0	350	69	113	111	171	128	592	
SPB-20	20% Phenyl methyl polysiloxane	SPB-35, SPB-1701, DB-1301	<20	300	67	116	117	174	131	605	
Di-(2-ethylhexyl)-sebacate			−20	125	72	168	108	180	125	653	G 11
DC 550	25% Phenyl methyl polysiloxane		20	225	81	124	124	189	145	663	G 28
Unsaturated hydrocarbons and other compounds of intermediate polarity											
Diisodecyl phthalate			20	150	84	173	137	218	155	767	G 24
OV-11	35% Phenyl methyl polysiloxane		0	350	102	142	145	219	178	786	
OV-1701	Vinyl methyl poly-siloxane	SPB-1701, SA-1701, DB-1701	0	250	67	170	152	228	171	789	
Poly-I 110				275	115	194	122	204	202	837	G 37
SP-2250	Poly(phenylmethyl-siloxane); 50% phenyl	OV-17, DB-17	0	375	119	158	162	243	202	884	G 3
Dexsil® 410	Carborane—methylcyano ethyl silicone		50	400	72	286	174	249	171	952	
UCON® LB-550-X	Polyalkylene glycol		20	200	118	271	158	243	206	996	
UCON LB-1880-X	Polyalkylene glycol			200	123	275	161	249	212	1020	G 18
Poly-A 103				275	115	331	144	263	214	1072	G 10

OV-22	Poly(diphenyldimethyl-siloxane); 65%:35%		0	350	160	188	191	283	253	1075	
Di(2-ethylhexyl) phthalate				150	135	254	213	320	235	1157	G 22
OV-25	Poly(diphenyldimethyl-siloxane); 75%:25%		0	350	178	204	208	305	280	1175	G 17
			Moderately polar compounds								
DC QF-1			0	250	144	233	355	463	305	1500	
OV-210	50% Trifluoropropyl-methylpolysiloxane	SP-2401, DB-210	0	275	146	238	358	468	310	1520	G 6
OV-215	Poly(trifluoropropyl-methylsiloxane)		0	275	149	240	363	478	315	1545	
UCON-50-HB-2000	Polyalkylene glycol		0	200	202	394	253	392	341	1582	
Triton® X-100	Octylphenoxy poly-ethoxy ethanol		0	190	203	399	268	402	362	1634	
UCON 50-HB-5100	Polyglycol		0	200	214	418	278	421	375	1706	
XE-60	Poly(cyanoethylphenyl-methylsiloxane)		0	250	204	381	340	493	367	1785	G 26
OV-225	25% Cyanopropyl 25% phenyl methyl polysiloxane	DB-225, DB-23	0	265	228	369	338	492	386	1813	G 19
Ipegal CO-880	Nonylphenoxypoly-(ethyleneoxy)ethanol		100	200	259	461	311	482	426	1939	G 31
Triton® X-305	Octylphenoxy poly-ethoxy ethanol		200	250	262	467	314	488	430	1961	

TABLE 11.13 McReynolds' Constants for Stationary Phases in Gas Chromatography (*Continued*)

Stationary phase	Chemical type	Similar stationary phases	Temp., °C		McReynolds' constants						USP code
			Min	Max	*x'*	*y'*	*z'*	*u'*	*s'*	Σ	
			Polar compounds								
Hi-EFF-3BP	Neopentylglycol succinate		50	230	272	469	366	539	474	2120	G 21
Carbowax 20M-TPA	Polyethyleneglycol + terephthalic acid		60	250	321	367	368	573	520	2149	G 25
Supelcowax™ 10	Polyethyleneglycol + terephthalic acid	DB-WAX, SA-WAX	50	280	305	551	360	562	484	2262	
SP-1000	Polyethyleneglycol + terephthalic acid		60	220	304	552	359	549	498	2262	
Carbowax 20M	Polyethyleneglycol	SP-2300	25	275	322	536	368	572	510	2308	G 16
Nukol™		SP-1000, FFAP, OV-351			311	572	374	572	520	2349	
Carbowax 3350		Formerly Carbowax 4000	60	200	325	551	375	582	520	2353	G 15
OV-351	Polyethyleneglycol + nitroterephthalic acid	SP-1000	50	270	335	552	382	583	540	2392	
SP-2300	36% Cyanopropyl		25	275	316	495	446	637	530	2424	
Silar 5 CP	50% Cyanopropyl phenyl silicone	SP-2300	0	250	319	495	446	637	531	2428	G 7

FFAP			50	250	340	580	397	602	627	2546	G 35
Hi-EFF-10BP	Phenyldiethanolamine succinate		20	230	386	555	472	674	656	2744	G 21
Carbowax 1450		Formerly 1540	50	175	371	639	453	666	641	2770	G 14
SP-2380					402	629	520	744	623	2918	
SP-2310	55% Cyanopropyl	Silar 7 CP	25	275	440	637	605	840	670	3192	
SP-2330	68% Cyanopropyl	SP-2331, SH-60	25	275	490	725	630	913	778	3536	
Silar 9 CP	90% Cyanopropyl phenyl		50	250	489	725	631	913	778	3536	G 8
Hi-EFF-1BP	Diethyleneglycol succinate		20	200	499	751	593	840	860	3543	G 4
SP-2340	75% Cyanopropyl phenyl	OV-275, SH-80	<25	275	520	757	659	942	800	3678	
Silar 10 CP	100% Cyanopropyl silicone	SP-2340	25	275	523	757	659	942	801	3682	G 5
THEED	Amino alcohol		0	125	463	942	626	801	893	3725	
OV-275	Dicyanoallylsilicone		25	250	629	872	763	110	849	4219	
Absolute index values on squalane for reference compounds:				653	590	627	652		699		

Note: USP code is the United States Pharmacopeia designation.

11.4.1 McReynolds' Constants

The *Kovats retention indices* (R.I.) indicate where compounds will appear on a chromatogram with respect to unbranched alkanes injected with the sample. By definition, the R.I. for pentane is 500, for hexane is 600, for heptane is 700, and so on, regardless of the column used or the operating conditions, although the exact conditions and column must be specified, such as liquid loading, particular support used, and any pretreatment. For example, suppose that on a 20% squalane column at 100°C, the retention times for hexane, benzene, and octane are found to be 15, 16, and 25 min, respectively. On a graph of ln t'_R (naperian logarithm of the adjusted retention time) of the alkanes versus their retention indices, a R.I. of 653 for benzene is read off the graph. The number 653 for benzene (see last line of Table 11.13 in the column headed "1" under "Reference compounds") means that it elutes halfway between hexane and heptane on a logarithmic time scale. If the experiment is repeated with a dinonyl phthalate column, the R.I for benzene is found to be 736 (lying between heptane and octane), which implies that dinonyl phthalate will retard benzene slightly more than squalane will; that is, dinonyl phthalate is slightly more polar than squalane by $\Delta I = 83$ units (the entry in Table 11.13 for dinonyl phthalate in the column headed "1" under "Reference compounds"). The difference gives a measure of solute-solvent interaction due to all intermolecular forces other than London dispersion forces. The latter are the principal solute-solvent effects with squalane.

TABLE 11.14 Characteristics of Selected Supercritical Fluids

Fluid	Critical temperature, K (°C)	Critical pressure, atm (psi)
Ammonia	406 (133)	111.3 (1636)
Argon	151 (−122)	48.1 (707)
Benzene	562 (289)	48.3 (710)
Butane	425 (125)	37.5 (551)
Carbon dioxide	304 (31)	72.8 (1070)
Carbon disulfide	552 (279)	78.0 (1147)
Chlorotrifluoromethane	379 (106)	40 (588)
2,2-Dimethylpropane	434 (161)	31.6 (464)
Ethane	305 (32)	48.2 (706)
Fluoromethane	318 (45)	58.0 (853)
Heptane	540 (267)	27.0 (397)
Hexane	507 (234)	29.3 (431)
Hydrogen sulfide	373 (100)	88.2 (1296)
Krypton	209 (−64)	54.3 (798)
Methane	191 (−82)	45.4 (667)
Methanol	513 (240)	79.9 (1175)
2-Methylpropane	408 (65)	36.0 (529)
Nitrogen	126 (−147)	33.5 (492)
Nitrogen(I) oxide	310 (37)	71.5 (1051)
Pentane	470 (197)	33.3 (490)
Propane	470 (197)	41.9 (616)
Sulfur dioxide	431 (158)	77.8 (1144)
Sulfur hexafluoride	319 (46)	37.1 (545)
Trichloromethane	536 (263)	54.9 (807)
Trifluoromethane	299 (26)	47.7 (701)
Water	647 (374)	217.6 (3199)
Xenon	290 (17)	57.6 (847)

Now the overall effects due to hydrogen bonding, dipole moment, acid-base properties, and molecular configuration can be expressed as

$$\sum \Delta I = ax' + by' + cz' + du' + es'$$

where $x' = \Delta I$ for benzene (the column headed "1" in Table 11.13, intermolecular forces typical of aromatics and olefins), $y' = \Delta I$ for 1-butanol (the column headed "2" in Table 11.13, electron attraction typical of alcohols, nitriles, acids, and nitro and alkyl monochlorides, dichlorides and trichlorides), $z' = \Delta I$ for 2-pentanone (the column headed "3" in Table 11.13, electron repulsion typical of ketones, ethers, aldehydes, esters, epoxides, and dimethylamino derivatives), $u' = \Delta I$ for 1-nitropropane (the column headed "4" in Table 11.13, typical of nitro and nitrile derivatives), and $s' = \Delta I$ for pyridine (or dioxane) (the column headed "5" in Table 11.13).

11.4.2 Chromatographic Behavior of Solutes

11.4.2.1 Retention Behavior. On a chromatogram the distance on the time axis from the point of sample injection to the peak of an eluted component is called the *uncorrected retention time* t_R. The corresponding retention volume is the product of retention time and flow rate, expressed as volume of mobile phase per unit time:

$$V_R = t_R F_c$$

The *average linear velocity u* of the mobile phase in terms of the column length L and the average linear velocity of eluent t_M (which is measured by the transit time of a nonretained solute) is

$$u = \frac{L}{t_M}$$

The *adjusted retention time* t'_R is given by

$$t'_R = t_R - t_M$$

When the mobile phase is a gas, a *compressibility factor j* must be applied to the adjusted retention volume to give the *net retention volume*:

$$V_N = jV'_R$$

The compressibility factor is expressed by

$$j = \frac{3[(P_i/P_o)^2 - 1]}{2[(P_i/P_o)^3 - 1]}$$

where P_i is the carrier gas pressure at the column inlet and P_o that at the outlet.

11.4.2.2 Partition Ratio. The partition ratio is the additional time a solute band takes to elute, as compared with an unretained solute (for which $k' = 0$), divided by the elution time of an unretained band:

$$k' = \frac{t_R - t_M}{t_M} = \frac{V_R - V_M}{V_M}$$

Retention time may be expressed as

$$t_R = t_M(1 + k') = \frac{L}{u}(1 + k')$$

11.4.2.3 Relative Retention. The relative retention α of two solutes, where solute 1 elutes before solute 2, is given variously by

$$\alpha = \frac{k'_2}{k'_1} = \frac{V'_{R,2}}{V'_{R,1}} = \frac{t'_{R,2}}{t'_{R,1}}$$

The relative retention is dependent on (1) the nature of the stationary and mobile phases and (2) the column operating temperature.

11.4.2.4 Column Efficiency. Under ideal conditions the profile of a solute band resembles that given by a Gaussian distribution curve (Fig. 11.1). The efficiency of a chromatographic system is expressed by the effective plate number N_{eff}, defined from the chromatogram of a single band,

$$N_{\text{eff}} = \frac{L}{H} = 16\left(\frac{t'_R}{W_b}\right)^2 = 5.54\left(\frac{t'_R}{W_{1/2}}\right)^2$$

where L is the column length, H is the plate height, t'_R is the adjusted time for elution of the band center, W_b is the width at the base of the peak ($W_b = 4\sigma$) as determined from the intersections of tangents to the inflection points with the baseline, and $W_{1/2}$ is the width at half the peak height. Column efficiency, when expressed as the number of theoretical plates N_{theor} uses the uncorrected retention time in the foregoing expression. The two column efficiencies are related by

$$N_{\text{eff}} = N_{\text{theor}}\left(\frac{k'}{k' + 1}\right)^2$$

11.4.2.5 Band Asymmetry. The peak asymmetry factor AF is often defined as the ratio of peak half-widths at 10% of peak height, that is, the ratio b/a, as shown in Fig. 11.2. When the asymmetry ratio lies outside the range 0.95–1.15 for a peak of $k' = 2$, the effective plate number should be calculated from the expression

$$N = \frac{41.7(t'_R/W_{0.1})}{(a/b) + 1.25}$$

11.4.2.6 Resolution. The degree of separation or resolution, Rs, of two adjacent peaks is defined as the distance between band peaks (or centers) divided by the average bandwidth using W_b, as shown in Fig. 11.3.

$$\text{Rs} = \frac{t_{R,2} - t_{R,1}}{0.5(W_2 + W_1)}$$

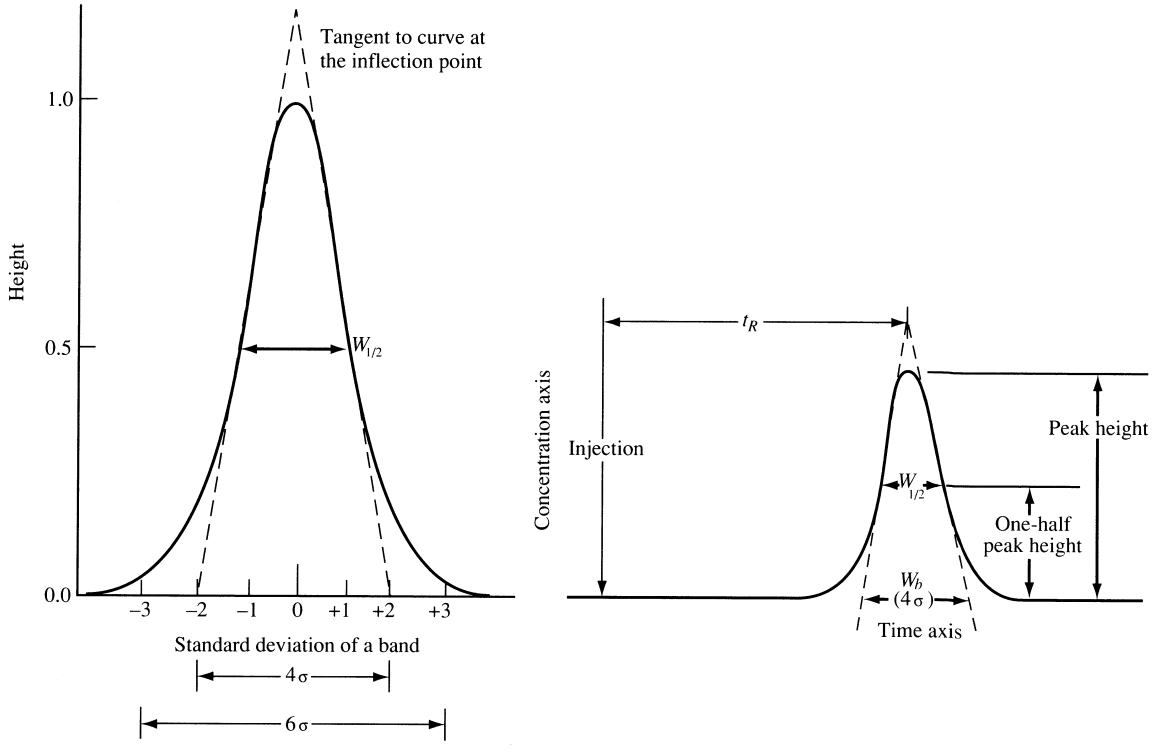

FIGURE 11.1 Profile of a solute band.

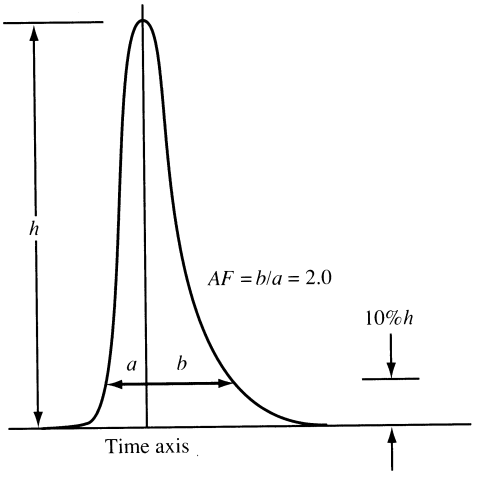

FIGURE 11.2 Band asymmetry.

For reasonable quantitative accuracy, peak maxima must be at least 4σ apart. If so, then Rs = 1.0, which corresponds approximately to a 3% overlap of peak areas. A value of Rs = 1.5 (for 6σ) represents essentially complete resolution with only 0.2% overlap of peak areas. These criteria pertain to roughly equal solute concentrations.

The fundamental resolution equation incorporates the terms involving the thermodynamics and kinetics of the chromatographic system:

$$\text{Rs} = \frac{1}{4}\left(\frac{\alpha - 1}{\alpha}\right)\left(\frac{k'}{1 + k'}\right)\left(\frac{L}{H}\right)^{1/2}$$

Three separate factors affect resolution: (1) a column selectivity factor that varies with α, (2) a capacity factor that varies with k' (taken usually as k_2), and (3) an efficiency factor that depends on the theoretical plate number.

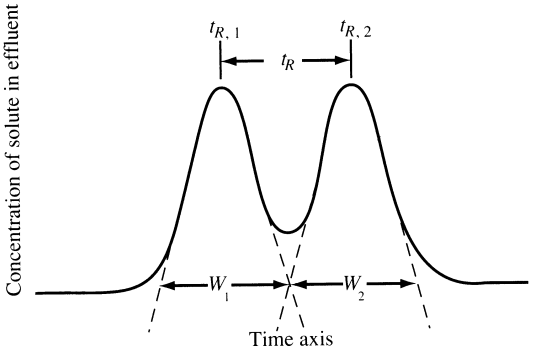

FIGURE 11.3 Definition of resolution.

11.4.2.7 Time of Analysis. The retention time required to perform a separation is given by

$$t_R = 16\mathrm{Rs}^2\left(\frac{\alpha}{\alpha - 1}\right)^2\left[\frac{(1 + k')^3}{(k')^2}\right]\left(\frac{H}{u}\right)$$

Now t_R is a minimum when $k' = 2$, that is, when $t_R = 3t_M$. There is little increase in analysis time when k' lies between 1 and 10. A twofold increase in the mobile-phase velocity roughly halves the analysis time (actually it is the ratio H/u which influences the analysis time). The ratio H/u can be obtained from the experimental plate height/velocity graph.

11.4.2.8 High-Performance Liquid Chromatography. Typical performances for various experimental conditions are given in Table 11.15. The data assume these reduced parameters: $h = 3$, $v = 4.5$. The *reduced plate height* is

$$h = \frac{H}{d_p} = \frac{L}{Nd_p}$$

The *reduced velocity* of the eluent is

$$v = \frac{ud_p}{D_M} = \frac{Ld_p}{t_M D_M}$$

In these expressions, d_p is the particle diameter of the stationary phase that constitutes one plate height. D_M is the diffusion coefficient of the solute in the mobile phase.

TABLE 11.15 Typical Performances in HPLC for Various Conditions

Performances		Column parameters		
N	t_M, s	L, cm	d_p, μm	P, atm (psi)
2 500	30	2.3	3	18.4 (270)
2 500	30	3.7	5	18.4 (270)
2 500	30	7.5	10	18.4 (270)
5 000	30	4.5	3	74 (1088)
5 000	30	7.5	5	74 (1088)
5 000	30	15.0	10	74 (1088)
10 000	30	9.0	3	300 (4410)
10 000	30	15.0	5	300 (4410)
10 000	30	30.0	10	300 (4410)
10 000	30	9.0	3	300 (4410)
10 000	60	9.0	3	150 (2200)
10 000	90	9.0	3	100 (1470)
15 000	90	2.3	3	223 (3275)
15 000	120	2.3	3	167 (2459)
11 100	30	10.0	3	369 (5420)
11 100	37	10.0	3	300 (4410)
11 100	101	10.0	3	100 (1470)
27 800	231	25.0	3	300 (4410)

Assumed reduced parameters: $h = 3, v = 4.5$. These are optimum values from a graph of reduced plate height versus reduced linear velocity of the mobile phase.

11.4.3 Ion-Exchange (Normal Pressure, Columnar)

Ion-exchange methods are based essentially on a reversible exchange of ions between an external liquid phase and an ionic solid phase. The solid phase consists of a polymeric matrix, insoluble, but permeable, which contains fixed charge groups and mobile counter ions of opposite charge. These counter ions can be exchanged for other ions in the external liquid phase. Enrichment of one or several of the components is obtained if selective exchange forces are operative. The method is limited to substances at least partially in ionized form.

11.4.3.1 Chemical Structure of Ion-Exchange Resins. An ion-exchange resin usually consists of polystyrene copolymerized with divinylbenzene to build up an inert three-dimensional, cross-linked matrix of hydrocarbon chains. Protruding from the polymer chains are the ion-exchange sites distributed statistically throughout the entire resin particle. The ionic sites are balanced by an equivalent number of mobile counter ions. The type and strength of the exchanger is determined by these active groups. Ion-exchangers are designated anionic or cationic, according to whether they have an affinity for negative or positive counter ions. Each main group is further subdivided into strongly or weakly ionized groups. A selection of commercially available ion-exchange resins is given in Table 11.16.

The cross-linking of a polystyrene resin is expressed as the proportion by weight percent of divinylbenzene in the reaction mixture; for example, "×8" for 8 percent cross-linking. As the percentage is increased, the ionic groups come into effectively closer proximity, resulting in increased selectivity. Intermediate cross-linking, in the range of 4 to 8 percent, is usually used. An increase in cross-linking decreases the diffusion rate in the resin particles; the diffusion rate is the rate-controlling step in column operations. Decreasing the particle size reduces the time required for attaining equilibrium, but at the same time decreases the flow rate until it is prohibitively slow unless pressure is applied.

In most inorganic chromatography, resins of 100 to 200 mesh size are suitable; difficult separations may require 200 to 400 mesh resins. A flow rate of 1 $mL \cdot cm^{-2} \cdot min^{-1}$ is often satisfactory. With HPLC columns, the flow rate in long columns of fine adsorbent can be increased by applying pressure.

11.4.3.1.1 Macroreticular Resins. Macroreticular resins are an agglomerate of randomly packed microspheres which extend through the agglomerate in a continuous non-gel pore structure. The channels throughout the rigid pore structure render the bead centers accessible even in non-aqueous solvents, in which microreticular resins do not swell sufficiently. Because of their high porosity and large pore diameters, these resins can handle large organic molecules.

11.4.3.1.2 Microreticular Resins. Microreticular resins, by contrast, are elastic gels that, in the dry state, avidly absorb water and other polar solvents in which they are immersed. While taking up solvent, the gel structure expands until the retractile stresses of the distended polymer network balance the osmotic effect. In nonpolar solvents, little or no swelling occurs and diffusion is impaired.

11.4.3.1.3 Ion-Exchange Membranes. Ion-exchange membranes are extremely flexible, strong membranes, composed of analytical grade ion-exchange resin beads (90%) permanently enmeshed in a poly(tetrafluoroethylene) membrane (10%). The membranes offer an alternative to column and batch methods, and can be used in many of the same applications as traditional ion exchange resins. Three ion-exchange resin types have been incorporated into membranes: AG 1-X8, AG 50W-X8, and Chelex 100.

11.4.3.2 Functional Groups

Sulfonate exchangers contain the group $—SO_3^-$, which is strongly acidic and completely dissociated whether in the H form or the cation form. These exchangers are used for cation exchange.

TABLE 11.16 Guide to Ion-Exchange Resins

Dowex is the trade name of Dow resins; X (followed by a numeral) is percent cross-linked. Mesh size (dry) are available in the range 50 to 100, 100 to 200, 200 to 400, and sometimes minus 400.

S-DVB is the acronym for styrene-divinylbenzene.

MP is the acronym for macroporous resin. Mesh size (dry) is available in the range 20 to 50, 100 to 200, and 200 to 400.

Bio-Rex is the trade name for certain resins sold by Bio-Rad Laboratories.

Amberlite and Duolite are trade names of Rohm & Haas resins.

Resin type and nominal percent cross-linkage	Minimum wet capacity, mequiv · mL^{-1}	Density (nominal), g · mL^{-1}	Comments
Anion exchange resins—gel type—strongly basic—quaternary ammonium functionality			
Dowex 1-X2	0.6	0.65	Strongly basic anion exchanger with S-DVB matrix for separation of small peptides, nucleotides, and large metal complexes. Molecular weight exclusion is <2700.
Dowex 1-X4	1.0	0.70	Strongly basic anion exchanger with S-DVB matrix for separation of organic acids, nucleotides, phosphoinositides, and other anions. Molecular weight exclusion is <1400.
Dowex 1-X8	1.2	0.75	Strongly basic anion exchanger with S-DVB matrix for separation of inorganic and organic anions with molecular weight exclusion <1000. 100–200 mesh is standard for analytical separations.
Dowex 2-X8	1.2	0.75	Strongly basic (but less basic than Dowex 1 type) anion exchanger with S-DVB matrix for deionization of carbohydrates and separation of sugars, sugar alcohols, and glycosides.
Amberlite IRA-400	1.4	1.11	8% cross-linkage. Used for systems essentially free of organic materials.
Amberlite IRA-402	1.3	1.07	Lower cross-linkage than IRA-400; better diffusion rate with large organic molecules.
Amberlite IRA-410	1.4	1.12	Dimethylethanolamine functionality and slightly lower basicity than IRA-400.
Amberlite IRA-458	1.2	1.08	Has an acrylic structure rather than S-DVB; hence more hydrophilic and resistant to organic fouling.
Anion exchange resin–gel type—intermediate basicity			
Bio-Rex 5	2.8	0.70	Intermediate basic anion exchanger with primarily tertiary amines on a polyalkyleneamine matrix for separation of organic acids.

TABLE 11.16 Guide to Ion-Exchange Resins (*Continued*)

Resin type and nominal percent cross-linkage	Minimum wet capacity, mequiv · mL^{-1}	Density (nominal), g · mL^{-1}	Comments
Anion exchange resins—gel type—weakly basic—polyamine functionality			
Dowex 4-X4	1.6	0.70	Weakly basic anion exchanger with tertiary amines on an acrylic matrix for the deionization of carbohydrates. Use at pH <7.
Amberlite IRA-68	1.6	1.06	Acrylic-DVB with unusually high capacity for large organic molecules.
Cation exchange resins—gel type—strongly acidic—sulfonic acid functionality			
Dowex 50W-X2	0.6	0.70	Strongly acidic cation exchanger with S-DVB matrix for separation of peptides, nucleotides, and cations. Molecular weight exclusion <2700.
Dowex 50W-X4	1.1	0.80	Strongly acidic cation exchanger with S-DVB matrix for separation of amino acids, nucleosides and cations. Molecular weight exclusion is <1400.
Dowex 50W-X8	1.7	0.80	Strongly acidic cation exchanger with S-DVB matrix for separation of amino acids, metal cations, and cations. Molecular weight exclusion is <1000. 100–200 mesh is standard for analytical applications.
Dowex 50W-X12	2.1	0.85	Strongly acidic cation exchanger with S-DVB matrix used primarily for metal separations.
Dowex 50W-X16	2.4	0.85	Strongly acidic cation exchanger with S-DVB matrix and high cross linkage.
Amberlite IR-120	1.9	1.26	8% styrene-DVB type; high physical stability.
Amberlite IR-122	2.1	1.32	10% styrene-DVB type; high physical stability and high capacity.
Weakly acidic cation exchangers—gel type—carboxylic acid functionality			
Duolite C-433	4.5	1.19	Acrylic-DVB type; very high capacity. Used for metals removal and neutralization of alkaline solutions.
Bio-Rex 70	2.4	0.70	Weakly acidic cation exchanger with carboxylate groups on a macroreticular acrylic matrix for separation and fractionation of proteins, peptides, enzymes, and amines, particularly high molecular weight solutes. Does not denature proteins as do styrene-based resins.

TABLE 11.16 Guide to Ion-Exchange Resins (*Continued*)

Resin type and nominal percent cross-linkage	Minimum wet capacity, mequiv · mL^{-1}	Density (nominal), g · mL^{-1}	Comments
Selective ion exchange resins			
Duolite GT-73	1.3	1.30	Removal of Ag, Cd, Cu, Hg, and Pb.
Amberlite IRA-743A	0.6	1.05	Boron specific ion exchange resin.
Amberlite IRC-718	1.0	1.14	Removal of transition metals.
Chelex® 100	0.4	0.65	Weakly acidic chelating resin with S-DVB matrix for heavy metal concentration.
Anion exchanger—macroreticular type—strongly basic—quaternary ammonium functionality			
Amberlite IRA-910	1.1	1.09	Dimethylethanolamine styrene-DVB type which offers slightly less silica removal than Amberlite IRA resin, but offers improved regeneration efficiency.
Amberlite IRA-938	0.5	1.20	Pore size distribution between 2500 and 23 000 nm; suitable for removal of high molecular weight organic materials.
Amberlite IRA-958	0.8		Acrylic-DVB; resistant to organic fouling.
AG MP-1	1.0	0.70	Strongly basic macroporous anion exchanger with S-DVB matrix for separation of some enzymes, radioactive anions, and other applications.
Cation exchange resin—macroreticular type—sulfonic acid functionality			
Amberlite 200	1.7	1.26	Styrene-DVB with 20% DVB by weight; superior physical stability and greater resistance to oxidation by factor of three over comparable gel type resin.
AG MP-50	1.5	0.80	Strongly acidic macroporous cation exchanger with S-DVB matrix for separation of radioactive cations and other applications.
Weak cation exchanger—macroreticular type—carboxylic acid or phenolic functionality			
Amberlite DP-1	2.5	1.17	Methacrylic acid-DVB; high resin capacity. Use pH >5.
Amberlite IRC-50	3.5	1.25	Methacrylic acid-DVB. Selectivity adsorbs organic gases such as antibiotics, alkaloids, peptides, and amino acids. Use pH >5.
Duolite C-464	3.0	1.13	Polyacrylic resin with high capacity and outstanding resistance to osmotic shock.

TABLE 11.16 Guide to Ion-Exchange Resins (*Continued*)

Resin type and nominal percent cross-linkage	Minimum wet capacity, mequiv · mL^{-1}	Density (nominal), g · mL^{-1}	Comments
Weak cation exchanger—macroreticular type—carboxylic acid or phenolic functionality (*continued*)			
Duolite A-7	2.2	1.12	Phenolic type resin. High porosity and hydrophilic matrix. pH range is 0 to 6.
Duolite A-368	1.7	1.04	Styrene-DVB; pH range is 0 to 9.
Amberlite IRA-35	1.1		Acrylic-DVB; pH range is 0 to 9.
Amberlite IRA-93	1.3	1.04	Styrene-DVB; pH range is 0 to 9. Excellent resistance to oxidation and organic fouling.
Liquid amines			
Amberlite LA-1			A secondary amine containing two highly branched aliphatic chains of M.W. 351 to 393. Solubility is 15 to 20 mg/mL in water. Used as 5 to 40% solutions in hydrocarbons.
Amberlite LA-2			A secondary amine of M.W. 353 to 395. Insoluble in water.
Microcrystalline exchanger			
AMP-1	4.0		Microcrystalline ammonium molybdophosphate with cation exchange capacity of 1.2 mequiv/g. Selectively adsorbs larger alkali metal ions from smaller alkali metal ions, particularly cesium.
Ion retardation resin			
AG 11 A8		0.70	Ion retardation resin containing paired anion (COO^-) and cation $(CH_3)_3N^+$ sites. Selectively retards ionic substances.

Source: J. A. Dean, ed., *Analytical Chemistry Handbook*, McGraw-Hill, New York, 1995.

Carboxylate exchangers contain —COOH groups which have weak acidic properties and will only function as cation exchangers when the pH is sufficiently high (pH $>$ 6) to permit complete dissociation of the —COOH site. Outside this range the ion exchanger can be used only at the cost of reduced capacity.

Quaternary ammonium exchangers contain $-R_4N^+$ groups which are strongly basic and completely dissociated in the OH form and the anion form.

Tertiary amine exchangers possess $-R_3NH_2$ groups which have exchanging properties only in an acidic medium when a proton is bound to the nitrogen atom.

Aminodiacetate exchangers have the $-N(CH_2COOH)_2$ group which has an unusually high preference for copper, iron, and other heavy metal cations and, to a lesser extent, for alkaline earth

cations. The resin selectivity for divalent over monovalent ions is approximately 5000 to 1. The resin functions as a chelating resin at pH 4 and above. At very low pH, the resin acts as an anion exchanger. This exchanger is the column packing often used for ligand exchange.

11.4.3.3 Ion-Exchange Equilibrium. Retention differences among cations with an anion exchanger, or among anions with a cation exchanger, are governed by the physical properties of the solvated ions. The stationary phase will show these preferences:

1. The ion of higher charge.
2. The ion with the smaller solvated radius. Energy is needed to strip away the solvation shell surrounding ions with large hydrated radii, even though their crystallographic ionic radii may be less than the average pore opening in the resin matrix.
3. The ion that has the greater polarizability (which determines the Van der Waals' attraction).

To accomplish any separation of two cations (or two anions) of the same net charge, the stationary phase must show a preference for one more than the other. No variation in the eluant concentration will improve the separation. However, if the exchange involves ions of different net charges, the separation factor does depend on the eluant concentration. The more dilute the counterion concentration in the eluant, the more selective the exchange becomes for polyvalent ions.

In the case of an ionized resin, initially in the H-form and in contact with a solution containing K^+ ions, an equilibrium exists:

$$\text{resin, } H^+ + K^+ \rightleftarrows \text{resin, } K^+ + H^+$$

which is characterized by the selectivity coefficient, $k_{K/H}$:

$$k_{K/H} = \frac{[K^+]_r\,[H^+]}{[H^+]_r\,[K^+]}$$

where the subscript *r* refers to the resin phase. Table 11.17 contains selectivity coefficients for cations and Table 11.18 for anions. Relative selectivities are of limited use for the prediction of the columnar

TABLE 11.17 Relative Selectivity of Various Counter Cations

Counterion	Relative selectivity for AG 50W-X8 resin	Counterion	Relative selectivity for AG 50W-X8 resin
H^+	1.0	Zn^{2+}	2.7
Li^+	0.86	Co^{2+}	2.8
Na^+	1.5	Cu^{2+}	2.9
NH_4^+	1.95	Cd^{2+}	2.95
K^+	2.5	Ni^{2+}	3.0
Rb^+	2.6	Ca^{2+}	3.9
Cs^+	2.7	Sr^{2+}	4.95
Cu^+	5.3	Hg^{2+}	7.2
Ag^+	7.6	Pb^{2+}	7.5
Tl^+	10.7	Ba^{2+}	8.7
Mn^{2+}	2.35	Ce^{3+}	22
Mg^{2+}	2.5	La^{3+}	22
Fe^{2+}	2.55		

TABLE 11.18 Relative Selectivity of Various Counter Anions

Counterion	Relative selectivity for Dowex 1-X8 resin	Relative selectivity for Dowex 2-X8 resin
OH^-	1.0	1.0
Benzenesulfonate$^-$	500	75
Salicylate$^-$	450	65
Citrate	220	23
I^-	175	17
Phenate$^-$	110	27
HSO_4^-	85	15
ClO_3^-	74	12
NO_3^-	65	8
Br^-	50	6
CN^-	28	3
HSO_3^-	27	3
BrO_3^-	27	3
NO_2^-	24	3
Cl^-	22	2.3
ClO_4^-	20	
SCN^-	8.0	
HCO_3^-	6.0	1.2
IO_3^-	5.5	0.5
$H_2PO_4^-$	5.0	0.5
Formate$^-$	4.6	0.5
Acetate$^-$	3.2	0.5
Propanoate$^-$	2.6	0.3
F^-	1.6	0.3

exchange behavior of a cation because they do not take account of the influence of the aqueous phase. More specific information about the behavior to be expected from a cation in a column elution experiment is given by the equilibrium distribution coefficient K_d.

The partitioning of the potassium ion between the resin and solution phases is described by the concentration distribution ratio, D_c:

$$(D_c)_K = \frac{[K^+]_r}{[K^+]}$$

Combining the equations for the selectivity coefficient and for D_c:

$$(D_c)_K = k_{K/H} \frac{[H^+]_r}{[H^+]}$$

The foregoing equation reveals that essentially the concentration distribution ratio for trace concentrations of an exchanging ion is independent of the respective solution of that ion and that the uptake of each trace ion by the resin is directly proportional to its solution concentration. However, the

concentration distribution ratios are inversely proportional to the solution concentration of the resin counterion.

To accomplish any separation of two cations (or two anions), one of these ions must be taken up by the resin in distinct preference to the other. This preference is expressed by the separation factor (or relative retention), $\alpha_{K/Na}$, using K^+ and Na^+ as the example:

$$\alpha_{K/Na} = \frac{(D_c)_K}{(D_c)_{Na}} = \frac{k_{K/H}}{k_{Na/H}} = K_{K/Na}$$

The more α deviates from unity for a given pair of ions, the easier it will be to separate them. If the selectivity coefficient is unfavorable for the separation of two ions of the same charge, no variation in the concentration of H^+ (the eluant) will improve the separation.

The situation is entirely different if the exchange involves ions of different net charges. Now the separation factor does depend on the eluant concentration. For example, the more dilute the counterion concentration in the eluant, the more selective the exchange becomes for the ion of higher charge.

In practice, it is more convenient to predict the behavior of an ion, for any chosen set of conditions, by employing a much simpler distribution coefficient, D_g, which is defined as the concentration of a solute in the resin phase divided by its concentration in the liquid phase, or:

$$D_g = \frac{\text{concentration of solute, resin phase}}{\text{concentration of solute, liquid phase}}$$

$$D_g = \frac{\text{\% solute within exchanger}}{\text{\% solute within solution}} \times \frac{\text{volume of solution}}{\text{mass of exchanger}}$$

D_g remains constant over a wide range of resin to liquid ratios. In a relatively short time, by simple equilibration of small known amounts of resin and solution followed by analysis of the phases, the distribution of solutes may be followed under many different sets of experimental conditions. Variables requiring investigation include the capacity and percent cross-linkage of resin, the type of resin itself, the temperature, and the concentration and pH of electrolyte in the equilibrating solution.

By comparing the ratio of the distribution coefficients for a pair of ions, a separation factor (or relative retention) is obtained for a specific experimental condition.

Instead of using D_g, separation data may be expressed in terms of a volume distribution coefficient D_v, which is defined as the amount of solution in the exchanger per cubic centimeter of resin bed divided by the amount per cubic centimeter in the liquid phase. The relation between D_g and D_v is given by:

$$D_v = D_g\rho$$

where ρ is the bed density of a column expressed in the units of mass of dry resin per cubic centimeter of column. The bed density can be determined by adding a known weight of dry resin to a graduated cylinder containing the eluting solution. After the resin has swelled to its maximum, a direct reading of the settled volume of resin is recorded.

Intelligent inspection of the relevant distribution coefficients will show whether a separation is feasible and what the most favorable eluant concentration is likely to be. In the columnar mode, an ion, even if not eluted, may move down the column a considerable distance and with the next eluant may appear in the eluate much earlier than indicated by the coefficient in the first eluant alone. A

distribution coefficient value of 12 or lower is required to elute an ion completely from a column containing about 10 g of dry resin using 250 to 300 mL of eluant. A larger volume of eluant is required only when exceptionally strong tailing occurs. Ions may be eluted completely by 300 to 400 mL of eluant from a column of 10 g of dry resin at D_g values of around 20. The first traces of an element will appear in the eluate at around 300 mL when its D_g value is about 50 to 60.

Example Shaking 50 mL of 0.001 *M* cesium salt solution with 1.0 g of a strong cation exchanger in the H-form (with a capacity of 3.0 mequiv · g^{-1}) removes the following amount of cesium. The selectivity coefficient, $k_{Cs/H}$, is 2.56, thus:

$$\frac{[Cs^+]_r[H^+]}{[Cs^+][H^+]_r} = 2.56$$

The maximum amount of cesium which can enter the resin is 50 mL × 0.001 *M* = 0.050 equiv. The minimum value of $[H^+]_r = 3.00 - 0.05 = 2.95$ mequiv, and the maximum value, assuming complete exchange of cesium ion for hydrogen ion, is 0.001 *M*. The minimum value of the distribution ratio is:

$$(D_c)_{Cs} = \frac{[Cs^+]_r}{[Cs^+]} = \frac{(2.56)(2.95)}{0.001} = 7550$$

$$\frac{\text{Amount of Cs, resin phase}}{\text{Amount of Cs, solution phase}} = \frac{(7550)(1.0\text{ g})}{50\text{ mL}} = 151$$

Thus, at equilibrium the 1.0 g of resin removed is:

$$\frac{100\% - x}{x} = 151$$

with all but 0.66% of cesium ions from solution. If the amount of resin were increased to 2.0 g, the amount of cesium remaining in solution would decrease to 0.33%, half the former value. However, if the depleted solution were decanted and placed in contact with 1 g of fresh resin, the amount of cesium remaining in solution would decrease to 0.004%. Two batch equilibrations would effectively remove the cesium from the solution.

11.5 GRAVIMETRIC ANALYSIS

TABLE 11.19 Gravimetric Factors

In the following table the elements are arranged in alphabetical order.

Example: To convert a given weight of Al_2O_3 to its equivalent of Al, multiply by the factor at the right, 0.52926; similarly to convert Al to Al_2O_3, multiply by the factor at the left, 1.8894.

Factor		Factor
	ALUMINUM **Al = 26.9815**	
0.74971	$Al \leftrightarrow Al_4C_3$	1.3341
0.058728	$Al \leftrightarrow Al(C_9H_6ON)_3$ (oxinate)	17.027
0.65829	$Al \leftrightarrow AlN$	1.5191
1.8894	$Al_2O_3 \leftrightarrow Al$	0.52926
1.4165	$Al_2O_3 \leftrightarrow Al_4C_3$	0.70596
0.38233	$Al_2O_3 \leftrightarrow AlCl_3$	2.6155
0.41804	$Al_2O_3 \leftrightarrow AlPO_4$	2.3921
0.29800	$Al_2O_3 \leftrightarrow Al_2(SO_4)_3$	3.3557
0.15300	$Al_2O_3 \leftrightarrow Al_2(SO_4)_3 \cdot 18H_2O$	6.5361
0.10746	$Al_2O_3 \leftrightarrow K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$	9.3055
0.11246	$Al_2O_3 \leftrightarrow (NH_4)_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$	8.8922
4.5197	$AlPO_4 \leftrightarrow Al$	0.22125
1.3946	$CaF_2 \leftrightarrow AlF_3$	0.71704
0.58196	$P_2O_5 \leftrightarrow AlPO_4$	1.7183
	AMMONIUM **NH_4 = 18.03858**	
1.1013	$Ag \leftrightarrow NH_4Br$	0.90802
2.0166	$Ag \leftrightarrow NH_4Cl$	0.49590
0.74424	$Ag \leftrightarrow NH_4I$	1.3437
1.9171	$AgBr \leftrightarrow NH_4Br$	0.52161
2.6792	$AgCl \leftrightarrow NH_4Cl$	0.37323
1.6198	$AgI \leftrightarrow NH_4I$	0.61737
1.7663	$BaSO_4 \leftrightarrow (NH_4)_2SO_4$	0.56615
0.81583	$Br \leftrightarrow NH_4Br$	1.2257
1.9654	$Cl \leftrightarrow NH_4$	0.50881
0.66277	$Cl \leftrightarrow NH_4Cl$	1.5088
0.68162	$HCl \leftrightarrow NH_4Cl$	1.4671
0.87553	$I \leftrightarrow NH_4I$	1.1422
14.410	$MgNH_4PO_4 \cdot 6H_2O \leftrightarrow NH_3$	0.069398
13.604	$MgNH_4PO_4 \cdot 6H_2O \leftrightarrow NH_4$	0.073506
9.4249	$MgNH_4PO_4 \cdot 6H_2O \leftrightarrow (NH_4)_2O$	0.10610
0.82244	$N \leftrightarrow NH_3$	1.2159
0.77648	$N \leftrightarrow NH_4$	1.2879
0.26185	$N \leftrightarrow NH_4Cl$	3.8189
0.17499	$N \leftrightarrow NH_4NO_3$	5.7145
0.53793	$N \leftrightarrow (NH_4)_2O$	1.8590
0.21200	$N \leftrightarrow (NH_4)_2SO_4$	4.7169
0.94412	$NH_3 \leftrightarrow NH_4$	1.0592
0.35449	$NH_3 \leftrightarrow (NH_4)_2CO_3$	2.8210
0.21543	$NH_3 \leftrightarrow NH_4HCO_3$	4.6419
0.21277	$NH_3 \leftrightarrow NH_4NO_3$	4.6998

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	AMMONIUM (*continued*) **NH_4 = 18.03858**	
0.65407	$NH_3 \leftrightarrow (NH_4)_2O$	1.5289
0.48596	$NH_3 \leftrightarrow NH_4OH$	2.0578
0.25777	$NH_3 \leftrightarrow (NH_4)_2SO_4$	3.8794
3.1409	$NH_4Cl \leftrightarrow NH_3$	0.31838
2.9654	$NH_4Cl \leftrightarrow NH_4$	0.33723
2.0543	$NH_4Cl \leftrightarrow (NH_4)_2O$	0.48677
1.5263	$NH_4Cl \leftrightarrow NH_4OH$	0.65516
2.5020	$NH_4OH \leftrightarrow N$	0.39967
1.9428	$NH_4OH \leftrightarrow NH_4$	0.51472
13.032	$(NH_4)_2PtCl_6 \leftrightarrow NH_3$	0.076737
12.303	$(NH_4)_2PtCl_6 \leftrightarrow NH_4$	0.081279
4.1490	$(NH_4)_2PtCl_6 \leftrightarrow NH_4Cl$	0.24102
2.7728	$(NH_4)_2PtCl_6 \leftrightarrow NH_4NO_3$	0.36065
8.5235	$(NH_4)_2PtCl_6 \leftrightarrow (NH_4)_2O$	0.11732
6.3328	$(NH_4)_2PtCl_6 \leftrightarrow NH_4OH$	0.15791
3.3592	$(NH_4)_2PtCl_6 \leftrightarrow (NH_4)_2SO_4$	0.29769
1.3473	$(NH_4)_2SO_4 \leftrightarrow H_2SO_4$	0.74223
3.1710	$N_2O_5 \leftrightarrow NH_3$	0.31536
0.67470	$N_2O_5 \leftrightarrow NH_4NO_3$	1.4821
2.0740	$N_2O_5 \leftrightarrow (NH_4)_2O$	0.48215
5.7275	$Pt \leftrightarrow NH_3$	0.17460
5.4074	$Pt \leftrightarrow NH_4$	0.18493
1.8235	$Pt \leftrightarrow NH_4Cl$	0.54838
1.2187	$Pt \leftrightarrow NH_4NO_3$	0.82058
3.7462	$Pt \leftrightarrow (NH_4)_2O$	0.26694
2.7833	$Pt \leftrightarrow NH_4OH$	0.35928
1.4764	$Pt \leftrightarrow (NH_4)_2SO_4$	0.67733
2.3505	$SO_3 \leftrightarrow NH_3$	0.42545
0.60589	$SO_3 \leftrightarrow (NH_4)_2SO_4$	1.6505
	ANTIMONY **Sb = 121.760**	
0.36460	$Sb \leftrightarrow KSbO \cdot C_4H_4O_6 \cdot {}^1\!/_2H_2O$	2.7428
0.83535	$Sb \leftrightarrow Sb_2O_4$	1.1971
0.75271	$Sb \leftrightarrow Sb_2O_5$	1.3285
0.43646	$Sb_2O_3 \leftrightarrow KSbO \cdot C_4H_4O_6 \cdot {}^1\!/_2H_2O$	2.2912
0.90106	$Sb_2O_3 \leftrightarrow Sb_2O_5$	1.1098
0.72184	$Sb_2O_3 \leftrightarrow Sb_2S_5$	1.3853
0.46042	$Sb_2O_4 \leftrightarrow KSbO \cdot C_4H_4O_6 \cdot {}^1\!/_2H_2O$	2.1719
1.2628	$Sb_2O_4 \leftrightarrow Sb$	0.79188
1.0549	$Sb_2O_4 \leftrightarrow Sb_2O_3$	0.94796
0.95053	$Sb_2O_4 \leftrightarrow Sb_2O_5$	1.0520
0.90523	$Sb_2O_4 \leftrightarrow Sb_2S_3$	1.1047
0.76147	$Sb_2O_4 \leftrightarrow Sb_2S_5$	1.3133
0.80110	$Sb_2O_5 \leftrightarrow Sb_2S_5$	1.2483
0.50862	$Sb_2S_3 \leftrightarrow KSbO \cdot C_4H_4O_6 \cdot {}^1\!/_2H_2O$	1.9661
1.3950	$Sb_2S_3 \leftrightarrow Sb$	0.71683
1.1653	$Sb_2S_3 \leftrightarrow Sb_2O_3$	0.85812
1.0500	$Sb_2S_3 \leftrightarrow Sb_2O_5$	0.95234
1.6584	$Sb_2S_5 \leftrightarrow Sb$	0.60299

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	ARSENIC **As = 74.9216**	
1.3203	$As_2O_3 \leftrightarrow As$	0.75738
0.86079	$As_2O_3 \leftrightarrow As_2O_5$	1.1617
1.5339	$As_2O_5 \leftrightarrow As$	0.65195
1.6420	$As_2S_3 \leftrightarrow As$	0.60903
1.2436	$As_2S_3 \leftrightarrow As_2O_3$	0.80413
1.0705	$As_2S_3 \leftrightarrow As_2O_5$	0.93418
0.79324	$As_2S_3 \leftrightarrow As_2S_5$	1.2606
2.0699	$As_2S_5 \leftrightarrow As$	0.48311
1.5678	$As_2S_5 \leftrightarrow As_2O_3$	0.63787
1.3495	$As_2S_5 \leftrightarrow As_2O_5$	0.74103
4.6729	$BaSO_4 \leftrightarrow As$	0.21400
3.5392	$BaSO_4 \leftrightarrow As_2O_3$	0.28255
3.0465	$BaSO_4 \leftrightarrow As_2O_6$	0.32825
2.8482	$BaSO_4 \leftrightarrow AsO_3$	0.35110
2.5202	$BaSO_4 \leftrightarrow AsO_4$	0.39680
2.0719	$Mg_2As_2O_7 \leftrightarrow As$	0.48265
1.5692	$Mg_2As_2O_7 \leftrightarrow As_2O_3$	0.63726
1.3509	$Mg_2As_2O_7 \leftrightarrow As_2O_5$	0.74032
1.2629	$Mg_2As_2O_7 \leftrightarrow AsO_2$	0.79186
1.1174	$Mg_2As_2O_7 \leftrightarrow AsO_4$	0.89493
1.2619	$Mg_2As_2O_7 \leftrightarrow As_2S_3$	0.79249
2.5397	$MgNH_4AsO_4 \cdot ½H_2O \leftrightarrow As$	0.39374
1.9235	$MgNH_4AsO_4 \cdot ½H_2O \leftrightarrow As_2O_3$	0.51988
1.6558	$MgNH_4AsO_4 \cdot ½H_2O \leftrightarrow As_2O_5$	0.60395
1.5480	$MgNH_4AsO_4 \cdot ½H_2O \leftrightarrow AsO_3$	0.64600
1.3697	$MgNH_4AsO_4 \cdot ½H_2O \leftrightarrow AsO_4$	0.73008
	BARIUM **Ba = 137.34**	
1.4369	$BaCO_3 \leftrightarrow Ba$	0.69592
0.94766	$BaCO_3 \leftrightarrow BaCl_2$	1.0552
0.76088	$BaCO_3 \leftrightarrow Ba(HCO_3)_2$	1.3143
1.2871	$BaCO_3 \leftrightarrow BaO$	0.77699
1.8446	$BaCrO_4 \leftrightarrow Ba$	0.54214
1.2165	$BaCrO_4 \leftrightarrow BaCl_2$	0.82205
1.2838	$BaCrO_4 \leftrightarrow BaCO_3$	0.77902
1.6521	$BaCrO_4 \leftrightarrow BaO$	0.60530
2.0345	$BaSiF_6 \leftrightarrow Ba$	0.49152
1.5936	$BaSiF_6 \leftrightarrow BaF_2$	0.62751
1.8222	$BaSiF_6 \leftrightarrow BaO$	0.54878
1.6994	$BaSO_4 \leftrightarrow Ba$	0.58843
1.1208	$BaSO_4 \leftrightarrow BaCl_2$	0.89224
0.95546	$BaSO_4 \leftrightarrow BaCl_2 \cdot 2H_2O$	1.0466
1.1827	$BaSO_4 \leftrightarrow BaCO_3$	0.84554
0.89308	$BaSO_4 \leftrightarrow Ba(NO_3)_2$	1.1197
1.5221	$BaSO_4 \leftrightarrow BaO$	0.65698
1.3783	$BaSO_4 \leftrightarrow BaO_2$	0.72554
1.3778	$BaSO_4 \leftrightarrow BaS$	0.72579
0.28701	$CO_2 \leftrightarrow BaO$	3.4842
0.22300	$CO_2 \leftrightarrow BaCO_3$	4.4842

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	BERYLLIUM **Be = 9.0122**	
8.8678	$BeCl_2 \leftrightarrow Be$	0.11277
2.7753	$BeO \leftrightarrow Be$	0.36033
0.31296	$BeO \leftrightarrow BeCl_2$	3.1953
0.14119	$BeO \leftrightarrow BeSO_4 \cdot 4H_2O$	7.0825
	BISMUTH **Bi = 208.980**	
0.89699	$Bi \leftrightarrow Bi_2O_3$	1.1148
1.6648	$BiAsO_4 \leftrightarrow Bi$	0.60069
1.4933	$BiAsO_4 \leftrightarrow Bi_2O_4$	0.66968
0.48030	$Bi_2O_3 \leftrightarrow Bi(NO_3)_3 \cdot 5H_2O$	2.0820
0.81183	$Bi_2O_3 \leftrightarrow BiONO_3$	1.2318
1.2462	$BiOCl \leftrightarrow Bi$	0.80244
0.53689	$BiOCl \leftrightarrow Bi(NO_3)_3 \cdot 5H_2O$	1.8626
1.1178	$BiOCl \leftrightarrow Bi_2O_3$	0.89460
0.90748	$BiOCl \leftrightarrow BiONO_3$	1.1019
1.2301	$Bi_2S_3 \leftrightarrow Bi$	0.81291
1.1034	$Bi_2S_3 \leftrightarrow Bi_2O_3$	0.90627
	BORON **B = 10.81**	
3.2199	$B_2O_3 \leftrightarrow B$	0.31057
0.81317	$B_2O_3 \leftrightarrow BO_2$	1.2298
0.59193	$B_2O_3 \leftrightarrow BO_3$	1.6894
0.89693	$B_2O_3 \leftrightarrow B_4O_7$	1.1149
0.56298	$B_2O_3 \leftrightarrow H_3BO_3$	1.7763
0.36510	$B_2O_3 \leftrightarrow Na_2B_4O_7 \cdot 10H_2O$	2.7389
6.4005	$B_6C \leftrightarrow C$	0.15624
11.646	$KBF_4 \leftrightarrow B$	0.085863
3.6171	$KBF_4 \leftrightarrow B_2O_3$	0.27647
2.0363	$KBF_4 \leftrightarrow H_3BO_3$	0.49108
1.3206	$KBF_4 \leftrightarrow Na_2B_4O_7 \cdot 10H_2O$	0.75723
	BROMINE **Br = 79.90**	
1.3499	$Ag \leftrightarrow Br$	0.74079
0.84333	$Ag \leftrightarrow BrO_3$	1.1858
1.3331	$Ag \leftrightarrow HBr$	0.75013
2.3499	$AgBr \leftrightarrow Br$	0.42555
1.4681	$AgBr \leftrightarrow BrO_3$	0.68117
2.3206	$AgBr \leftrightarrow HBr$	0.43091
0.55756	$Br \leftrightarrow AgCl$	1.7935
9.9892	$Br \leftrightarrow O$	0.10010
1.1858	$BrO_3 \leftrightarrow Ag$	0.84333
	CADMIUM **Cd = 112.40**	
0.61317	$Cd \leftrightarrow CdCl_2$	1.6309
0.47545	$Cd \leftrightarrow Cd(NO_3)_2$	2.1033
1.1423	$CdO \leftrightarrow Cd$	0.87539

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	CADMIUM (*continued*) **Cd = 112.40**	
0.70045	$CdO \leftrightarrow CdCl_2$	1.4276
0.54312	$CdO \leftrightarrow Cd(NO_3)_2$	1.8412
1.2852	$CdS \leftrightarrow Cd$	0.77807
0.78806	$CdS \leftrightarrow CdCl_2$	1.2689
0.61106	$CdS \leftrightarrow Cd(NO_3)_2$	1.6365
1.1251	$CdS \leftrightarrow CdO$	0.88883
0.69298	$CdS \leftrightarrow CdSO_4$	1.4430
1.8546	$CdSO_4 \leftrightarrow Cd$	0.53919
1.1372	$CdSO_4 \leftrightarrow CdCl_2$	0.87935
0.88177	$CdSO_4 \leftrightarrow Cd(NO_3)_2$	1.1341
1.6235	$CdSO_4 \leftrightarrow CdO$	0.61595
	CALCIUM **Ca = 40.08**	
3.2352	$BaSO_4 \leftrightarrow CaS$	0.30910
1.7144	$BaSO_4 \leftrightarrow CaSO_4$	0.58329
1.3556	$BaSO_4 \leftrightarrow CaSO_4 \cdot 2H_2O$	0.73766
0.36111	$Ca \leftrightarrow CaCl_2$	2.7692
0.51334	$Ca \leftrightarrow CaF_2$	1.9480
0.71471	$Ca \leftrightarrow CaO$	1.3992
2.4973	$CaCO_3 \leftrightarrow Ca$	0.40044
0.90179	$CaCO_3 \leftrightarrow CaCl_2$	1.1089
0.61742	$CaCO_3 \leftrightarrow Ca(HCO_3)_2$	1.6196
1.7848	$CaCO \leftrightarrow CaO$	0.56029
0.73520	$CaCO_3 \leftrightarrow CaSO_4$	1.3602
0.58134	$CaCO_3 \leftrightarrow CaSO_4 \cdot 2H_2O$	1.7202
1.3726	$CaCO_3 \leftrightarrow HCl$	0.72856
0.50526	$CaO \leftrightarrow CaCl_2$	1.9792
0.71825	$CaO \leftrightarrow CaF_2$	1.3923
0.34593	$CaO \leftrightarrow Ca(HCO_3)_2$	2.8907
0.75685	$CaO \leftrightarrow Ca(OH)_2$	1.3213
0.41192	$CaO \leftrightarrow CaSO_4$	2.4276
0.32572	$CaO \leftrightarrow CaSO_4 \cdot 2H_2O$	3.0701
2.5797	$Ca_3(PO_4)_2 \leftrightarrow Ca$	0.38765
1.8437	$Ca_3(PO_4)_2 \leftrightarrow CaO$	0.54239
0.75946	$Ca_3(PO_4)_2 \leftrightarrow CaSO_4$	1.3167
3.3967	$CaSO_4 \leftrightarrow Ca$	0.29440
1.2266	$CaSO_4 \leftrightarrow CaCl_2$	0.81526
1.3602	$CaSO_4 \leftrightarrow CaCO_3$	0.73520
1.7437	$CaSO_4 \leftrightarrow CaF_2$	0.57351
2.4276	$CaSO_4 \leftrightarrow CaO$	0.41192
1.7691	$Cl \leftrightarrow Ca$	0.56526
0.63885	$Cl \leftrightarrow CaCl_2$	1.5653
1.2644	$Cl \leftrightarrow CaO$	0.79089
0.78479	$CO_2 \leftrightarrow CaO$	1.2742
0.43970	$CO_2 \leftrightarrow CaCO_3$	2.2743
0.77989	$Mg_2As_2O_7 \leftrightarrow Ca_3(AsO_4)_2$	1.2822
0.71883	$MgO \leftrightarrow CaO$	1.3912
0.71755	$Mg_2P_2O_7 \leftrightarrow Ca_3(PO_4)_2$	1.3936
12.098	$(NH_4)_3PO_4 \cdot 12MoO_3 \leftrightarrow Ca_3(PO_4)_2$	0.082657

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	CALCIUM (*continued*) **Ca = 40.08**	
0.65824	$N_2O_5 \leftrightarrow Ca(NO_3)_2$	1.5192
0.45761	$P_2O_3 \leftrightarrow Ca_3(PO_4)_2$	2.1853
1.4277	$SO_3 \leftrightarrow CaO$	0.70044
0.58809	$SO_3 \leftrightarrow CaSO_4$	1.7004
0.46502	$SO_3 \leftrightarrow CaSO_4 \cdot 2H_2O$	2.1505
0.80523	$WO_3 \leftrightarrow CaWO_4$	1.2419
	CARBON **C = 12.011**	
3.9913	$Ag \leftrightarrow HCN$	0.25054
1.6565	$Ag \leftrightarrow KCN$	0.60369
4.9541	$AgCN \leftrightarrow HCN$	0.20185
2.0561	$AgCN \leftrightarrow KCN$	0.48637
16.431	$BaCO_3 \leftrightarrow C$	0.060861
4.4842	$BaCO_3 \leftrightarrow CO_2$	0.22301
3.2887	$BaCO_3 \leftrightarrow CO_3$	0.30407
3.4842	$BaO \leftrightarrow CO_2$	0.28701
1.7421	$BaO \leftrightarrow CO_2$, bicarbonate	0.57402
0.19432	$CN \leftrightarrow AgCN$	5.1461
0.24120	$CN \leftrightarrow Ag$	4.1460
0.35000	$SCN \leftrightarrow AgSCN$	2.8572
0.47757	$SCN \leftrightarrow CuSCN$	2.0939
0.24885	$SCN \leftrightarrow BaSO_4$	4.0185
1.2742	$CaO \leftrightarrow CO_2$	0.78479
0.63712	$CaO \leftrightarrow CO_2$, bicarbonate	1.5696
0.33936	$CO_2 \leftrightarrow Ba(HCO_3)_2$	2.9467
3.6641	$CO_2 \leftrightarrow C$	0.27291
0.43970	$CO_2 \leftrightarrow CaCO_3$	2.2743
0.54297	$CO_2 \leftrightarrow Ca(HCO_3)_2$	1.8417
0.73341	$CO_2 \leftrightarrow CO_3$	1.3635
0.13507	$CO_2 \leftrightarrow Cs_2CO_3$	7.4033
0.22695	$CO_2 \leftrightarrow CsHCO_3$	4.4063
0.37986	$CO_2 \leftrightarrow FeCO_3$	2.6326
0.49483	$CO_2 \leftrightarrow Fe(HCO_3)_2$	2.0209
0.31843	$CO_2 \leftrightarrow K_2CO_3$	3.1404
0.43957	$CO_2 \leftrightarrow KHCO_3$	2.2749
0.46718	$CO_2 \leftrightarrow K_2O$	2.1405
0.59564	$CO_2 \leftrightarrow Li_2CO_3$	1.6789
0.64762	$CO_2 \leftrightarrow LiHCO_3$	1.5441
1.4730	$CO_2 \leftrightarrow Li_2O$	0.67887
0.52193	$CO_2 \leftrightarrow MgCO_3$	1.9159
0.60143	$CO_2 \leftrightarrow Mg(HCO_3)_2$	1.6627
1.0918	$CO_2 \leftrightarrow MgO$	0.91595
0.38286	$CO_2 \leftrightarrow MnCO_3$	2.6119
0.49737	$CO_2 \leftrightarrow Mn(HCO_3)_2$	2.0106
0.62041	$CO_2 \leftrightarrow MnO$	1.6118
0.41523	$CO_2 \leftrightarrow Na_2CO_3$	2.4083
0.52388	$CO_2 \leftrightarrow NaHCO_3$	1.9088
0.71008	$CO_2 \leftrightarrow Na_2O$	1.4083
0.45802	$CO_2 \leftrightarrow (NH_4)_2CO_3$	2.1833

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	CARBON (*continued*) **C = 12.011**	
0.55669	$CO_2 \leftrightarrow NH_4HCO_3$	1.7963
0.16471	$CO_2 \leftrightarrow PbCO_3$	6.0713
0.19055	$CO_2 \leftrightarrow Rb_2CO_3$	5.2477
0.30043	$CO_2 \leftrightarrow RbHCO_3$	3.3286
0.23542	$CO_2 \leftrightarrow Rb_2O$	4.2477
0.29811	$CO_2 \leftrightarrow SrCO_3$	3.3545
0.41984	$CO_2 \leftrightarrow Sr(HCO_3)_2$	2.3818
0.42474	$CO_2 \leftrightarrow SrO$	2.3545
	CERIUM **Ce = 140.12**	
0.36100	$Ce \leftrightarrow Ce(NO_3)_4$	2.7701
0.24746	$Ce \leftrightarrow Ce(NO_3)_4 \cdot 2NH_4NO_3 \cdot H_2O$	4.0411
0.81408	$Ce \leftrightarrow CeO_2$	1.2284
0.85377	$Ce \leftrightarrow Ce_2O_3$	1.1713
0.49302	$Ce \leftrightarrow Ce_2(SO_4)_3$	2.0283
1.0527	$Ce_2(C_2O_4)_3 \cdot 3H_2O \leftrightarrow Ce_2(SO_4)_3$	0.94998
2.1351	$Ce_2(C_2O_4)_3 \cdot 3H_2O \leftrightarrow Ce$	0.46835
0.44345	$CeO_2 \leftrightarrow Ce(NO_3)_4$	2.2551
0.30397	$CeO_2 \leftrightarrow Ce(NO_3)_4 \cdot 2NH_4NO_3 \cdot H_2O$	3.2898
0.42284	$Ce_2O_3 \leftrightarrow Ce(NO_3)_4$	2.3650
0.28984	$Ce_2O_3 \leftrightarrow Ce(NO_3)_4 \cdot 2NH_4NO_3 \cdot H_2O$	3.4502
0.95352	$Ce_2O_3 \leftrightarrow CeO_2$	1.0487
0.57746	$Ce_2O_3 \leftrightarrow Ce_2(SO_4)_3$	1.7317
	CESIUM **Cs = 137.905**	
0.85127	$AgCl \leftrightarrow CsCl$	1.1747
0.26675	$Cl \leftrightarrow Cs$	3.7489
0.21058	$Cl \leftrightarrow CsCl$	4.7488
0.78944	$Cs \leftrightarrow CsCl$	1.2667
0.57200	$Cs \leftrightarrow CsClO_4$	1.7483
0.81585	$Cs \leftrightarrow Cs_2CO_3$	1.2257
0.94326	$Cs \leftrightarrow Cs_2O$	1.0602
0.83693	$Cs_2O \leftrightarrow CsCl$	1.1948
0.77876	$Cs_2O \leftrightarrow Cs_2SO_4$	1.2841
2.5341	$Cs_2PtCl_6 \leftrightarrow Cs$	0.39461
2.0005	$Cs_2PtCl_6 \leftrightarrow CsCl$	0.49987
2.0675	$Cs_2PtCl_6 \leftrightarrow Cs_2CO_3$	0.48369
2.3903	$Cs_2PtCl_6 \leftrightarrow Cs_2O$	0.41835
1.3613	$Cs_2SO_4 \leftrightarrow Cs$	0.73457
1.0747	$Cs_2SO_4 \leftrightarrow CsCl$	0.93050
1.1106	$Cs_2SO_4 \leftrightarrow Cs_2CO_3$	0.90038
0.28410	$SO_3 \leftrightarrow Cs_2O$	3.5199
	CHLORINE **Cl = 35.453**	
3.0426	$Ag \leftrightarrow Cl$	0.32866
2.9585	$Ag \leftrightarrow HCl$	0.33801
4.0425	$AgCl \leftrightarrow Cl$	0.24737

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	CHLORINE (*continued*) **Cl = 35.453**	
3.9308	$AgCl \leftrightarrow HCl$	0.25440
3.5728	$BaCrO_4 \leftrightarrow Cl$	0.27990
0.56526	$Ca \leftrightarrow Cl$	1.7691
0.97235	$Cl \leftrightarrow HCl$	1.0284
0.58227	$ClO_3 \leftrightarrow AgCl$	1.7174
1.1193	$ClO_3 \leftrightarrow KCl$	0.89340
1.4279	$ClO_3 \leftrightarrow NaCl$	0.70033
0.69391	$ClO_4 \leftrightarrow AgCl$	1.4411
1.3339	$ClO_4 \leftrightarrow KCl$	0.74967
1.7017	$ClO_4 \leftrightarrow NaCl$	0.58766
1.1029	$K \leftrightarrow Cl$	0.90668
2.1029	$KCl \leftrightarrow Cl$	0.47553
0.19572	$Li \leftrightarrow Cl$	5.1092
0.34288	$Mg \leftrightarrow Cl$	2.9165
1.3429	$MgCl_2 \leftrightarrow Cl$	0.74467
1.2261	$MnO_2 \leftrightarrow Cl$	0.81560
0.64846	$Na \leftrightarrow Cl$	1.5421
1.6485	$NaCl \leftrightarrow Cl$	0.60663
0.50881	$NH_4 \leftrightarrow Cl$	1.9654
1.4671	$NH_4Cl \leftrightarrow HCl$	0.68162
1.8121	$(NH_4)_2SO_4 \leftrightarrow HCl$	0.55185
4.5580	$PbCrO_4 \leftrightarrow Cl$	0.21939
	CHROMIUM **Cr = 51.996**	
4.8721	$BaCrO_4 \leftrightarrow Cr$	0.20525
3.3335	$BaCrO_4 \leftrightarrow Cr_2O_3$	0.29998
2.5335	$BaCrO_4 \leftrightarrow CrO_3$	0.39472
2.1841	$BaCrO_4 \leftrightarrow CrO_4$	0.45786
0.70718	$BaCrO_4 \leftrightarrow Cr_2(SO_4)_3 \cdot 18H_2O$	1.4141
7.4935	$Cr_3C_2 \leftrightarrow C$	0.13345
1.9231	$CrO_3 \leftrightarrow Cr$	0.51999
1.4616	$Cr_2O_3 \leftrightarrow Cr$	0.68420
0.76000	$Cr_2O_3 \leftrightarrow CrO_3$	1.3158
0.65519	$Cr_2O_3 \leftrightarrow CrO_4$	1.5263
3.7349	$K_2CrO_4 \leftrightarrow Cr$	0.26774
1.9421	$K_2CrO_4 \leftrightarrow CrO_3$	0.51490
1.4710	$K_2Cr_2O_7 \leftrightarrow CrO_3$	0.67979
6.2155	$PbCrO_4 \leftrightarrow Cr$	0.16089
4.2527	$PbCrO_4 \leftrightarrow Cr_2O_3$	0.23515
3.2320	$PbCrO_4 \leftrightarrow CrO_3$	0.30941
2.7863	$PbCrO_4 \leftrightarrow CrO_4$	0.35890
0.90217	$PbCrO_4 \leftrightarrow Cr_2(SO_4)_3 \cdot 18H_2O$	1.1084
1.6642	$PbCrO_4 \leftrightarrow K_2CrO_4$	0.60090
2.1971	$PbCrO_4 \leftrightarrow K_2Cr_2O_7$	0.45515
	COBALT **Co = 58.9332**	
0.20249	$Co \leftrightarrow Co(NO_3)_2 \cdot 6H_2O$	4.9385
0.78648	$Co \leftrightarrow CoO$	1.2715

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	COBALT (*continued*) **Co = 58.9332**	
0.20965	$Co \leftrightarrow CoSO_4 \cdot 7H_2O$	4.7698
7.6743	$K_3[Co(NO_2)_6] \leftrightarrow Co$	0.13030
6.0357	$K_3[Co(NO_2)_6] \leftrightarrow CoO$	0.16568
1.3620	$Co_3O_4 \leftrightarrow Co$	0.73422
1.0712	$Co_3O_4 \leftrightarrow CoO$	0.93355
2.4758	$Co_2P_2O_7 \leftrightarrow Co$	0.40391
1.9471	$Co_2P_2O_7 \leftrightarrow CoO$	0.51357
3.2233	$CoNH_4PO_4 \cdot H_2O \leftrightarrow Co$	0.31024
2.5351	$CoNH_4PO_4 \cdot H_2O \leftrightarrow CoO$	0.39447
2.6299	$CoSO_4 \leftrightarrow Co$	0.38024
2.0684	$CoSO_4 \leftrightarrow CoO$	0.48347
3.7514	$CoSO_4 \cdot 7H_2O \leftrightarrow CoO$	0.26657
7.0656	$(CoSO_4)_2 \cdot (K_2SO_4)_3 \leftrightarrow Co$	0.14153
5.5569	$(CoSO_4)_2 \cdot (K_2SO_4)_3 \leftrightarrow CoO$	0.17996
	COPPER **Cu = 63.544**	
0.25071	$Cu \leftrightarrow Cu_2C_2H_3O_2 \cdot (AsO_2)_3$	3.9887
0.79885	$Cu \leftrightarrow CuO$	1.2518
0.25449	$Cu \leftrightarrow CuSO_4 \cdot 5H_2O$	3.9295
1.9141	$CuSCN \leftrightarrow Cu$	0.52245
1.5291	$CuSCN \leftrightarrow CuO$	0.65400
0.31856	$CuO \leftrightarrow CuSO_4 \cdot 5H_2O$	3.1391
1.1259	$Cu_2O \leftrightarrow Cu$	0.88817
1.2523	$Cu_2S \leftrightarrow Cu$	0.79854
1.0004	$Cu_2S \leftrightarrow CuO$	0.99961
1.1122	$Cu_2S \leftrightarrow Cu_2O$	0.89908
0.31869	$Cu_2S \leftrightarrow CuSO_4 \cdot 5H_2O$	3.1379
0.91872	$Mg_2As_2O_7 \leftrightarrow Cu_2C_2H_3O_2(AsO_2)_3$	1.0885
	ERBIUM **Er = 167.26**	
1.1435	$Er_2O_3 \leftrightarrow Er$	0.87452
	FLUORINE **F = 18.9984**	
1.5936	$BaSiF_6 \leftrightarrow BaF_2$	0.62751
2.4513	$BaSiF_6 \leftrightarrow F$	0.40795
2.3277	$BaSiF_6 \leftrightarrow 6HF$	0.42960
1.9392	$BaSiF_6 \leftrightarrow H_2SiF_6$	0.51568
2.6847	$BaSiF_6 \leftrightarrow SiF_4$	0.37249
1.9666	$BaSiF_6 \leftrightarrow SiF_6$	0.50848
1.6256	$CaF_2 \leftrightarrow H_2SiF_6$	0.61516
1.6486	$CaF_2 \leftrightarrow SiF_6$	0.60658
3.5829	$CaSO_4 \leftrightarrow F$	0.27910
2.4024	$CaSO_4 \leftrightarrow HF$	0.29391
0.48666	$F \leftrightarrow CaF_2$	2.0548
0.51248	$HF \leftrightarrow CaF_2$	1.9513
1.2641	$H_2SiF_6 \leftrightarrow F$	0.79109
3.6011	$H_2SiF_6 \leftrightarrow 2HF$	0.27769

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	FLUORINE (*continued*) **F = 18.9984**	
1.2004	$H_2SiF_6 \leftrightarrow 6HF$	0.83308
1.3844	$H_2SiF_6 \leftrightarrow SiF_4$	0.72233
1.0141	$H_2SiF_6 \leftrightarrow SiF_6$	0.98605
2.0556	$KF \cdot HF \leftrightarrow 2F$	0.48647
1.9520	$KF \cdot HF \leftrightarrow 2HF$	0.51228
0.67218	$KF \cdot HF \leftrightarrow 2KF$	1.4877
0.41489	$KF \cdot HF \leftrightarrow 2(KF \cdot 2H_2O)$	2.4103
1.9325	$K_2SiF_6 \leftrightarrow F$	0.51748
1.8351	$K_2SiF_6 \leftrightarrow 6HF$	0.54494
1.5288	$K_2SiF_6 \leftrightarrow H_2SiF_6$	0.65412
1.8957	$K_2SiF_6 \leftrightarrow 2KF$	0.52751
1.5504	$K_2SiF_6 \leftrightarrow SiF_6$	0.64500
1.9495	$NH_4F \leftrightarrow F$	0.51295
1.5013	$NH_4F \cdot HF \leftrightarrow 2F$	0.66611
1.4256	$NH_4F \cdot HF \leftrightarrow 2HF$	0.70145
0.49090	$NH_4F \cdot HF \leftrightarrow 2KF$	2.0371
0.30300	$NH_4F \cdot HF \leftrightarrow 2(KF \cdot 2H_2O)$	3.3003
1.5629	$(NH_4)_2SiF_6 \leftrightarrow F$	0.63985
1.4841	$(NH_4)_2SiF_6 \leftrightarrow 6HF$	0.67381
1.2364	$(NH_4)_2SiF_6 \leftrightarrow H_2SiF_6$	0.80881
2.4050	$(NH_4)_2SiF_6 \leftrightarrow 2NH_4F$	0.41580
1.2539	$(NH_4)_2SiF_6 \leftrightarrow SiF_6$	0.79753
2.2101	$NaF \leftrightarrow F$	0.45246
1.6498	$Na_2SiF_6 \leftrightarrow F$	0.60614
1.5666	$Na_2SiF_6 \leftrightarrow 6HF$	0.63831
1.3052	$Na_3SiF_6 \leftrightarrow H_2SiF_6$	0.76619
2.2394	$Na_2SiF_6 \leftrightarrow 2NaF$	0.44654
1.3236	$Na_2SiF_6 \leftrightarrow SiF_6$	0.75550
	GALLIUM **Ga = 69.72**	
1.3442	$Ga_2O_3 \leftrightarrow Ga$	0.74392
1.6898	$Ga_2S_3 \leftrightarrow Ga$	0.59178
	GERMANIUM **Ge = 72.59**	
1.4408	$GeO_2 \leftrightarrow Ge$	0.69404
3.6476	$K_2GeF_6 \leftrightarrow Ge$	0.27415
	GOLD **Au = 196.967**	
0.64936	$Au \leftrightarrow AuCl_3$	1.5400
0.47826	$Au \leftrightarrow HAuCl_4 \cdot 4H_2O$	2.0909
0.54995	$Au \leftrightarrow KAu(CN)_4 \cdot H_2O$	1.8183
	HYDROGEN **H = 1.0079**	
8.9365	$H_2O \leftrightarrow H$	0.11190
7.9364	$O \leftrightarrow H$	0.12600
0.35607	$HSCN \leftrightarrow AgSCN$	2.8084

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	HYDROGEN (*continued*) **H = 1.0079**	
0.48586	HSCN ↔ CuSCN	2.0582
0.25317	HSCN ↔ $BaSO_4$	3.9499
	INDIUM **In = 114.82**	
1.2090	In_2O_3 ↔ In	0.82711
1.4189	In_2S_3 ↔ In	0.70476
	IODINE **I = 126.904**	
0.84333	Ag ↔ HI	1.1858
0.85004	Ag ↔ I	1.1764
1.1294	AgCl ↔ I	0.88543
1.8354	AgI ↔ HI	0.54483
1.8500	AgI ↔ I	0.54053
1.3423	AgI ↔ IO_3	0.74498
1.2298	AgI ↔ IO_4	0.81314
1.4066	AgI ↔ I_2O_5	0.71091
1.2836	AgI ↔ I_2O_7	0.77904
0.41592	Pd ↔ HI	2.4043
0.41921	Pd ↔ I	2.3854
1.4081	PdI_2 ↔ HI	0.71020
1.4192	PdI_2 ↔ I	0.70462
1.0297	PdI_2 ↔ IO_3	0.97113
0.94343	PdI_2 ↔ IO_4	1.0600
1.0791	PdI_2 ↔ I_2O_5	0.92671
0.98472	PdI_2 ↔ I_2O_7	1.0155
2.5899	TlI ↔ HI	0.38612
2.6105	TlI ↔ I	0.38307
1.8941	TlI ↔ IO_3	0.52797
1.7353	TlI ↔ IO_4	0.57627
1.9848	TlI ↔ I_2O_5	0.50383
1.8112	TlI ↔ I_2O_7	0.55211
	IRON **Fe = 55.845**	
2.2598	Ag ↔ $Fe_7(CN)_{18}$ (Prussian blue)	0.44252
0.54503	CN ↔ $Fe_7(CN)_{18}$	1.8347
0.61256	CO_2 ↔ FeO	1.6325
0.37986	CO_2 ↔ $FeCO_3$	2.6326
0.49483	CO_2 ↔ $Fe(HCO_3)_2$	2.0209
0.31396	Fe ↔ $Fe(HCO_3)_2$	3.1851
0.44061	Fe ↔ $FeCl_2$	2.2696
0.77730	Fe ↔ FeO	1.2865
0.69943	Fe ↔ Fe_2O_3	1.4297
0.72359	Fe ↔ Fe_3O_4	1.3820
0.36763	Fe ↔ $FeSO_4$	2.7201
0.20087	Fe ↔ $FeSO_4 \cdot 7H_2O$	4.9782
0.14242	Fe ↔ $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$	7.0217
0.62011	FeO ↔ $FeCO_3$	1.6126

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	IRON (*continued*) **Fe = 55.845**	
0.40390	$FeO \leftrightarrow Fe(HCO_3)_2$	2.4759
0.89982	$FeO \leftrightarrow Fe_2O_3$	1.1113
0.49223	$Fe_2O_3 \leftrightarrow FeCl_2$	2.0316
0.68915	$Fe_2O_3 \leftrightarrow FeCO_3$	1.4511
0.44887	$Fe_2O_3 \leftrightarrow Fe(HCO_3)_2$	2.2278
0.33422	$Fe_2O_3 \leftrightarrow Fe(HCO_3)_3$	2.9920
1.1113	$Fe_2O_3 \leftrightarrow FeO$	0.89982
1.0345	$Fe_2O_3 \leftrightarrow Fe_3O_4$	0.96662
0.52941	$Fe_2O_3 \leftrightarrow FePO_4$	1.8889
0.52561	$Fe_2O_3 \leftrightarrow FeSO_4$	1.9026
0.28719	$Fe_2O_3 \leftrightarrow FeSO_4 \cdot 7H_2O$	3.4820
0.20361	$Fe_2O_3 \leftrightarrow FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$	4.9113
0.39934	$Fe_2O_3 \leftrightarrow Fe_2(SO_4)_3$	2.5041
2.7006	$FePO_4 \leftrightarrow Fe$	0.37029
2.0992	$FePO_4 \leftrightarrow FeO$	0.47637
1.5741	$FeS \leftrightarrow Fe$	0.63527
1.2236	$FeS \leftrightarrow FeO$	0.81726
1.1010	$FeS \leftrightarrow Fe_2O_3$	0.90825
0.79699	$Mg_2As_2O_7 \leftrightarrow FeAsO_4$	1.2547
1.1144	$SO_3 \leftrightarrow FeO$	0.89738
0.52704	$SO_3 \leftrightarrow FeSO_4$	1.8974
	LANTHANUM **La = 138.91**	
1.1728	$La_2O_3 \leftrightarrow La$	0.85268
	LEAD **Pb = 207.2**	
0.77541	$Pb \leftrightarrow PbCO_3$	1.2896
0.80141	$Pb \leftrightarrow (PbCO_3)_2 \cdot Pb(OH)_2$	1.2478
0.85901	$Pb \leftrightarrow Pb(OH)_2$	1.1641
0.92831	$Pb \leftrightarrow PbO$	1.0772
1.3422	$PbCl_2 \leftrightarrow Pb$	0.74502
1.2460	$PbCl_2 \leftrightarrow PbO$	0.80255
1.5598	$PbCrO_4 \leftrightarrow Pb$	0.64110
0.85198	$PbCrO_4 \leftrightarrow Pb(C_2H_3O_2)_2 \cdot 3H_2O$	1.1737
1.2501	$PbCrO_4 \leftrightarrow (PbCO_3)_2 \cdot Pb(OH)_2$	0.79997
1.4480	$PbCrO_4 \leftrightarrow PbO$	0.69061
1.4142	$PbCrO_4 \leftrightarrow Pb_3O_4$	0.70711
1.0657	$PbCrO_4 \leftrightarrow PbSO_4$	0.93833
0.83529	$PbO \leftrightarrow PbCO_3$	1.1972
0.67388	$PbO \leftrightarrow Pb(NO_3)_2$	1.4839
0.93311	$PbO \leftrightarrow PbO_2$	1.0717
1.1544	$PbO_2 \leftrightarrow Pb$	0.86622
0.72219	$PbO_2 \leftrightarrow Pb(NO_3)_2$	1.3847
1.1547	$PbS \leftrightarrow Pb$	0.86600
1.0720	$PbS \leftrightarrow PbO$	0.93287
0.78895	$PbS \leftrightarrow PbSO_4$	1.2675
1.2993	$PbSO_4 \leftrightarrow BaSO_4$	0.76966
1.4636	$PbSO_4 \leftrightarrow Pb$	0.68323

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	LEAD (*continued*) **Pb = 207.2**	
0.79944	$PbSO_4 \leftrightarrow Pb(C_2H_3O_2)_2 \cdot 3H_2O$	1.2509
1.1349	$PbSO_4 \leftrightarrow PbCO_3$	0.88112
1.1730	$PbSO_4 \leftrightarrow (PbCO_3)_2 \cdot Pb(OH)_2$	0.85254
0.91561	$PbSO_4 \leftrightarrow Pb(NO_3)_2$	1.0922
1.3587	$PbSO_4 \leftrightarrow PbO$	0.73599
1.2678	$PbSO_4 \leftrightarrow PbO_2$	0.78875
1.3270	$PbSO_4 \leftrightarrow Pb_3O_4$	0.75358
	LITHIUM **Li = 6.941**	
0.59562	$CO_2 \leftrightarrow Li_2CO_3$	1.6789
0.64759	$CO_2 \leftrightarrow LiHCO_3$	1.5442
1.4729	$CO_2 \leftrightarrow Li_2O$	0.67894
6.1086	$LiCl \leftrightarrow Li$	0.16369
2.8378	$LiCl \leftrightarrow Li_2O$	0.35239
5.3228	$Li_2CO_3 \leftrightarrow Li$	0.18787
0.87147	$Li_2CO_3 \leftrightarrow LiCl$	1.1475
0.54364	$Li_2CO_3 \leftrightarrow LiHCO_3$	1.8395
2.4730	$Li_2CO_3 \leftrightarrow Li_2O$	0.40436
4.5491	$LiHCO_3 \leftrightarrow Li_2O$	0.21983
3.7371	$LiF \leftrightarrow Li$	0.26759
2.1525	$Li_2O \leftrightarrow Li$	0.46457
0.27176	$Li_2O \leftrightarrow Li_2SO_4$	3.6798
5.5609	$Li_2PO_4 \leftrightarrow Li$	0.17983
0.91047	$Li_3PO_4 \leftrightarrow LiCl$	1.0983
1.0447	$Li_3PO_4 \leftrightarrow Li_2CO_3$	0.95717
0.56797	$Li_3PO_4 \leftrightarrow LiHCO_3$	1.7607
2.5837	$Li_3PO_4 \leftrightarrow Li_2O$	0.38704
0.70214	$Li_3PO_4 \leftrightarrow Li_2SO_4$	1.4242
0.60331	$Li_3PO_4 \leftrightarrow Li_2SO_4 \cdot H_2O$	1.6575
7.9153	$Li_2SO_4 \leftrightarrow Li$	0.12634
1.2967	$Li_2SO_4 \leftrightarrow LiCl$	0.77118
2.6797	$SO_3 \leftrightarrow Li_2O$	0.37317
0.72823	$SO_3 \leftrightarrow Li_2SO_4$	1.3732
	MAGNESIUM **Mg = 24.305**	
1.9390	$BaSO_4 \leftrightarrow MgSO_4$	0.51572
0.94693	$BaSO_4 \leftrightarrow MgSO_4 \cdot 7H_2O$	1.0560
6.5755	$Br \leftrightarrow Mg$	0.15208
0.86800	$Br \leftrightarrow MgBr_2$	1.1521
0.54691	$Br \leftrightarrow MgBr_2 \cdot 6H_2O$	1.8285
2.9173	$Cl \leftrightarrow Mg$	0.34278
0.74472	$Cl \leftrightarrow MgCl_2$	1.3429
0.25533	$Mg \leftrightarrow MgCl_2$	3.9165
0.28883	$Mg \leftrightarrow MgCO_3$	3.4683
10.4427	$I \leftrightarrow Mg$	0.095761
0.91261	$I \leftrightarrow MgI_2$	1.09576
0.34876	$Cl \leftrightarrow MgCl_2 \cdot 6H_2O$	2.8673
0.52193	$CO_2 \leftrightarrow MgCO_3$	1.9160

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	MAGNESIUM (*continued*) **Mg = 24.305**	
1.0918	$CO_2 \leftrightarrow MgO$	0.91595
0.57616	$MgCO_3 \leftrightarrow Mg(HCO_3)_2$	1.7356
10.094	$MgNH_4PO_4 \cdot 6H_2O \leftrightarrow Mg$	0.099067
6.0879	$MgNH_4PO_4 \cdot 6H_2O \leftrightarrow MgO$	0.16426
1.6581	$MgO \leftrightarrow Mg$	0.60311
0.47807	$MgO \leftrightarrow MgCO_3$	2.0918
0.27544	$MgO \leftrightarrow Mg(HCO_3)_2$	3.6305
0.33489	$MgO \leftrightarrow MgSO_4$	2.9860
4.5784	$Mg_2P_2O_7 \leftrightarrow Mg$	0.21841
1.1687	$Mg_2P_2O_7 \leftrightarrow MgCl_2$	0.85562
0.54737	$Mg_2P_2O_7 \leftrightarrow MgCl_2 \cdot 6H_2O$	1.8269
0.40049	$Mg_2P_2O_7 \leftrightarrow MgCl_2 \cdot KCl \cdot 6H_2O$	2.4969
1.3198	$Mg_2P_2O_7 \leftrightarrow MgCO_3$	0.75770
0.76040	$Mg_2P_2O_7 \leftrightarrow Mg(HCO_3)_2$	1.3151
2.7607	$Mg_2P_2O_7 \leftrightarrow MgO$	0.36223
0.92452	$Mg_2P_2O_7 \leftrightarrow MgSO_4$	1.0816
0.45150	$Mg_2P_2O_7 \leftrightarrow MgSO_4 \cdot 7H_2O$	2.2149
4.9523	$MgSO_4 \leftrightarrow Mg$	0.20193
1.9864	$SO_3 \leftrightarrow MgO$	0.50343
0.6651	$SO_3 \leftrightarrow MgSO_4$	1.5034
0.38482	$SO_3 \leftrightarrow MgSO_4 \cdot 7H_2O$	3.0786
	MANGANESE **Mn = 54.9380**	
1.5457	$BaSO_4 \leftrightarrow MnSO_4$	0.64696
0.38286	$CO_2 \leftrightarrow MnCO_3$	2.6119
0.62041	$CO_2 \leftrightarrow MnO$	1.6118
0.47793	$Mn \leftrightarrow MnCO_3$	2.0924
0.77446	$Mn \leftrightarrow MnO$	1.2912
0.63193	$Mn \leftrightarrow MnO_2$	1.5825
0.69599	$Mn \leftrightarrow Mn_2O_3$	1.4368
0.76126	$MnCO_3 \leftrightarrow MnSO_4$	1.3136
1.5395	$Mn(HCO_3)_2 \leftrightarrow MnCO_3$	0.64955
0.61711	$MnO \leftrightarrow MnCO_3$	1.6205
0.40084	$MnO \leftrightarrow Mn(HCO_3)_2$	2.4947
0.89868	$MnO \leftrightarrow Mn_2O_3$	1.1127
0.46978	$MnO \leftrightarrow MnSO_4$	2.1286
1.3883	$Mn_3O_4 \leftrightarrow Mn$	0.72031
0.66351	$Mn_3O_4 \leftrightarrow MnCO_3$	1.5071
0.43098	$Mn_3O_4 \leftrightarrow Mn(HCO_3)_2$	2.3203
1.0752	$Mn_3O_4 \leftrightarrow MnO$	0.93008
0.96625	$Mn_3O_4 \leftrightarrow Mn_2O_3$	1.0349
0.87731	$Mn_3O_4 \leftrightarrow MnO_2$	1.1399
0.50510	$Mn_3O_4 \leftrightarrow MnSO_4$	1.9798
2.5831	$Mn_2P_2O_7 \leftrightarrow Mn$	0.38713
1.2345	$Mn_2P_2O_7 \leftrightarrow MnCO_3$	0.81002
2.0005	$Mn_2P_2O_7 \leftrightarrow MnO$	0.49987
1.6324	$Mn_2P_2O_7 \leftrightarrow MnO_2$	0.61261
0.93980	$Mn_2P_2O_7 \leftrightarrow MnSO_4$	1.0641
1.5836	$MnS \leftrightarrow Mn$	0.63146

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	MANGANESE (*continued*) **Mn = 54.9380**	
0.75687	$MnS \leftrightarrow MnCO_3$	1.3212
1.2265	$MnS \leftrightarrow MnO$	0.81535
0.57617	$MnS \leftrightarrow MnSO_4$	1.7356
2.7486	$MnSO_4 \leftrightarrow Mn$	0.36383
1.1286	$SO_3 \leftrightarrow MnO$	0.88603
0.53021	$SO_3 \leftrightarrow MnSO_4$	1.8860
	MERCURY **Hg = 200.59**	
0.73882	$Hg \leftrightarrow HgCl_2$	1.3535
0.92613	$Hg \leftrightarrow HgO$	1.0798
0.86220	$Hg \leftrightarrow HgS$	1.1598
1.1767	$HgCl \leftrightarrow Hg$	0.84981
0.86939	$HgCl \leftrightarrow HgCl_2$	1.1502
0.89889	$HgCl \leftrightarrow HgNO_3$	1.1125
1.1316	$HgCl \leftrightarrow Hg_2O$	0.88371
1.0898	$HgCl \leftrightarrow HgO$	0.91760
1.0146	$HgCl \leftrightarrow HgS$	0.98564
0.98564	$HgS \leftrightarrow HgCl$	1.0146
0.85691	$HgS \leftrightarrow HgCl_2$	1.1670
0.92091	$HgS \leftrightarrow Hg(CN)_2$	1.0859
0.88598	$HgS \leftrightarrow HgNO_3$	1.1287
0.71673	$HgS \leftrightarrow Hg(NO_3)_2$	1.3952
0.67903	$HgS \leftrightarrow Hg(NO_3)_2 \cdot H_2O$	1.4727
1.1153	$HgS \leftrightarrow Hg_2O$	0.89658
1.0741	$HgS \leftrightarrow HgO$	0.93097
0.78426	$HgS \leftrightarrow HgSO_4$	1.2751
	MOLYBDENUM **Mo = 95.94**	
8.9876	$MoC \leftrightarrow C$	0.11126
1.5003	$MoO_3 \leftrightarrow Mo$	0.66653
0.73436	$MoO_3 \leftrightarrow (NH_4)_2MoO_4$	1.3617
2.0026	$MoS_3 \leftrightarrow Mo$	0.49935
1.3348	$MoS_4 \leftrightarrow MoO_3$	0.74918
0.98021	$MoS_3 \leftrightarrow (NH_4)_2MoO_4$	1.0202
1.0863	$(NH_4)_3PO_4 \cdot 12MoO_3 \leftrightarrow MoO_3$	0.92058
0.79771	$(NH_4)_3PO_4 \cdot 12MoO_3 \leftrightarrow (NH_4)_2MoO_4$	1.2536
3.8267	$PbMoO_4 \leftrightarrow Mo$	0.26132
2.5506	$PbMoO_4 \leftrightarrow MoO_3$	0.39207
1.8730	$PbMoO_4 \leftrightarrow (NH_4)_2MoO_4$	0.53390
	NEODYMIUM **Nd = 144.24**	
1.1664	$Nd_2O_3 \leftrightarrow Nd$	0.85735
	NICKEL **Ni = 58.71**	
0.20319	Ni ↔ Ni dimethylglyoxime	4.9215
0.20188	$Ni \leftrightarrow Ni(NO_3)_2 \cdot 6H_2O$	4.9533

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	NICKEL (*continued*) **Ni = 58.71**	
0.78585	$Ni \leftrightarrow NiO$	1.2725
0.20902	$Ni \leftrightarrow NiSO_4 \cdot 7H_2O$	4.7842
3.8675	Ni dimethylglyoxime $\leftrightarrow$ NiO	0.25856
0.25690	$NiO \leftrightarrow Ni(NO_3)_2 \cdot 6H_2O$	3.8926
0.26598	$NiO \leftrightarrow NiSO_4 \cdot 7H_2O$	3.7597
2.6362	$NiSO_4 \leftrightarrow Ni$	0.37934
0.53220	$NiSO_4 \leftrightarrow Ni(NO_3)_2 \cdot 6H_2O$	1.8790
2.0716	$NiSO_4 \leftrightarrow NiO$	0.48271
0.55102	$NiSO_4 \leftrightarrow NiSO_4 \cdot 7H_2O$	1.8148
	NIOBIUM **Nb = 92.906**	
7.7351	$Nb \leftrightarrow C$	0.12928
8.7353	$NbC \leftrightarrow C$	0.11448
11.065	$Nb_2O_5 \leftrightarrow 2C$	0.090373
1.4305	$Nb_2O_5 \leftrightarrow Nb$	0.69904
	NITROGEN **N = 14.0067**	
3.2731	$AgNO_2 \leftrightarrow HNO_2$	0.30552
4.0488	$AgNO_2 \leftrightarrow N_2O_3$	0.24698
1.8722	$KNO_3 \leftrightarrow N_2O_5$	053412
0.22229	$N \leftrightarrow HNO_3$	4.4987
0.30446	$N \leftrightarrow NO_2$	3.2845
0.36855	$N \leftrightarrow N_2O_3$	2.7134
0.22590	$N \leftrightarrow NO_3$	4.4268
0.25936	$N \leftrightarrow N_2O_5$	3.8556
6.0680	$NaNO_3 \leftrightarrow N$	0.16480
1.5738	$NaNO_3 \leftrightarrow N_2O_5$	0.63539
0.47619	$NO \leftrightarrow HNO_3$	2.1000
0.65222	$NO \leftrightarrow NO_2$	1.5332
0.78951	$NO \leftrightarrow N_2O_3$	1.2666
0.48393	$NO \leftrightarrow NO_3$	2.0664
0.55561	$NO \leftrightarrow N_2O_5$	1.7998
0.27028	$NH_3 \leftrightarrow HNO_3$	3.6999
1.2159	$NH_3 \leftrightarrow N$	0.82244
0.31536	$NH_3 \leftrightarrow N_2O_5$	3.1710
0.27467	$NH_3 \leftrightarrow NO_3$	3.6407
0.84890	$NH_4Cl \leftrightarrow HNO_3$	1.1780
0.86270	$NH_4Cl \leftrightarrow NO_3$	1.1591
0.99050	$NH_4Cl \leftrightarrow N_2O_5$	1.0096
3.8189	$NH_4Cl \leftrightarrow N$	0.26185
3.5221	$(NH_4)_2PtCl_6 \leftrightarrow HNO_3$	0.28393
15.845	$(NH_4)_2PtCl_6 \leftrightarrow N$	0.063112
4.1096	$(NH_4)_2PtCl_6 \leftrightarrow N_2O_6$	0.24333
3.5794	$(NH_4)_2PtCl_6 \leftrightarrow NO_3$	0.27938
4.7169	$(NH_4)_2SO_4 \leftrightarrow N$	0.21200
1.2234	$(NH_4)_2SO_4 \leftrightarrow N_2O_5$	0.81739
1.5480	$Pt \leftrightarrow HNO_3$	0.64599
6.9640	$Pt \leftrightarrow N$	0.14360

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	NITROGEN (*continued*) **N = 14.0067**	
1.5732	$Pt \leftrightarrow NO_3$	0.63566
1.8062	$Pt \leftrightarrow N_2O_5$	0.55364
0.63528	$SO_3 \leftrightarrow HNO_3$	1.5741
2.8579	$SO_3 \leftrightarrow N$	0.34990
0.74125	$SO_3 \leftrightarrow N_2O_5$	1.3491
	OSMIUM **Os = 190.2**	
1.3365	$OsO_4 \leftrightarrow Os$	0.74823
	PALLADIUM **Pd = 106.4**	
0.49873	$Pd \leftrightarrow PdCl_2 \cdot 2H_2O$	2.0051
0.46179	$Pd \leftrightarrow Pd(NO_3)_2$	2.1655
3.3854	$PdI_2 \leftrightarrow Pd$	0.29538
3.7342	$K_2PdCl_6 \leftrightarrow Pd$	0.26779
1.8624	$K_2PdCl_6 \leftrightarrow PdCl_2 \cdot 2H_2O$	0.53695
	PHOSPHORUS **P = 30.9738**	
13.514	$Ag_3PO_4 \leftrightarrow P$	0.073998
4.4075	$Ag_3PO_4 \leftrightarrow PO_4$	0.22689
5.8980	$Ag_3PO_4 \leftrightarrow P_2O_5$	0.16955
9.7730	$Ag_4P_2O_7 \leftrightarrow P$	0.10232
3.1874	$Ag_4P_2O_7 \leftrightarrow PO_4$	0.31374
4.2653	$Ag_4P_2O_7 \leftrightarrow P_2O_5$	0.23445
0.71833	$Al_2O_3 \leftrightarrow P_2O_5$	1.3921
1.2841	$AlPO_4 \leftrightarrow PO_4$	0.77877
1.7183	$AlPO_4 \leftrightarrow P_2O_5$	0.58196
2.1853	$Ca_3(PO_4)_2 \leftrightarrow P_2O_5$	0.45761
1.5881	$FePO_4 \leftrightarrow PO_4$	0.62970
2.1251	$FePO_4 \leftrightarrow P_2O_5$	0.47056
0.78392	$Mg_2P_2O_7 \leftrightarrow Na_2HPO_4$	1.2756
0.31073	$Mg_2P_2O_7 \leftrightarrow Na_2HPO_4 \cdot 12H_2O$	3.2182
0.53229	$Mg_2P_2O_7 \leftrightarrow NaNH_4HPO_4 \cdot 4H_2O$	1.8787
3.5929	$Mg_2P_2O_7 \leftrightarrow P$	0.27833
1.1718	$Mg_2P_2O_7 \leftrightarrow PO_4$	0.85340
1.5681	$Mg_2P_2O_7 \leftrightarrow P_2O_5$	0.63773
60.577	$(NH_4)_3PO_4 \cdot 12MoO_3 \leftrightarrow P$	0.016508
19.757	$(NH_4)_3PO_4 \cdot 12MoO_3 \leftrightarrow PO_4$	0.050616
26.438	$(NH_4)_3PO_4 \cdot 12MoO_3 \leftrightarrow P_2O_5$	0.037824
0.63773	$P_2O_5 \leftrightarrow Mg_2P_2O_7$	1.5681
0.49993	$P_2O_5 \leftrightarrow Na_2HPO_4$	2.0003
0.19816	$P_2O_5 \leftrightarrow Na_2HPO_4 \cdot 12H_2O$	5.0464
0.33946	$P_2O_5 \leftrightarrow NaNH_4HPO_4 \cdot 4H_2O$	2.9459
2.2913	$P_2O_5 \leftrightarrow P$	0.43644
58.057	$P_2O_5 \cdot 24MoO_3 \leftrightarrow P$	0.017225
18.935	$P_2O_5 \cdot 24MoO_3 \leftrightarrow PO_4$	0.052813
25.338	$P_2O_5 \cdot 24MoO_3 \leftrightarrow P_2O_5$	0.039466
11.526	$U_2P_2O_{11} \leftrightarrow P$	0.086762

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	PHOSPHORUS (*continued*) **P = 30.9738**	
3.7590	$U_2P_2O_{11} \leftrightarrow PO_4$	0.26603
5.0303	$U_2P_2O_{11} \leftrightarrow P_2O_5$	0.19880
	PLATINUM **Pt = 195.09**	
0.93839	$K_2PtCl_6 \leftrightarrow H_2PtCl_6 \cdot 6H_2O$	1.0657
2.4912	$K_2PtCl_6 \leftrightarrow Pt$	0.40141
1.4426	$K_2PtCl_6 \leftrightarrow PtCl_4$	0.69320
1.1383	$K_2PtCl_6 \leftrightarrow PtCl_4 \cdot 5H_2O$	0.87854
2.2753	$(NH_4)_2PtCl_6 \leftrightarrow Pt$	0.43950
1.3176	$(NH_4)_2PtCl_6 \leftrightarrow PtCl_4$	0.75897
1.0885	$(NH_4)_2PtCl_6 \leftrightarrow PtCl_6$	0.91872
0.37668	$Pt \leftrightarrow H_2PtCl_6 \cdot 6H_2O$	2.6548
0.57907	$Pt \leftrightarrow PtCl_4$	1.7269
0.45691	$Pt \leftrightarrow PtCl_4 \cdot 5H_2O$	2.1886
	POTASSIUM **K = 39.098**	
0.90639	$Ag \leftrightarrow KBr$	1.1033
1.4469	$Ag \leftrightarrow KCl$	0.69116
0.88021	$Ag \leftrightarrow KClO_3$	1.1361
0.77856	$Ag \leftrightarrow KClO_4$	1.2844
1.6565	$Ag \leftrightarrow KCN$	0.60369
0.64978	$Ag \leftrightarrow Kl$	1.5390
1.5779	$AgBr \leftrightarrow KBr$	0.63377
1.1244	$AgBr \leftrightarrow KBrO_3$	0.88939
1.9223	$AgCl \leftrightarrow KCl$	0.52020
1.1695	$AgCl \leftrightarrow KClO_3$	0.85508
1.0344	$AgCl \leftrightarrow KClO_4$	0.96672
2.0561	$AgCN \leftrightarrow KCN$	0.48637
1.4142	$AgI \leftrightarrow Kl$	0.70712
1.0971	$AgI \leftrightarrow KlO_3$	0.91153
1.3045	$BaCrO_4 \leftrightarrow K_2CrO_4$	0.76659
1.7222	$BaCrO_4 \leftrightarrow K_2Cr_2O_7$	0.58065
1.7140	$BaSO_4 \leftrightarrow KHSO_4$	0.58342
2.1166	$BaSO_4 \leftrightarrow K_2S$	0.47245
1.3393	$BaSO_4 \leftrightarrow K_2SO_4$	0.74666
2.0436	$Br \leftrightarrow K$	0.48933
0.67145	$Br \leftrightarrow KBr$	1.4893
0.41473	$CaF_2 \leftrightarrow KF \cdot 2H_2O$	2.4112
0.72315	$CaSO_4 \leftrightarrow KF \cdot 2H_2O$	1.3828
0.90668	$Cl \leftrightarrow K$	1.1029
0.47553	$Cl \leftrightarrow KCl$	2.1029
0.28929	$Cl \leftrightarrow KClO_3$	3.4567
0.25589	$Cl \leftrightarrow KClO_4$	3.9080
0.75269	$Cl \leftrightarrow K_2O$	1.3286
0.46718	$CO_2 \leftrightarrow K_2O$	2.1405
0.31843	$CO_2 \leftrightarrow K_2CO_3$	3.1404
0.76441	$I \leftrightarrow Kl$	1.3082
0.59299	$I \leftrightarrow KlO_3$	1.6864

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	POTASSIUM (*continued*) **K = 39.098**	
0.31907	$K \leftrightarrow KClO_3$	3.1341
0.83016	$K \leftrightarrow K_2O$	1.2046
0.38673	$K \leftrightarrow KNO_3$	2.5858
3.0436	$KBr \leftrightarrow K$	0.32856
2.5267	$KBr \leftrightarrow K_2O$	0.39578
1.9067	$KCl \leftrightarrow K$	0.52447
1.0789	$KCl \leftrightarrow K_2CO_3$	0.92690
0.50685	$KCl \leftrightarrow K_2Cr_2O_7$	1.9730
0.74466	$KCl \leftrightarrow KHCO_3$	1.3429
0.73737	$KCl \leftrightarrow KNO_3$	1.3562
1.5829	$KCl \leftrightarrow K_2O$	0.63177
0.85563	$KCl \leftrightarrow K_2SO_4$	1.1687
1.6437	$KClO_3 \leftrightarrow KCl$	0.60836
3.5433	$KClO_4 \leftrightarrow K$	0.28222
1.8584	$KClO_4 \leftrightarrow KCl$	0.53811
2.9415	$KClO_4 \leftrightarrow K_2O$	0.33996
4.2456	$Kl \leftrightarrow K$	0.23554
3.5245	$Kl \leftrightarrow K_2O$	0.28373
0.38435	$K_2O \leftrightarrow KClO_3$	2.6018
0.68159	$K_2O \leftrightarrow K_2CO_3$	1.4672
0.32021	$K_2O \leftrightarrow K_2Cr_2O_7$	3.1229
0.47045	$K_2O \leftrightarrow KHCO_3$	2.1256
0.46584	$K_2O \leftrightarrow KNO_3$	2.1466
0.81194	$KOH \leftrightarrow K_2CO_3$	1.2316
1.1912	$KOH \leftrightarrow K_2O$	0.83946
6.2146	$K_2PtCl_6 \leftrightarrow K$	0.16091
3.5165	$K_2PtCl_6 \leftrightarrow K_2CO_3$	0.28438
3.2594	$K_2PtCl_6 \leftrightarrow KCl$	0.30680
2.4271	$K_2PtCl_6 \leftrightarrow KHCO_3$	0.41201
2.4034	$K_2PtCl_6 \leftrightarrow KNO_3$	0.41608
5.1592	$K_2PtCl_6 \leftrightarrow K_2O$	0.19383
2.7888	$K_2PtCl_6 \leftrightarrow K_2SO_4$	0.35857
0.51224	$K_2PtCl_6 \leftrightarrow K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$	1.9522
0.48659	$K_2PtCl_6 \leftrightarrow K_2SO_4 \cdot Cr_2(SO_4)_3 \cdot 24H_2O$	2.0551
1.2609	$K_2SO_4 \leftrightarrow K_2CO_3$	0.79308
0.87031	$K_2SO_4 \leftrightarrow KHCO_3$	1.1490
0.63990	$K_2SO_4 \leftrightarrow KHSO_4$	1.5627
1.0238	$K_2SO_4 \leftrightarrow KNO_2$	0.97674
0.86179	$K_2SO_4 \leftrightarrow KNO_3$	1.1604
2.2285	$K_2SO_4 \leftrightarrow K$	0.44875
1.8499	$K_2SO_4 \leftrightarrow K_2O$	0.54056
1.5804	$K_2SO_4 \leftrightarrow K_2S$	0.63275
0.60582	$Mg_2As_2O_7 \leftrightarrow K_3AsO_4$	1.6506
0.71164	$Mg_2As_2O_7 \leftrightarrow K_2HAsO_4$	1.4052
0.40040	$Mn_2O_3 \leftrightarrow K_2MnO_4$	2.4975
0.49946	$Mn_2O_3 \leftrightarrow KMnO_4$	2.0022
0.44132	$MnS \leftrightarrow K_2MnO_4$	2.2659
0.55051	$MnS \leftrightarrow KMnO_4$	1.8165
0.13853	$N \leftrightarrow KNO_3$	7.2185
0.16844	$NH_3 \leftrightarrow KNO_3$	5.9368

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	POTASSIUM (*continued*) **K = 39.098**	
0.29677	$NO \leftrightarrow KNO_3$	3.3697
0.44656	$N_2O_3 \leftrightarrow KNO_2$	2.2393
1.1466	$N_2O_5 \leftrightarrow K_2O$	0.87217
0.53412	$N_2O_5 \leftrightarrow KNO_3$	1.8722
2.4946	$Pt \leftrightarrow K$	0.40086
1.3084	$Pt \leftrightarrow KCl$	0.76431
2.0710	$Pt \leftrightarrow K_2O$	0.48287
0.38943	$SiO_2 \leftrightarrow K_2SiO_3$	2.5679
0.45941	$SO_3 \leftrightarrow K_2SO_4$	2.1767
	PRASEODYMIUM **Pr = 140.908**	
1.1703	$Pr_2O_3 \leftrightarrow Pr$	0.85449
	RHODIUM **Rh = 102.905**	
0.26758	$Rh \leftrightarrow Na_3RhCl_6$	3.7372
0.49178	$Rh \leftrightarrow RhCl_3$	2.0334
	RUBIDIUM **Rb = 85.468**	
1.6768	$AgCl \leftrightarrow Rb$	0.59636
1.1852	$AgCl \leftrightarrow RbCl$	0.84371
0.41480	$Cl \leftrightarrow Rb$	2.4108
0.29319	$Cl \leftrightarrow RbCl$	3.4107
0.70683	$Rb \leftrightarrow RbCl$	1.4148
0.74016	$Rb \leftrightarrow Rb_2CO_3$	1.3511
0.91441	$Rb \leftrightarrow Rb_2O$	1.0936
0.64023	$Rb \leftrightarrow Rb_2SO_4$	1.5620
1.0472	$RbCl \leftrightarrow Rb_2CO_3$	0.95497
0.90577	$RbCl \leftrightarrow Rb_2SO_4$	1.1040
2.1636	$RbClO_4 \leftrightarrow Rb$	0.46220
0.78828	$Rb_2CO_3 \leftrightarrow RbHCO_3$	1.2686
0.77299	$Rb_2O \leftrightarrow RbCl$	1.2937
0.70015	$Rb_2O \leftrightarrow Rb_2SO_4$	1.4283
3.3857	$Rb_2PtCl_6 \leftrightarrow Rb$	0.29536
2.3931	$Rb_2PtCl_6 \leftrightarrow RbCl$	0.41787
2.5060	$Rb_2PtCl_6 \leftrightarrow Rb_2CO_3$	0.39905
1.9754	$Rb_2PtCl_6 \leftrightarrow RbHCO_3$	0.50623
3.0959	$Rb_2PtCl_6 \leftrightarrow Rb_2O$	0.32301
1.1561	$Rb_2SO_4 \leftrightarrow Rb_2CO_3$	0.86498
0.91133	$Rb_2SO_4 \leftrightarrow RbHCO_3$	1.0973
	SELENIUM **Se = 78.96**	
0.61224	$Se \leftrightarrow H_2SeO_3$	1.6334
0.54466	$Se \leftrightarrow H_2SeO_4$	1.8360
0.71161	$Se \leftrightarrow SeO_2$	1.4053
0.62193	$Se \leftrightarrow SeO_3$	1.6079

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	SILICON **Si = 28.086**	
2.6847	$BaSiF_6 \leftrightarrow SiF_4$	0.37249
4.6504	$BaSiF_6 \leftrightarrow SiO_2$	0.21503
2.1163	$K_2SiF_6 \leftrightarrow SiF_4$	0.47249
3.6661	$K_2SiF_6 \leftrightarrow SiO_2$	0.27277
3.3384	$SiC \leftrightarrow C$	0.29954
0.91111	$SiC \leftrightarrow CO_2$	1.0976
0.76933	$SiO_2 \leftrightarrow H_2SiO_3$	1.2998
2.1393	$SiO_2 \leftrightarrow Si$	0.46744
0.57730	$SiO_2 \leftrightarrow SiF_4$	1.7322
0.78972	$SiO_2 \leftrightarrow SiO_3$	1.2663
0.65250	$SiO_2 \leftrightarrow SiO_4$	1.5326
1.6651	$SiO_2 \leftrightarrow Si_2O$	0.60057
0.62514	$SiO_2 \leftrightarrow Si(OH)_4$	1.5997
	SILVER **Ag = 107.868**	
0.63501	$Ag \leftrightarrow AgNO_3$	1.5748
0.93096	$Ag \leftrightarrow Ag_2O$	1.0742
1.7408	$AgBr \leftrightarrow Ag$	0.57445
1.3286	$AgCl \leftrightarrow Ag$	0.75265
0.84371	$AgCl \leftrightarrow AgNO_3$	1.1852
1.2369	$AgCl \leftrightarrow Ag_2O$	0.80847
1.7935	$AgCl \leftrightarrow Br$	0.55756
1.2412	$AgCN \leftrightarrow Ag$	0.80566
2.1764	$AgI \leftrightarrow Ag$	0.45947
1.2935	$Ag_3PO_4 \leftrightarrow Ag$	0.77311
1.4031	$Ag_4P_2O_7 \leftrightarrow Ag$	0.71269
0.74079	$Br \leftrightarrow Ag$	1.3499
0.42555	$Br \leftrightarrow AgBr$	2.3499
0.32866	$Cl \leftrightarrow Ag$	3.0426
0.24737	$Cl \leftrightarrow AgCl$	4.0425
1.1764	$I \leftrightarrow Ag$	0.85004
0.54053	$I \leftrightarrow AgI$	1.8500
	SODIUM **Na = 22.9898**	
1.0483	$Ag \leftrightarrow NaBr$	0.95393
1.8457	$Ag \leftrightarrow NaCl$	0.54179
0.71966	$Ag \leftrightarrow NaI$	1.3895
1.8249	$AgBr \leftrightarrow NaBr$	0.54798
2.4523	$AgCl \leftrightarrow NaCl$	0.40778
1.5663	$AgI \leftrightarrow NaI$	0.63845
1.9440	$BaSO_4 \leftrightarrow NaHSO_4$	0.51440
1.6905	$BaSO_4 \leftrightarrow NaHSO_4 \cdot H_2O$	0.59156
2.9906	$BaSO_4 \leftrightarrow Na_2S$	0.33438
1.8518	$BaSO_4 \leftrightarrow Na_2SO_3$	0.54002
0.92564	$BaSO_4 \leftrightarrow Na_2SO_3 \cdot 7H_2O$	1.0803
1.6432	$BaSO_4 \leftrightarrow Na_2SO_4$	0.60857
0.72442	$BaSO_4 \leftrightarrow Na_2SO_4 \cdot 10H_2O$	1.3804

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	SODIUM (*continued*) **Na = 22.9898**	
0.69198	$B_2O_3 \leftrightarrow Na_2B_4O_7$	1.4451
0.36510	$B_2O_3 \leftrightarrow Na_2B_4O_7 \cdot 10H_2O$	2.7389
3.4758	$Br \leftrightarrow Na$	0.28770
0.77657	$Br \leftrightarrow NaBr$	1.2877
2.5786	$Br \leftrightarrow Na_2O$	0.38781
0.94956	$CaCl_2 \leftrightarrow NaCl$	1.0531
0.94433	$CaCO_3 \leftrightarrow Na_2CO_3$	1.0590
0.92975	$CaF_2 \leftrightarrow NaF$	1.0756
0.52910	$CaO \leftrightarrow Na_2CO_3$	1.8900
1.2845	$CaSO_4 \leftrightarrow Na_2CO_3$	0.77854
1.5421	$Cl \leftrightarrow Na$	0.64846
0.60663	$Cl \leftrightarrow NaCl$	1.6485
1.1442	$Cl \leftrightarrow Na_2O$	0.87410
0.41520	$CO_2 \leftrightarrow Na_2CO_3$	2.4083
0.71008	$CO_2 \leftrightarrow Na_2O$	1.4083
1.2292	$H_3BO_3 \leftrightarrow Na_2B_4O_7$	0.81357
0.64853	$H_3BO_3 \leftrightarrow Na_2B_4O_7 \cdot 10H_2O$	1.5419
5.5198	$I \leftrightarrow Na$	0.18117
0.84662	$I \leftrightarrow NaI$	1.1812
4.0949	$I \leftrightarrow Na_2O$	0.24420
2.5029	$KBF_4 \leftrightarrow Na_2B_4O_7$	0.39954
1.3206	$KBF_4 \leftrightarrow Na_2B_4O_7 \cdot 10H_2O$	0.75724
0.91360	$Mg_2As_2O_7 \leftrightarrow Na_2HAsO_3$	1.0946
0.83497	$Mg_2As_2O_7 \leftrightarrow Na_2HAsO_4$	1.1976
0.81462	$MgCl_2 \leftrightarrow NaCl$	1.2276
0.67882	$Mg_2P_2O_7 \leftrightarrow Na_3PO_4$	1.4731
0.78392	$Mg_2P_2O_7 \leftrightarrow Na_2HPO_4$	1.2757
0.31073	$Mg_2P_2O_7 \leftrightarrow NaHPO_4 \cdot 12H_2O$	3.2182
0.53229	$Mg_2P_2O_7 \leftrightarrow NaNH_4 \cdot HPO_4 \cdot 4H_2O$	1.8787
0.49897	$Mg_2P_2O_7 \leftrightarrow Na_4P_2O_7 \cdot 10H_2O$	2.0041
4.4759	$NaBr \leftrightarrow Na$	0.22342
3.3205	$NaBr \leftrightarrow Na_2O$	0.30116
65.502	$NaOAc \cdot Mg(OAc)_2 \cdot UO_2(OAc)_2 \cdot 6½H_2O \leftrightarrow Na$	0.015267
14.635	Triple $MgOAc \leftrightarrow NaBr$	0.066331
28.416	Triple $MgOAc \leftrightarrow Na_2CO_3$	0.035192
25.768	Triple $MgOAc \leftrightarrow NaCl$	0.038809
17.926	Triple $MgOAc \leftrightarrow NaHCO_3$	0.055785
10.047	Triple $MgOAc \leftrightarrow NaI$	0.099535
37.650	Triple $MgOAc \leftrightarrow NaOH$	0.026560
48.594	Triple $MgOAc \leftrightarrow Na_2O$	0.020579
21.204	Triple $MgOAc \leftrightarrow Na_2SO_4$	0.047161
66.894	$NaOAc \cdot Zn(OAc)_2 \cdot UO_2(OAc)_2 \cdot 6H_2O \leftrightarrow Na$	0.014949
14.946	Triple $ZnOAc \leftrightarrow NaBr$	0.066909
29.020	Triple $ZnOAc \leftrightarrow Na_2CO_3$	0.034459
26.315	Triple $ZnOAc \leftrightarrow NaCl$	0.038002
18.307	Triple $ZnOAc \leftrightarrow NaHCO_3$	0.054624
10.260	Triple $ZnOAc \leftrightarrow NaI$	0.097464
38.451	Triple $ZnOAc \leftrightarrow NaOH$	0.026008
49.626	Triple $ZnOAc \leftrightarrow Na_2O$	0.020151
21.654	Triple $ZnOAc \leftrightarrow Na_2SO_4$	0.046180

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	SODIUM (*continued*) **Na = 22.9898**	
2.5421	$NaCl \leftrightarrow Na$	0.39337
1.1028	$NaCl \leftrightarrow Na_2CO_3$	0.90678
0.69569	$NaCl \leftrightarrow NaHCO_3$	1.4374
0.82337	$NaCl \leftrightarrow Na_2HPO_4$	1.2145
1.8859	$NaCl \leftrightarrow Na_2O$	0.53025
0.82291	$NaCl \leftrightarrow Na_2SO_4$	1.2152
0.74267	$NaClO_3 \leftrightarrow AgCl$	1.3465
1.8213	$NaClO_3 \leftrightarrow NaCl$	0.54907
0.85432	$NaClO_4 \leftrightarrow AgCl$	1.1705
2.0950	$NaClO_4 \leftrightarrow NaCl$	0.47732
2.3051	$Na_2CO_3 \leftrightarrow Na$	0.43381
0.63084	$Na_2CO_3 \leftrightarrow NaHCO_3$	1.5852
1.7101	$Na_2CO_3 \leftrightarrow Na_2O$	0.58476
1.3250	$Na_2CO_3 \leftrightarrow NaOH$	0.75473
3.6541	$NaHCO_3 \leftrightarrow Na$	0.27367
2.7108	$NaHCO_3 \leftrightarrow Na_2O$	0.36889
6.5198	$NaI \leftrightarrow Na$	0.15338
4.8368	$NaI \leftrightarrow Na_2O$	0.20675
1.3480	$Na_2O \leftrightarrow Na$	0.74186
0.43659	$Na_2O \leftrightarrow Na_2HPO_4$	2.2905
0.36460	$Na_2O \leftrightarrow NaNO_3$	2.7427
0.77480	$Na_2O \leftrightarrow NaOH$	1.2907
0.93653	$Na_4P_2O_7 \leftrightarrow Na_2HPO_4$	1.0678
0.37122	$Na_4P_2O_7 \leftrightarrow Na_2HPO_4 \cdot 12H_2O$	2.6938
3.0892	$Na_2SO_4 \leftrightarrow Na$	0.32371
1.3401	$Na_2SO_4 \leftrightarrow Na_2CO_3$	0.74620
0.49640	$Na_2SO_4 \leftrightarrow Na_2CO_3 \cdot 10H_2O$	2.0145
2.2917	$Na_2SO_4 \leftrightarrow Na_2O$	0.43635
0.16480	$N \leftrightarrow NaNO_3$	6.0680
0.20038	$NH_3 \leftrightarrow NaNO_3$	4.9906
0.081461	$NH_3 \leftrightarrow NaNH_4HPO_4 \cdot 4H_2O$	12.276
0.35303	$NO \leftrightarrow NaNO_3$	2.8326
0.63539	$N_2O_5 \leftrightarrow NaNO_3$	1.5738
1.7427	$N_2O_5 \leftrightarrow Na_2O$	0.57383
0.49993	$P_2O_5 \leftrightarrow Na_2HPO_4$	2.0003
0.19816	$P_2O_5 \leftrightarrow Na_2HPO_4 \cdot 12H_2O$	5.0464
0.33946	$P_2O_5 \leftrightarrow NaNH_4HPO_4 \cdot H_2O$	2.9459
0.61564	$SO_2 \leftrightarrow NaHSO_3$	1.6243
0.50828	$SO_2 \leftrightarrow Na_2SO_3$	1.9674
0.25407	$SO_2 \leftrightarrow Na_2SO_3 \cdot 7H_2O$	3.9360
1.2918	$SO_2 \leftrightarrow Na_2O$	0.77414
0.56366	$SO_2 \leftrightarrow Na_2SO_4$	1.7741
	STRONTIUM **Sr = 87.62**	
0.29811	$CO_2 \leftrightarrow SrCO_8$	3.3545
0.77265	$SO_3 \leftrightarrow SrO$	1.2942
0.43588	$SO_3 \leftrightarrow SrSO_4$	2.2942
0.41402	$Sr \leftrightarrow Sr(NO_3)_2$	2.4153
1.6849	$SrCO_3 \leftrightarrow Sr$	0.59351

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	STRONTIUM (*continued*) **Sr = 87.62**	
0.93124	$SrCO_3 \leftrightarrow SrCl_2$	1.0738
0.70424	$SrCO_3 \leftrightarrow Sr(HCO_3)_2$	1.4200
0.69759	$SrCO_3 \leftrightarrow Sr(NO_3)_2$	1.4335
1.1826	$SrO \leftrightarrow Sr$	0.84559
0.65363	$SrO \leftrightarrow SrCl_2$	1.5299
0.70189	$SrO \leftrightarrow SrCO_3$	1.4247
0.49430	$SrO \leftrightarrow Sr(HCO_3)_2$	2.0231
0.48963	$SrO \leftrightarrow Sr(NO_3)_2$	2.0424
2.0963	$SrSO_4 \leftrightarrow Sr$	0.47703
1.1586	$SrSO_4 \leftrightarrow SrCl_2$	0.86308
1.2442	$SrSO_4 \leftrightarrow SrCO_3$	0.80373
0.86793	$SrSO_4 \leftrightarrow Sr(NO_3)_2$	1.1522
1.7726	$SrSO_4 \leftrightarrow SrO$	0.56413
	SULFUR **S = 32.06**	
2.4064	$As_2S_3 \leftrightarrow H_2S$	0.41556
2.5577	$As_2S_3 \leftrightarrow S$	0.39097
3.8906	$BaSO_4 \leftrightarrow FeS_2$	0.25703
6.8486	$BaSO_4 \leftrightarrow H_2S$	0.14602
2.8436	$BaSO_4 \leftrightarrow H_2SO_3$	0.35166
2.3797	$BaSO_4 \leftrightarrow H_2SO_4$	0.42022
7.2792	$BaSO_4 \leftrightarrow S$	0.13738
3.6433	$BaSO_4 \leftrightarrow SO_2$	0.27448
2.9152	$BaSO_4 \leftrightarrow SO_3$	0.34302
2.4297	$BaSO_4 \leftrightarrow SO_4$	0.41158
4.2388	$CdS \leftrightarrow H_2S$	0.23591
4.5054	$CdS \leftrightarrow S$	0.22196
1.2250	$H_2SO_4 \leftrightarrow SO_3$	0.81631
1.6505	$(NH_4)_2SO_4 \leftrightarrow SO_3$	0.60589
1.3473	$(NH_4)_2SO_4 \leftrightarrow H_2SO_4$	0.74223
2.3492	$SO_3 \leftrightarrow H_2S$	0.42567
	TANTALUM **Ta = 180.948**	
0.81898	$Ta \leftrightarrow Ta_2O_5$	1.2210
0.50515	$Ta \leftrightarrow TaCl_5$	1.9796
16.065	$TaC \leftrightarrow C$	0.062246
1.0664	$TaC \leftrightarrow Ta$	0.93776
0.61680	$Ta_2O_5 \leftrightarrow TaCl_5$	1.6213
1.0376	$Ta_2O_5 \leftrightarrow Ta_2O_4$	0.96379
	TELLURIUM **Te = 127.60**	
0.65906	$Te \leftrightarrow H_2TeO_4$	1.5173
0.55565	$Te \leftrightarrow H_2TeO_4 \cdot 2H_2O$	1.7997
0.79950	$Te \leftrightarrow TeO_2$	1.2508
0.72665	$Te \leftrightarrow TeO_3$	1.3762
1.5645	$(TeO_2)_2SO_3 \leftrightarrow Te$	0.63918

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	THALLIUM **Tl = 204.37**	
0.87198	$Tl \leftrightarrow Tl_2CO_3$	1.1468
0.85218	$Tl \leftrightarrow TlCl$	1.1735
0.61693	$Tl \leftrightarrow Tll$	1.6209
0.76724	$Tl \leftrightarrow TlNO_3$	1.3034
0.96232	$Tl \leftrightarrow Tl_2O$	1.0391
1.2838	$Tl_2CrO_4 \leftrightarrow Tl$	0.77895
1.4750	$TlHSO_4 \leftrightarrow Tl$	0.67798
1.9977	$Tl_2PtCl_6 \leftrightarrow Tl$	0.50057
1.7024	$Tl_2PtCl_6 \leftrightarrow TlCl$	0.58740
1.7420	$Tl_2PtCl_6 \leftrightarrow Tl_2CO_3$	0.57406
1.2325	$Tl_2PtCl_6 \leftrightarrow TlI$	0.81139
1.5327	$Tl_2PtCl_6 \leftrightarrow TlNO_3$	0.65243
1.9225	$Tl_2PtCl_6 \leftrightarrow Tl_2O$	0.52017
1.6176	$Tl_2PtCl_6 \leftrightarrow Tl_2SO_4$	0.61821
1.2350	$Tl_2SO_4 \leftrightarrow Tl$	0.80971
	THORIUM **Th = 232.038**	
1.1379	$ThO_2 \leftrightarrow Th$	0.87881
0.70627	$ThO_2 \leftrightarrow ThCl_4$	1.4159
0.44893	$ThO_2 \leftrightarrow Th(NO_3)_4 \cdot 6H_2O$	2.2275
	TIN **Sn = 118.69**	
0.62600	$Sn \leftrightarrow SnCl_2$	1.5974
0.52604	$Sn \leftrightarrow SnCl_2 \cdot 2H_2O$	1.9010
0.45562	$Sn \leftrightarrow SnCl_4$	2.1948
0.32297	$Sn \leftrightarrow SnCl_4 \cdot (NH_4Cl)_2$	3.0962
0.88121	$Sn \leftrightarrow SnO$	1.1348
0.78764	$Sn \leftrightarrow SnO_2$	1.2696
0.79478	$SnO_2 \leftrightarrow SnCl_2$	1.2582
0.66786	$SnO_2 \leftrightarrow SnCl_2 \cdot 2H_2O$	1.4973
0.57846	$SnO_2 \leftrightarrow SnCl_4$	1.7287
0.41005	$SnO_2 \leftrightarrow SnCl_4 \cdot (NH_4Cl)_2$	2.4387
1.1188	$SnO_2 \leftrightarrow SnO$	0.89382
	TITANIUM **Ti = 47.867**	
2.1059	$K_2TiF_6 \leftrightarrow F$	0.47485
3.0699	$K_2TiF_6 \leftrightarrow K$	0.32574
2.0660	$K_2TiF_6 \leftrightarrow 2KF$	0.48403
1.2752	$K_2TiF_6 \leftrightarrow 2(KF \cdot 2H_2O)$	0.78421
5.0150	$K_2TiF_6 \leftrightarrow Ti$	0.19940
3.0057	$K_2TiF_6 \leftrightarrow TiO_2$	0.33270
3.9853	$Ti \leftrightarrow C$	0.25092
4.9853	$TiC \leftrightarrow C$	0.20059
1.2509	$TiC \leftrightarrow Ti$	0.79940
1.6299	$TiF_4 \leftrightarrow F$	0.61354
1.6685	$TiO_2 \leftrightarrow Ti$	0.59934

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	TUNGSTEN **W = 183.85**	
3.9348	$FeWO_4 \leftrightarrow Fe_3O_4$	0.25414
1.3099	$FeWO_4 \leftrightarrow WO_3$	0.76344
6.7515	$MgWO_4 \leftrightarrow MgO$	0.14812
1.1739	$MgWO_4 \leftrightarrow WO_3$	0.85189
4.2684	$MnWO_4 \leftrightarrow MnO$	0.23428
1.3060	$MnWO_4 \leftrightarrow WO_3$	0.76571
2.0387	$PbWO_4 \leftrightarrow PbO$	0.49051
2.4751	$PbWO_4 \leftrightarrow W$	0.40403
1.9626	$PbWO_4 \leftrightarrow WO_3$	0.50952
15.307	$W \leftrightarrow C$	0.065330
0.96837	$W \leftrightarrow W_2C$	1.0327
0.93868	$W \leftrightarrow WC$	1.0653
31.614	$W_2C \leftrightarrow C$	0.031632
16.307	$WC \leftrightarrow C$	0.061324
1.1741	$WO_2 \leftrightarrow W$	0.85175
4.1515	$WO_3 \leftrightarrow Fe$	0.24088
1.2611	$WO_3 \leftrightarrow W$	0.79297
	URANIUM **U = 238.03**	
1.1344	$UO_2 \leftrightarrow U$	0.88149
1.1792	$U_3O_8 \leftrightarrow U$	0.84800
1.0395	$U_3O_8 \leftrightarrow UO_2$	0.96200
0.55901	$U_3O_8 \leftrightarrow UO_2(NO_3)_2 \cdot 6H_2O$	1.7889
1.4998	$U_2P_2O_{11} \leftrightarrow U$	0.66675
1.3221	$U_2P_2O_{11} \leftrightarrow UO_2$	0.75639
	VANADIUM **V = 50.941**	
5.2413	$VC \leftrightarrow C$	0.19079
1.7852	$V_2O_5 \leftrightarrow V$	0.56017
0.79120	$V_2O_5 \leftrightarrow VO_4$	1.2639
	YTTERBIUM **Yb = 173.04**	
1.1387	$Yb_2O_3 \leftrightarrow Yb$	0.87820
	ZINC **Zn = 65.38**	
2.3955	$BaSO_4 \leftrightarrow ZnS$	0.41745
0.81171	$BaSO_4 \leftrightarrow ZnSO_4 \cdot 7H_2O$	1.2320
0.80338	$Zn \leftrightarrow ZnO$	1.2447
2.7288	$ZnNH_4PO_4 \leftrightarrow Zn$	0.36646
2.1922	$ZnNH_4PO_4 \leftrightarrow ZnO$	0.45616
0.59707	$ZnO \leftrightarrow ZnCl_2$	1.6748
0.64898	$ZnO \leftrightarrow ZnCO_3$	1.5409
0.28298	$ZnO \leftrightarrow ZnSO_4 \cdot 7H_2O$	3.5338
2.3304	$Zn_2P_2O_7 \leftrightarrow Zn$	0.42911
1.8722	$Zn_2P_2O_7 \leftrightarrow ZnO$	0.53413
1.4905	$ZnS \leftrightarrow Zn$	0.67091
1.1974	$ZnS \leftrightarrow ZnO$	0.83512
0.33885	$ZnS \leftrightarrow ZnSO_4 \cdot 7H_2O$	2.9511

TABLE 11.19 Gravimetric Factors (*Continued*)

Factor		Factor
	ZIRCONIUM **Zr = 91.22**	
2.4864	$K_2ZrF_6 \leftrightarrow F$	0.40219
2.4390	$K_2ZrF_6 \leftrightarrow 2KF$	0.41001
1.5054	$K_2ZrF_6 \leftrightarrow 2(KF \cdot 2H_2O)$	0.66427
3.1069	$K_2ZrF_6 \leftrightarrow Zr$	0.32187
2.3000	$K_2ZrF_6 \leftrightarrow ZrO_2$	0.43478
8.5946	$ZrC \leftrightarrow C$	0.11635
2.2004	$ZrF_4 \leftrightarrow F$	0.45447
1.3508	$ZrO_2 \leftrightarrow Zr$	0.74030
0.46470	$ZrO_2 \leftrightarrow ZrP_2O_7$	2.1519

TABLE 11.20 Elements Precipitated by General Analytical Reagents

This table includes the more common reagents used in gravimetric determinations. The lists of elements precipitated are not in all cases exhaustive. The usual solvent for a precipitating agent is indicated in parentheses after its name or formula. When the symbol of an element or radical is italicized, the element may be quantitatively determined by the use of the reagent in question.

Reagent	Conditions	Substances precipitated
Ammonia, NH_3 (aqueous)	After removal of acid sulfide group.	*Al*, Au, *Be*, Co, *Cr*, *Cu*, *Fe*, Ga, *In*, Ir, *La*, Nb, Ni, Os, P, *Pb*, *rare earths*, *Sc*, Si, *Sn*, Ta, *Th*, *Ti*, *U*, V, *Y*, *Zn*, *Zr*
Ammonium polysulfide, $(NH_4)_2S_x$ (aqueous)	After removal of acid sulfide and $(NH_4)_2S$ groups.	Co, Mn, Ni, Si, Tl, V, W, Zn
Anthranilic acid, $NH_2C_6H_4COOH$ (aqueous)	1% aqueous solution (pH 6); Cu separated from others at pH 2.9.	Ag, *Cd*, *Co*, *Cu*, Fe, *Hg*, *Mn*, *Ni*, *Pb*, *Zn*
α-Benzoin oxime, $C_6H_5CHOHC(=NOH)C_6H_5$ (1–2% alcohol)	(a) Strongly acid medium.	(a) Cr(VI), *Mo(VI)*, Nb, Pd(II), Ta(V), V(V), *W(VI)*
	(b) Ammoniacal tartrate medium.	(b) Above list
Benzidine, $H_2NC_6H_4C_6H_4NH_2$ (alcohol), 0.1*M* HCl		Cd, Fe(III), IO_3^-, PO_4^{3-}, SO_4^{2-}, *W(VI)*
N-Benzoylphenylhydroxylamine, $C_6H_5CO(C_6H_5)NOH$ (aqueous)	Similar to cupferron (*q.v.*). Cu, Fe(III), and Al complexes can be weighed as such; Ti compound must be ignited to the oxide.	See Cupferron
Cinchonine, $C_{19}H_{21}N_2OH$, 6*M* HCl		Ir, Mo, Pt, *W*
Cupferron, $C_6H_5N(NO)ONH_4$ (aqueous)	Group precipitant for several higher-charged metal ions from strongly acid solution. Precipitate ignited to metal oxide.	*Al*, *Bi*, *Cu*, *Fe*, *Ga*, La, Mo, *Nb*, Pd, rare earths, Sb, *Sn*, Ta, *Th*, *Ti*, Tl, *U*, *V*, W, *Zr*
1,2-Cyclohexanedionedioxime	More water soluble than dimethylglyoxime; less subject to coprecipitation with metal chelate.	See Dimethylglyoxime

TABLE 11.20 Elements Precipitated by General Analytical Reagents (*Continued*)

Reagent	Conditions	Substances precipitated
Diammonium hydrogen phosphate, $(NH_4)_2HPO_4$ (aqueous)	(a) Acid medium. (b) Ammoniacal medium containing citrate or tartrate.	(a) *Bi*, *Co*, Hf, In, Ti, *Zn*, *Zr* (b) Au, Ba, *Be*, Ca, Hg, In, La, *Mg*, *Mn*, Pb, rare earths, Sr, Th, U, *Zr*
Dimethylglyoxime, $[CH_3C(NOH)]_2$ (alcohol)	(a) Dilute HCl or H_2SO_4 medium. (b) Ammoniacal tartrate medium about pH 8. Weighed as such.	(a) Au, *Pd*, Se (b) *Ni* (and Co, Fe if present in large amounts)
Hydrazine, N_2H_4 (aqueous)		Ag, Au, *Cu*, *Hg*, Ir, *Os*, Pd, Pt, *Rh*, Ru, *Se*, *Te*
Hydrogen sulfide, H_2S	(a) 0.2–0.5*M* H^+. (b) Ammoniacal solution after removal of acid sulfide group.	(a) Ag, *As*, Au, Bi, Cd, *Cu*, *Ge*, *Hg*, In, *Ir*, *Mo*, Os, Pb, Pd, *Pt*, Re, *Rh*, Ru, Sb, Se, Sn, Te, Tl, V, W, Zn (b) Co, Fe, Ga, In, Mn, Ni, Tl, U, V, Zn
4-Hydroxyphenylarsonic acid, $C_6H_4(OH)AsO(OH)_2$ (aqueous)	Dilute acid solution.	Ce, *Fe*, *Sn*, *Th*, *Ti*, *Zr*
8-Hydroxyquinoline (oxine), C_9H_6NOH, (alcohol)	(a) HOAc–OAc^- buffer. (b) Ammoniacal solution.	(a) Ag, *Al*, Bi, *Cd*, *Co*, Cr, *Cu*, *Fe*, Ga, Hg, *In*, La, *Mn*, *Mo*, Nb, *Ni*, Pb, Pd, rare earths, Sb, Ta, Th, Ti, V, W, *Zn*, *Zr* (b) Same as in (a) except for Ag; in addition, Ba, *Be*, *Ca*, *Mg*, Sn, *Sr*
2-Mercaptobenzothiazole, $C_6H_4(SCN)SH$ (acetic acid solution)	Ammoniacal solution, except for Cu, when a dilute acid solution is used.	Ag, *Au*, *Bi*, *Cd*, *Cu*, Hg, *Ir*, *Pb*, *Pt*, *Rh*, Tl
Nitron (diphenylenedianilohydrotriazole), $C_{20}H_{16}N_4$, (5% acetic acid)	Dilute H_2SO_4 medium.	*B*, *ClO_3^-*, *ClO_4^-*, *NO_3^-*, *ReO_4^-*, *W*
1-Nitroso-2-naphthol, $C_{10}H_6(NO)OH$ (very dilute alkali)	Selective for Co; acid solution. Precipitate ignited to Co_3O_4.	Ag, Au, B, *Co*, Cr, *Cu*, *Fe*, Mo, Pd, Ti, V, W, Zr
Oxalic acid, $H_2C_2O_4$, (aqueous)	Dilute acid solution.	*Ag*, *Au*, Cu, *Hg*, *La*, Ni, *Pb*, *rare earths*, *Sc*, *Th*, U(IV), W, *Zr*
Phenylarsonic acid, $C_6H_5AsO(OH)_2$, (aqueous)	Selective precipitants for quadrivalent metals in acid solution. Metals weighed as dioxides.	*Bi*, Ce(IV), Fe, *Hf*, *Mg*, *Sn*, *Ta*, *Th*, Ti, U(IV), W, *Zr*
Phenylthiohydantoic acid, $C_6H_5N{=}C(NH_2)SCH_2COOH$ (aqueous or alcohol)		Bi, Cd, *Co*, Cu, Fe, Hg, Ni, Pb, Sb
Picrolonic acid, $C_{10}H_7O_5N_4H$ (aqueous)	Neutral solution.	*Ca*, Mg, *Pb*, *Th*
Propylarsonic acid, $C_3H_9AsO(OH)_2$ (aqueous)	Preferred for W; see Phenylarsonic acid.	
Pyridine plus thiocyanate	Dilute acid solution.	*Ag*, *Cd*, *Cu*, *Mn*, *Ni*
Quinaldic acid, C_9B_6NCOOH (aqueous)	Dilute acid solution.	Ag, *Cd*, Co, *Cu*, Fe, Hg, Mo, Ni, Pb, Pd, Pt(II), *U*, W, *Zn*
Salicylaldoxime, $C_7H_5(OH)NOH$ (alcohol)	Dilute acid solution.	Ag, *Bi*, Cd, Co, *Cu*, Fe, Hg, Mg, Mn, Ni, *Pb*, *Pd*, V, Zn
Silver nitrate, $AgNO_3$ (aqueous)	(a) Dilute HNO_3 solution. (b) Acetate buffer, pH 5–7.	(a) Br^-, Cl^-, I^-, SCN^- (b) *As(V)*, *CN^-*, *OCN^-*, *IO_3^-*, *Mo(VI)*, *N_3^-*, *S^{2-}*, *V(V)*

TABLE 11.20 Elements Precipitated by General Analytical Reagents (*Continued*)

Reagent	Conditions	Substances precipitated
Sodium tetraphenylborate, $NaB(C_6H_5)_4$ (aqueous)	Specific for K group of alkali metals from dilute HNO_3 or HOAc solution (pH 2), or pH 6.5 in presence of EDTA.	*Cs, K,* NH_4^+, *Rb*
Tannic acid (tannin), $C_{14}H_{10}O_9$ (aqueous)	Acts as negative colloid that is a flocculent for positively charged hydrous oxide sols. Noteworthy for W in acid solution, and for Ta (from Nb in acidic oxalate medium).	*Al, Be,* Cr, Ga, *Ge,* Nb, Sb, *Sn, Ta, Th, Ti, U,* V, *W, Zr*
Tartaric acid, $HOOC(CHOH)_2COOH$ (aqueous)		*Ca, K, Mg, Sc, Sr, Ta*
Tetraphenylarsonium chloride, $(C_6H_5)_4AsCl$ (aqueous)	$(C_6H_5)_4AsTlCl_4$ and $(C_6H_5)_4AsReO_4$ weighed as such.	*Re, Tl*
Thioglycolic-β-aminonaphthalide, thionalide, $C_{10}H_7NHCOCH_2SH$ (alcohol)	(a) Acid solution.	(a) Ag, As, Au, Bi, *Cu, Hg, Os, Pb,* Pd, *Rh, Ru,* Sb, Sn, Tl
	(b) Carbonate medium containing tartrate.	(b) Au, Cd, Cu, Hg(II), Tl(I)
	(c) Carbonate medium containing tartrate and cyanide.	(c) Au, Bi, Pb, Sb, Sn, Tl
	(d) Strongly alkaline medium containing tartrate and cyanide.	(d) *Tl*

Source: J. A. Dean, ed., *Analytical Chemistry Handbook,* McGraw-Hill, New York, 1995.

TABLE 11.21 Cleaning Solutions for Fritted Glassware

Material	Cleaning solution
Fatty materials	Carbon tetrachloride.
Organic matter	Hot concentrated sulfuric acid plus a few drops of sodium or potassium nitrate solution.
Albumen	Hot aqueous ammonia or hot hydrochloric acid.
Glucose	Hot mixed acid (sulfuric plus nitric acids).
Copper or iron oxides	Hot hydrochloric acid plus potassium chlorate.
Mercury residue	Not nitric acid.
Silver chloride	Aqueous ammonia or sodium thiosulfate.
Aluminous and siliceous residues	A 2% hydrofluoric acid solution followed by concentrated sulfuric acid; rinse immediately with distilled water followed by a few milliliters of acetone. Repeat rinsing until all trace of acid is removed.

TABLE 11.22 Common Fluxes

Flux	Melting point, °C	Types of crucible used for fusion	Type of substances decomposed
Na_2CO_3	851	Pt	For silicates, and silica-containing samples; alumina-containing samples; insoluble phosphates and sulfates
Na_2CO_3 plus an oxidizing agent such as KNO_3, $KClO_3$, or Na_2O_2		Pt (do not use with Na_2O_2) or Ni	For samples needing an oxidizing agent
NaOH or KOH	320–380	Au, Ag, Ni	For silicates, silicon carbide, certain minerals
Na_2O_2	Decomposes	Fe, Ni	For sulfides, acid-insoluble alloys of Fe, Ni, Cr, Mo, W, and Li; Pt alloys; Cr, Sn, Zn minerals
$K_2S_2O_7$	300	Pt or porcelain	Acid flux for insoluble oxides and oxide-containing samples
B_2O_3	577	Pt	For silicates and oxides when alkalis are to be determined
$CaCO_3$ plus NH_4Cl		Ni	For decomposing silicates in the determination of alkali element

TABLE 11.23 Membrane Filters

Filter pore size, μm	Maximum rigid particle to penetrate, μm	Filter pore size, μm	Maximum rigid particle to penetrate, μm
14	17	0.65	0.68
10	12	0.60	0.65
8	9.4	0.45	0.47
7	9.0	0.30	0.32
5	6.2	0.22	0.24
3	3.9	0.20	0.25
2	2.5	0.10	0.108
1.2	1.5	0.05	0.053
1.0	1.1	0.025	0.028
0.8	0.95		

TABLE 11.24 Porosities of Fritted Glassware

Porosity	Nominal maximum pore size, μm	Principal uses
Extra coarse	170–220	Filtration of very coarse materials. Gas dispersion, gas washing, and extractor beds. Support of other filter materials.
Coarse	40–60	Filtration of coarse materials. Gas dispersion, gas washing, gas absorption. Mercury filtration. For extraction apparatus.
Medium	10–15	Filtration of crystalline precipitates. Removal of "floaters" from distilled water.
Fine	4–5.5	Filtration of fine precipitates. As a mercury valve. In extraction apparatus.
Very fine	2–2.5	General bacteria filtrations.
Ultra fine	0.9–1.4	General bacteria filtrations.

TABLE 11.25 Tolerances for Analytical Weights

By Alan D. Westland with Fred E. Beamish.

This table gives the individual and group tolerances established by the National Bureau of Standards (Washington, D.C.) for classes M, S, S-1, and P weights. Individual tolerances are "acceptance tolerances" for new weights. Group tolerances are defined by the National Bureau of Standards as follows: "The corrections of individual weights shall be such that no combination of weights that is intended to be used in a weighing shall differ from the sum of the nominal values by more than the amount listed under the group tolerances."

For class S-1 weights, two-thirds of the weights in a set must be within one-half of the individual tolerances given below. No group tolerances have been specified for class P weights. See *Natl. Bur. Standards Circ.* 547, sec. 1 (1954).

	Class M		Class S			
Denomination	Individual tolerance, mg	Group tolerance, mg	Individual tolerance, mg	Group tolerance, mg	Class S-1, individual tolerance, mg	Class P, individual tolerance, mg
100 g	0.50		0.25	None	1.0	2.0
50 g	0.25	None	0.12	specified	0.60	1.2
30 g	0.15	specified	0.074		0.45	0.90
20 g	0.10		0.074	0.154	0.35	0.70
10 g	0.050		0.074		0.25	0.50
5 g	0.034		0.054		0.18	0.36
3 g	0.034	0.065	0.054	0.105	0.15	0.14
2 g	0.034		0.054		0.13	0.26
1 g	0.034		0.054		0.10	0.20
500 mg	0.0054		0.025		0.080	0.16
300 mg	0.0054	0.0105	0.025	0.055	0.070	0.14
200 mg	0.0054		0.025		0.060	0.12
100 mg	0.0054		0.025		0.050	0.10
50 mg	0.0054		0.014		0.042	0.085
30 mg	0.0054	0.0105	0.014	0.034	0.038	0.076
20 mg	0.0054		0.014		0.035	0.070

TABLE 11.25 Tolerances for Analytical Weights (*Continued*)

Denomination	Class M		Class S		Class S-1, individual tolerance, mg	Class P, individual tolerance, mg
	Individual tolerance, mg	Group tolerance, mg	Individual tolerance, mg	Group tolerance, mg		
10 mg	0.0054		0.014		0.030	0.060
5 mg	0.0054		0.014		0.028	0.055
3 mg	0.0054	0.0105	0.014	0.034	0.026	0.052
2 mg	0.0054		0.014		0.025	0.050
1 mg	0.0054		0.014		0.025	0.050
½ mg	0.0054		0.014		0.025	.....

TABLE 11.26 Heating Temperatures, Composition of Weighing Forms, and Gravimetric Factors

The minimum temperature required for heating a pure precipitate to constant weight is frequently lower than that commonly recommended in gravimetric procedures. However, the higher temperature is very often still to be preferred in order to ensure that contaminating substances are expelled. The thermal stability ranges of various precipitates as deduced from thermograms are also tabulated. Where a stronger ignition is advisable, the safe upper limit can be ascertained.

Gravimetric factors are based on the 1993 International Atomic Weights. The factor Ag: 0.7526 given in the first line of the table indicates that the weight of precipitate obtained (AgCl) is to be multiplied by 0.7526 to calculate the corresponding weight of silver.

Element	Thermal stability range, °C	Final heating temperature, °C	Composition of weighing form	Gravimetric factors
Ag	70–600	130–150	AgCl	Ag: 0.7526
Al	>475	1200	Al_2O_3	Al: 0.5293
	>743	>743	$AlPO_4$	Al: 0.2212; Al_2O_3: 0.4180
	102–220	110	$Al(C_9H_6NO)_3$	Al: 0.0587; Al_2O_3: 0.1110
As	200–275	105–110	Al_2S_3	As: 0.6090; As_2O_3: 0.8041
		850	$Mg_2As_2O_7$	As: 0.4827; As_2O_3: 0.6373
		vacuum at 25	$MgNH_4AsO_4 \cdot 6H_2O$	As: 0.2589
Au	20–957	1060	Au	
Ba	780–1100	780	$BaSO_4$	Ba: 0.5884; BaO: 0.6570
	<60	<60	$BaCrO_4$	Ba: 0.5421; BaO: 0.6053
Be	>900	1000	BeO	Be: 0.3603
Bi		100	BiOCl	Bi: 0.8024; Bi_2O_3: 0.8946
		100	$Bi(C_{12}H_{10}NOS)_3$	Bi: 0.2387
	379–961	800	$BiPO_4$	Bi: 0.6875; Bi_2O_3: 0.7665
Br	70–946	130–150	AgBr	Br: 0.4256
Ca	478–635	475–525	$CaCO_3$	Ca: 0.4004; CaO: 0.5601
	838–1025	950–1000	CaO	Ca: 0.7147
		air-dried	$Ca(picrolonate)_2 \cdot 8H_2O$	Ca: 0.05642
Cd		>320	$CdSO_4$	Cd: 0.5392; CdO: 0.6159
		125	$Cd(C_{10}H_6NO_2)_2$	Cd: 0.2462
	218–420		CdS	Cd: 0.7781; CdO: 0.8888
Ce	>360	500–600	CeO_2	Ce: 0.8141
Cl	70–600	130–150	AgCl	Cl: 0.2474

TABLE 11.26 Heating Temperatures, Composition of Weighing Forms, and Gravimetric Factors (*Continued*)

Element	Thermal stability range, °C	Final heating temperature, °C	Composition of weighing form	Gravimetric factors
Co	285–946	750–850	Co_3O_4	Co: 0.7342
		130	$Co(C_{10}H_6NO_2)_3 \cdot 2H_2O$	Co: 0.09639; CoO: 0.1226
		450–500	$CoSO_4$	Co: 0.3802
Cr		120	$PbCrO_4$	Cr: 0.1609
Cu		105–120	CuSCN	Cu: 0.5225; CuO: 0.6540
	<115	100–105	$Cu(C_7H_5NO_2)_2$	Cu: 0.1891
		105–115	$Cu(C_{13}H_{11}NO_2)$	Cu: 0.2201
		110–115	$Cu(C_{10}H_6NO_2) \cdot H_2O$	Cu: 0.1494
		105	$Cu(C_{12}H_{10}NOS)_2 \cdot H_2O$	Cu: 0.1237
F	66–538	130–140	PbClF	F: 0.07261
Fe	470–946	900	Fe_2O_3	Fe: 0.6994
Ga	408–946	900	Ga_2O_3	Ga: 0.7439
Hg		105	$Hg(C_{12}H_{10}NOS)_2$	Hg: 0.3169
I	60–900	130–150	AgI	I: 0.5405
In	345–1200	1200	In_2O_3	In: 0.8271
Ir			IrO_2	Ir: 0.8573
K	73–653	<653	$KClO_4$	K: 0.2822; K_2O: 0.3399
		<270	K_2PtCl_6	K: 0.1609; K_2O: 0.1938
			KIO_4	K: 0.1700
		120	$KB(C_6H_5)_4$	K: 0.1091
Li		200	Li_2SO_4	Li: 0.1263; Li_2O: 0.2718
Mg		1050–1100	$Mg_2P_2O_7$	Mg: 0.2184; MgO: 0.3622
	88–300	155–160	$Mg(C_9H_6NO)_2$	Mg: 0.07775; MgO: 0.1289
Mn	>946	1000	Mn_3O_4	Mn: 0.7203
		1000	$Mn_2P_2O_7$	Mn: 0.3871; MnO: 0.4998
Mo		>505	$PbMoO_4$	Mo: 0.2613; MoO_3: 0.3291
		500–525	MoO_3	Mo: 0.6666
N (as NO_3^-)	20–242	105	Nitron nitrate	N: 0.3732; NO_3: 0.1652
Na	360–674	125	$NaMg(UO_2)_3(C_2H_3O_2)_9 \cdot 6.5\ H_2O$	Na: 0.01527; Na_2O: 0.02058
Nb	650–950	900	Nb_2O_3	Nb: 0.6990
Ni	79–172	110–120	$Ni(C_4H_7N_2O_2)_2$	Ni: 0.2032; NiO: 0.2586
Os		800 (in H_2)	Os metal	
P		>477	$Mg_2P_2O_7$	P: 0.2783; PO_4: 0.8536
	160–415	110	$(NH_4)_3[P(Mo_3O_{10})_4]$	P: 0.0165; P_2O_5: 0.0378
Pb	271–959	500–600	$PbSO_4$	Pb: 0.6832; PbO: 0.7359
		600	$PbMoO_4$	Pb: 0.5643; PbO: 0.6078
		120	$PbCrO_4$	Pb: 0.6411
	271–959	600–800	$PbSO_4$	Pb: 0.6832; PbO: 0.7359
		105	$Pb(C_{12}H_{10}NOS)_2$	Pb: 0.3240
Pd	45–171	110	$Pd(C_4H_7N_2O_2)_2$	Pd: 0.3162
Rb	70–674	<674	Rb_2PtCl_6	Rb: 0.2954; Rb_2O: 0.3230
Re		130	$(C_6H_5)_4AsReO_4$	Re: 0.2939
		110	Nitron perrhenate	Re: 0.3306
S		>780	$BaSO_4$	S: 0.1374; SO_3: 0.3430; SO_4: 0.4116
Sb		100	$Sb(C_{12}H_{10}NOS)_3$	Sb: 0.1581
SCN^-		130	AgSCN	SCN: 0.3500
		110–120	CuSCN	SCN: 0.4775
Se		120–130	Se metal	SeO_2: 1.4052
Si	358–946	>358	SiO_2	Si: 0.4675

TABLE 11.26 Heating Temperatures, Composition of Weighing Forms, and Gravimetric Factors (*Continued*)

Element	Thermal stability range, °C	Final heating temperature, °C	Composition of weighing form	Gravimetric factors
Sn	>834	900	SnO_2	Sn: 0.7877
Sr		130–140	$Sr(NO_3)_2$	Sr: 0.4140
	100–300	100–300	$SrSO_4$	Sr: 0.4770; SrO: 0.5641
Te		105	Te metal	
Th	610–946	700–800	ThO_2	Th: 0.8788
		900	ThP_2O_7	Th: 0.5863
Ti	350–946	900	TiO_2	Ti: 0.5992
Tl(III)		100	$Tl(C_{12}H_{10}NOS)$	Tl: 0.4860
U		1000	U_3O_8	U: 0.8480; UO_2: 0.9620
V	581–946	700–800	V_2O_5	V: 0.5602
W	>674	800–900	WO_3	W: 0.7930
Zn	>1000	950–1000	ZnO	Zn: 0.8034
		1000	$Zn_2P_2O_7$	Zn: 0.4292; ZnO: 0.5342
		125	$Zn(C_{10}H_6NO_2)_2 \cdot H_2O$	Zn: 0.1529
Zr		>850	ZrP_2O_7	Zr: 0.3440; ZrO_2: 0.4647
		1200	ZrO_2	Zr: 0.7403

Source: J. A. Dean, ed., *Analytical Chemistry Handbook*, McGraw-Hill, New York, 1995.

11.6 VOLUMETRIC ANALYSIS

11.6.1 Acid-Base Titrations in Aqueous Media

TABLE 11.27 Primary Standards for Aqueous Acid-Base Titrations

Standard	Formula weight	Preparation
		Basic substances for standardizing acidic solutions
$(HOCH_3)_3CNHH_2$	121.137	Tris(hydroxymethyl)aminomethane is available commercially as a primary standard. Dry at 100–103°C (<110°C). In titrations with a strong acid the equivalence point is at about pH 4.5–5. Equivalent weight is the formula weight. [J. H. Fossum, P. C. Markunas, and J. A. Riddick, *Anal. Chem.*, **23:**491 (1951).]
HgO	216.59	Dissolve 100 g pure $HgCl_2$ in 1 L H_2O, and add with stirring to 650 mL 1.5 *M* NaOH. Filter and wash with H_2O until washings are neutral to phenolphthalein. Dry to constant weight at or below 40°C, and store in a dark bottle. To 0.4 g HgO (≡ 40 mL 0.1*N* acid) add 10–15 g KBr plus 20–25 mL H_2O. Stir, excluding CO_2, until solution is complete. Titrate with acid to pH 5–8. Equivalent weight is one-half formula weight.
$Na_2B_4O_7 \cdot 10H_2O$	381.372	Recrystallize reagent-grade salt twice from water at temperatures below 55°C. Wash the crystals with H_2O, twice with ethanol, and twice with diethyl ether. Let stand in a hygrostat oversaturated $NaBr \cdot 2H_2O$ or saturated NaCl-sucrose solution. Use methyl red indicator. Equivalent weight is one-half the formula weight.

TABLE 11.27 Primary Standards for Aqueous Acid-Base Titrations (*Continued*)

Standard	Formula weight	Preparation
		Basic substances for standardizing acidic solutions (*continued*)
Na_2CO_3	105.989	Heat reagent-grade material for 1 hr at 255–265°C. Cool in an efficient desiccator. Titrate sample with acid to pH 4–5 (first green tint of bromocresol green), boil the solution to eliminate the carbon dioxide, cool, and again titrate to pH 4–5. Equivalent weight is one-half the formula weight.
NaCl	58.45	Accurately weigh about 6 g NaCl and dissolve in distilled water. Pass the solution through a well-rinsed cation exchange column (Dowex 50W) in the hydrogen form. The equivalent amount of HCl is washed from the column (in 10 column volumes) into a volumetric flask and made up to volume. Equivalent weight is the formula weight.
		Acidic substances for standardizing basic solutions
C_6H_5COOH	122.125	Pure benzoic acid is available from NIST (National Institute for Science and Technology). Dissolve 0.5 g in 20 mL of neutral ethanol (run a blank), excluding CO_2, add 20–50 mL, and titrate using phenolphthalein as indicator.
o-$C_6H_4(COOK)(COOH)$	204.22	Potassium hydrogen *o*-phthalate is available commercially as primary standard, also from NIST. Dry at <135°C. Dissolve in water, excluding CO_2, and titrate with phenolphthalein as indicator. For $Ba(OH)_2$ solution, perform the titration at an elevated temperature to prevent precipitation of Ba phthalate.
$KH(IO_3)_2$	389.915	Potassium hydrogen bis(iodate) is available commercially in a primary standard grade. Dry at 110°C. Dissolve a weighed amount of the salt in water, excluding CO_2, and titrate to pH 5–8. [I. M. Kolthoff and L. H. van Berk, *J. Am. Chem. Soc.*, **48:**2800 (1926)].
NH_2SO_3H	97.09	Hydrogen amidosulfate (sulfamic acid) acts as a strong acid. Primary standard grade is available commercially. Since it does undergo slow hydrolysis, an acid end point (pH 4 to 6.5) should be chosen unless fresh reagent is available, then the end point can be in the range pH 4 to 9. [W. F. Wagner, J. A. Wuellner, and C. E. Feiler, *Anal. Chem.*, **24:**1491 (1952). M. J. Butler, G. F. Smith, and L. F. Audrieth, *Ind. Eng. Chem., Anal. Ed.*, **10:**690 (1938)].

TABLE 11.28 Titrimetric (Volumetric) Factors

Acids

The following factors are the equivalent of 1 mL of *normal acid.* Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

The equivalents of the esters are based on the results of saponification.

The indicators methyl orange and phenolphthalein are indicated by the abbreviations MO and pH, respectively.

Substance	Formula	Grams
Ammonia	NH_3	0.017031
Ammonium	NH_4	0.018039
Ammonium chloride	NH_4Cl	0.053492
Ammonium hydroxide	NH_4OH	0.035046
Ammonium oleate	$C_{17}H_{33}CO_2NH_4$	0.29950
Ammonium oxide	$(NH_4)_2O$	0.026038
Amyl acetate	$CH_3CO_2C_5H_{11}$	0.13019
Barium carbonate (MO)	$BaCO_3$	0.09867
Barium hydroxide	$Ba(OH)_2$	0.085677
Barium oxide	BaO	0.07667
Bornyl acetate	$CH_3CO_2C_{10}H_{17}$	0.19629
Calcium carbonate (MO)	$CaCO_3$	0.05004
Calcium hydroxide	$Ca(OH)_2$	0.037047
Calcium oleate	$(C_{17}H_{33}CO_2)_2Ca$	0.30150
Calcium oxide	CaO	0.02804
Calcium stearate	$(C_{17}H_{35}CO_2)_2Ca$	0.30352
Casein (N 6.38)	.....	0.089371
Ethyl acetate	$CH_3CO_2C_2H_5$	0.088107
Glue (N 5.60)	.....	0.078445
Hydrochloric acid	HCl	0.036461
Magnesium carbonate (MO)	$MgCO_3$	0.04216
Magnesium oxide	MgO	0.02016
Menthyl acetate	$CH_3CO_2C_{10}H_{19}$	0.19831
Methyl acetate	$CH_3CO_2CH_3$	0.074080
Nicotine	$C_{10}H_{14}N_2$	0.16224
Nitrogen	N	0.014007
Potassium carbonate (MO)	K_2CO_3	0.06911
Potassium carbonate, acid (MO)	$KHCO_3$	0.10012
Potassium nitrate	KNO_3	0.10111
Potassium oleate	$C_{17}H_{33}CO_2K$	0.32057
Potassium oxide	K_2O	0.04710
Potassium stearate	$C_{17}K_{35}CO_2K$	0.32258
Protein (N 5.70)	.....	0.079846
Protein (N 6.25)	.....	0.087550
Sodium acetate	CH_3CO_2Na	0.082035
Sodium acetate	$CH_3CO_2Na \cdot 3H_2O$	0.13608
Sodium borate, tetra- (MO)	$Na_2B_4O_7$	0.10061
Sodium borate, tetra- (MO)	$Na_2B_4O_7 \cdot 10H_2O$	0.19069
Sodium carbonate (MO)	Na_2CO_3	0.052994
Sodium carbonate (MO)	$Na_2CO_3 \cdot H_2O$	0.062002
Sodium carbonate (MO)	$Na_2CO_3 \cdot 10H_2O$	0.14307
Sodium carbonate, acid (MO)	$NaHCO_3$	0.084007
Sodium hydroxide	NaOH	0.39997
Sodium oleate	$C_{17}H_{33}CO_2Na$	0.30445

TABLE 11.28 Titrimetric (Volumetric) Factors (*Continued*)

Acids (*continued*)

Substance	Formula	Grams
Sodium oxalate	$Na_2C_2O_4$	0.067000
Sodium oxide	Na_2O	0.030990
Sodium phosphate (MO)	Na_2HPO_4	0.14196
Sodium phosphate (MO)	$Na_2PHO_4 \cdot 12H_2O$	0.35814
Sodium phosphate (MO)	Na_3PO_4	0.081970
Sodium phosphate (PH)	Na_3PO_4	0.16394
Sodium silicate	$Na_2Si_4O_9$	0.15111
Sodium stearate	$C_{17}H_{35}CO_2Na$	0.30647
Sodium sulfide (MO)	Na_2S	0.039022

Alkali

The following factors are the equivalent of the milliliter of *normal alkali*. Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

The equivalents of the esters are based on the results of saponification.

The indicators methyl orange and phenolphthalein are indicated by the abbreviations MO and PH, respectively.

Substance	Formula	Grams
Abietic acid (PH)	$HC_{20}H_{29}O_2$	0.30246
Acetic acid (PH)	CH_3CO_2H	0.06005
Acetic anhydride (PH)	$(CH_3CO)_2O$	0.051045
Aluminum sulfate	$Al_2(SO_4)_3$	0.05702
Amyl acetate	$CH_3CO_2C_5H_{11}$	0.13019
Benzoic acid (PH)	$C_6H_5CO_2H$	0.12212
Borate tetra- (PH)	B_4O_7	0.03881
Boric acid (PH)	H_3BO_3	0.061833
Boric anhydride (PH)	B_2O_3	0.03486
Bornyl acetate	$CH_3CO_2C_{10}H_{17}$	0.19629
Butyric acid (PH)	$C_3H_7CO_2H$	0.088107
Calcium acetate	$(CH_3CO_2)_2Ca$	0.079085
Calcium oleate	$(C_{17}H_{33}CO_2)_2Ca$	0.30150
Calcium stearate	$(C_{17}H_{35}CO_2)_2Ca$	0.30352
Carbon dioxide (PH)	CO_2	0.022005
Chlorine	Cl	0.035453
Citric acid (PH)	$H_3C_6H_5O_7 \cdot H_2O$	0.070047
Ethyl acetate	$CH_3CO_2C_2H_5$	0.088107
Formaldehyde	HCHO	0.030026
Formic acid (PH)	HCO_2H	0.046026
Glycerol (sap. of acetyl)	$C_3H_5(OH)_3$	0.030698
Hydriodic acid	HI	0.12791
Hydrobromic acid	HBr	0.080917
Hydrochloric acid	HCl	0.036461
Lactic acid (PH)	$HC_3H_5O_3$	0.090079
Lead acetate	$(CH_3CO_2)_2Pb \cdot 3H_2O$	0.18966
Maleic acid (PH)	$(CHCO_2H)_2$	0.058037
Malic acid (PH)	$H_2C_4H_4O_5$	0.067045
Menthol (sap. of acetyl)	$C_{10}H_{19}OH$	0.15627

TABLE 11.28 Titrimetric (Volumetric) Factors (*Continued*)

Alkali (*continued*)

Substance	Formula	Grams
Menthyl acetate	$CH_3CO_2C_{10}H_{19}$	0.19831
Methyl acetate	$CH_3CO_2CH_3$	0.074080
Nitrate	NO_3	0.062005
Nitric acid	HNO_3	0.063013
Nitrogen	N	0.014007
Nitrogen pentoxide	N_2O_5	0.054005
Oleic acid (PH)	$C_{17}H_{33}CO_2H$	0.28247
Oxalic acid (PH)	$(CO_2H)_2$	0.045018
Oxalic acid (PH)	$(CO_2H)_2 \cdot 2H_2O$	0.063033
Phosphoric acid (MO)	H_3PO_4	0.097995
Phosphoric acid (PH)	H_3PO_4	0.048998
Potassium carbonate, acid (MO)	$KHCO_3$	0.10012
Potassium oleate	$C_{17}K_{33}CO_2K$	0.32056
Potassium oxalate, acid (PH)	KHC_2O_4	0.12813
Potassium phthalate, acid (PH)	$HC_8H_4O_4K$	0.20423
Potassium stearate	$C_{17}H_{35}CO_2K$	0.32258
Sodium benzoate	$C_6H_5CO_2Na$	0.14411
Sodium borate, tetra- (PH)	$Na_2B_4O_7$	0.050305
Sodium borate, tetra- (PH)	$Na_2B_4O_7 \cdot 10H_2O$	0.095343
Sodium carbonate, acid (MO)	$NaHCO_3$	0.084007
Sodium oleate	$C_{17}H_{33}CO_2Na$	0.30445
Sodium salicylate	$C_6H_5OCO_2Na$	0.16011
Stearic acid (PH)	$C_{17}H_{35}CO_2H$	0.28449
Succinic acid (PH)	$(CH_2CO_2H)_2$	0.059045
Sulfate	SO_4	0.048031
Sulfur dioxide (PH)	SO_2	0.032031
Sulfur trioxide	SO_3	0.040031
Sulfuric acid	H_2SO_4	0.049039
Sulfurous acid (PH)	H_2SO_3	0.041039
Tartaric acid (PH)	$H_2C_4H_4O_6$	0.075044
Tartaric acid (PH)	$H_2C_4H_4O_6 \cdot H_2O$	0.084052

Iodine

The following factors are the equivalent of 1 mL of *normal iodine.* Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

Substance	Formula	Grams
Acetone	$(CH_3)_2CO$	0.0096801
Ammonium chromate	$(NH_4)_2CrO_4$	0.050690
Antimony	Sb	0.06088
Antimony trioxide	Sb_2O_3	0.07287
Arsenic	As	0.037461
Arsenic pentoxide	As_2O_5	0.057460
Arsenic trioxide	As_2O_3	0.049460
Arsenite	AsO_3	0.061460
Bleaching powder	$CaOCl_2$	0.063493
Bromine	Br	0.079909
Chlorine	Cl	0.035453
Chromic oxide	Cr_2O_3	0.02533

TABLE 11.28 Titrimetric (Volumetric) Factors (*Continued*)

Iodine (*continued*)

Substance	Formula	Grams
Chromium trioxide	CrO_3	0.033331
Copper	Cu	0.06354
Copper oxide	CuO	0.07954
Copper sulfate	$CuSO_4$	0.15960
Copper sulfate	$CuSO_4 \cdot 5H_2O$	0.24968
Ferric iron	Fe^{3+}	0.05585
Ferric oxide	Fe_2O_3	0.07985
Hydrogen sulfide	H_2S	0.017040
Iodine	I	0.126904
Lead chromate	$PbCrO_4$	0.10773
Lead dioxide	PbO_2	0.11959
Nitrous acid	HNO_2	0.023507
Oxygen	O	0.0079997
Potassium chlorate	$KClO_3$	0.020426
Potassium chromate	K_2CrO_4	0.064733
Potassium dichromate	$K_2Cr_2O_7$	0.049032
Potassium nitrite	KNO_2	0.042554
Potassium permanganate	$KMnO_4$	0.031608
Red lead	Pb_3O_4	0.34278
Sodium chromate	Na_2CrO_4	0.053991
Sodium dichromate	$Na_2Cr_2O_7$	0.043661
Sodium dichromate	$Na_2Cr_2O_7 \cdot 2H_2O$	0.049666
Sodium nitrite	$NaNO_2$	0.034498
Sodium sulfide	Na_2S	0.039022
Sodium sulfide	$Na_2S \cdot 9H_2O$	0.12009
Sodium sulfite	Na_2SO_3	0.063021
Sodium sulfite	$Na_2SO_3 \cdot 7H_2O$	0.12607
Sodium thiosulfate	$Na_2S_2O_3$	0.15811
Sulfur	S	0.016032
Sulfur dioxide	SO_2	0.032031
Sulfurous acid	H_2SO_3	0.041039
Tin	Sn	0.059345

Potassium dichromate

The following factors are the equivalent of 1 mL of *normal potassium dichromate.* Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

Substance	Formula	Grams
Chromic oxide	Cr_2O_3	0.025332
Chromium trioxide	CrO_3	0.033331
Ferrous iron	Fe^{2+}	0.055847
Ferrous oxide	FeO	0.071846
Ferroso-ferric oxide	Fe_3O_4	0.077180
Ferrous sulfate	$FeSO_4$	0.15191
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	0.27802
Glycerol	$C_3H_5(OH)_3$	0.0065782
Lead chromate	$PbCrO_4$	0.10773
Zinc	Zn	0.032685

TABLE 11.28 Titrimetric (Volumetric) Factors (*Continued*)

Potassium permanganate

The following factors are the equivalent of 1 mL of *normal potassium permanganate.* Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

Substance	Formula	Grams
Ammonium oxalate	$(NH_4)_2C_2O_4$	0.062049
Ammonium oxalate	$(NH_4)_2C_2O_4 \cdot H_2O$	0.071056
Ammonium peroxydisulfate	$(NH_4)_2S_2O_8$	0.11410
Antimony	Sb	0.060875
Barium peroxide	BaO_2	0.084669
Barium peroxide	$BaO_2 \cdot 8H_2O$	0.15673
Calcium carbonate	$CaCO_3$	0.050045
Calcium oxide	CaO	0.02804
Calcium peroxide	CaO_2	0.036039
Calcium sulfate	$CaSO_4$	0.068071
Calcium sulfate	$CaSO_4 \cdot 2H_2O$	0.086086
Ferric oxide	Fe_2O_3	0.079846
Ferroso-ferric oxide	Fe_3O_4	0.077180
Ferrous ammonium sulfate	$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$	0.39214
Ferrous oxide	FeO	0.071846
Ferrous sulfate	$FeSO_4$	0.15191
Ferrous sulfate	$FeSO_4 \cdot 7H_2O$	0.27802
Formic acid	HCO_2H	0.023013
Hydrogen peroxide	H_2O_2	0.017007
Iodine	I	0.126904
Iron	Fe	0.055847
Manganese	Mn	0.010988
Manganese dioxide	MnO_2	0.043468
Manganous oxide (Volhard)	MnO	0.035469
Molybdenum trioxide titration from yellow ppt. after reduction	MoO_3	0.047979
Oxalic acid	$(CO_2H)_2$	0.045018
Oxalic acid	$(CO_2H)_2 \cdot 2H_2O$	0.063033
Phosphorus titration from yellow ppt. after reduction	P	0.0008604
Phosphorus pentoxide to titration from yellow ppt. after reduction	P_2O_5	0.0019715
Potassium dichromate	$K_2Cr_2O_7$	0.049032
Potassium nitrite	KNO_2	0.042552
Potassium persulfate	$K_2S_2O_8$	0.13516
Sodium nitrite	$NaNO_2$	0.034498
Sodium oxalate	$Na_2C_2O_4$	0.067000
Sodium persulfate	$Na_2S_2O_8$	0.11905
Tin	Sn	0.059345

TABLE 11.28 Titrimetric (Volumetric) Factors (*Continued*)

Silver nitrate

The following factors are the equivalent of 1 mL of *normal silver nitrate.* Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

Substance	Formula	Grams
Ammonium bromide	NH_4Br	0.097948
Ammonium chloride	NH_4Cl	0.053492
Ammonium iodide	NH_4I	0.14494
Ammonium thiocyanate	NH_4SCN	0.076120
Barium chloride	$BaCl_2$	0.10412
Barium chloride	$BaCl_2 \cdot 2H_2O$	0.12214
Bromine	Br	0.079909
Cadmium chloride	$CdCl_2$	0.091653
Cadmium iodide	CdI_2	0.18310
Calcium chloride	$CaCl_2$	0.055493
Chlorine	Cl	0.035453
Ferric chloride	$FeCl_3$	0.054069
Ferrous chloride	$FeCl_2$	0.063377
Hydriodic acid	HI	0.12791
Hydrobromic acid	HBr	0.080917
Hydrochloric acid	HCl	0.036461
Iodine	I	0.126904
Lithium chloride	LiCl	0.042392
Lead chloride	$PbCl_2$	0.13905
Magnesium chloride	$MgCl_2$	0.047609
Magnesium chloride	$MgCl_2 \cdot 6H_2O$	0.10166
Potassium bromide	KBr	0.11901
Potassium chloride	KCl	0.074555
Potassium iodide	KI	0.16601
Potassium oxide	K_2O	0.047102
Potassium thiocyanate	KSCN	0.097184
Silver	Ag	0.10787
Silver iodide	AgI	0.23477
Silver nitrate	$AgNO_3$	0.16987
Sodium bromide	NaBr	0.10290
Sodium bromide	$NaBr \cdot 2H_2O$	0.13893
Sodium chloride	NaCl	0.058443
Sodium iodide	NaI	0.14989
Sodium iodide	$NaI \cdot 2H_2O$	0.18592
Sodium oxide	Na_2O	0.030990
Strontium chloride	$SrCl_2$	0.079263
Strontium chloride	$SrCl_2 \cdot 6H_2O$	0.13331
Zinc chloride	$ZnCl_2$	0.068138

TABLE 11.28 Titrimetric (Volumetric) Factors (*Continued*)

Sodium thiosulfate

The following factors are the equivalent of 1 mL of *normal sodium thiosulfate*. Where the normality of the solution being used is other than normal, multiply the factors given in the table below by the normality of the solution employed.

Substance	Formula	Grams
Acetone	$(CH_3)_2CO$	0.0096801
Ammonium chromate	$(NH_4)_2CrO_4$	0.050690
Antimony	Sb	0.06088
Antimony trioxide	Sb_2O_3	0.07287
Bleaching powder	$CaOCl_2$	0.063493
Bromine	Br	0.079909
Chlorine	Cl	0.035453
Chromic oxide	Cr_2O_3	0.02533
Chromium trioxide	CrO_3	0.033331
Copper	Cu	0.06354
Copper oxide	CuO	0.07954
Copper sulfate	$CuSO_4$	0.15960
Copper sulfate	$CuSO_4 \cdot 5H_2O$	0.24968
Iodine	I	0.126904
Lead chromate	$PbCrO_4$	0.10773
Lead dioxide	PbO_2	0.11959
Nitrous acid	HNO_2	0.023507
Potassium chromate	K_2CrO_4	0.064733
Potassium dichromate	$K_2Cr_2O_7$	0.049032
Red lead	Pb_3O_4	0.34278
Sodium chromate	Na_2CrO_4	0.053991
Sodium dichromate	$Na_2Cr_2O_7$	0.043661
Sodium dichromate	$Na_2Cr_2O_7 \cdot 2H_2O$	0.049666
Sodium nitrite	$NaNO_2$	0.034498
Sodium thiosulfate	$Na_2S_2O_3$	0.15811
Sodium thiosulfate	$Na_2S_2O_3 \cdot 5H_2O$	0.24818
Sulfur	S	0.016032
Sulfur dioxide	SO_2	0.032031
Tin	Sn	0.059345

11.6.2 Titrimetric (Volumetric) Factors for Acid-Base Titrations

Titrimetric (volumetric) factors for acids and bases are given in Table 11.28. Suitable indicators for acid-base titrations may be found in Tables 8.23 and 8.24.

11.6.3 Standard Volumetric (Titrimetric) Redox Solutions

Alkaline arsenite, 0.1*N* As(III) to As(V). Dissolve 4.9460 g of primary standard grade As_2O_3 in 40 mL of 30% NaOH solution. Dilute with 200 mL of water. Acidify the solution with 6*N* HCl to the acid color of methyl red indicator. Add to this solution 40 g of $NaHCO_3$ and dilute to 1 L.

Ceric sulfate, 0.1*N* Ce(IV) to Ce(III). Dissolve 63.26 g of cerium(IV) ammonium sulfate dihydrate in 500 mL of 2*N* sulfuric acid. Dilute the solution to 1 L and standardize against the

alkaline arsenite solution as follows: measure, accurately, 30 to 40 mL of arsenite solution into an Erlenmeyer flask and dilute to 150 mL. Add slowly, to prevent excessive frothing, 20 mL of 4*N* sulfuric acid, 2 drops of 0.01*M* osmium tetraoxide solution, and 4 drops of 1,10-phenanthroline iron(II) complex indicator. Titrate with the ceric sulfate solution to a faint blue endpoint. Compute the normality of the ceric solution from the normality of the arsenite solution.

Iron(II) ammonium sulfate hexahydrate, 0.1*N* Fe(II) to Fe(III). Dissolve 39.2139 g of $FeSO_4 \cdot 2(NH_4)_2SO_4 \cdot 6H_2O$ in 500 mL of 1*N* sulfuric acid and dilute to 1 L. If desired, check against standard dichromate or permanganate solution.

Iodine, 0.1*N* (0 to 1−). Dissolve 12.690 g of resublimed iodine in 25 mL of a solution containing 15 g of KI which is free from iodate. After all the solid has dissolved, dilute to 1 L. If desired, check against a standard arsenite or standard thiosulfate solution.

Potassium bromate, 0.1*N* (5+ to 1−). Weigh out 2.7833 g of $KBrO_3$, dissolve in water, and dilute to 1 L.

Potassium dichromate, 0.1*N* Cr(VI) to Cr(III). Weigh out 4.9030 g of $K_2Cr_2O_7$ that has been dried at 120°C, dissolve in water, and dilute to 1 L.

Potassium iodate, 0.1*N* (5+ to 1−). Weigh out exactly 3.5667 g of KIO_3 (free from iodide), dried at 120°C, and dissolve in water containing about 15 g of KI, and dilute to 1 L.

Potassium permanganate, 0.1*N* (7+ to 2+). Dissolve about 3.3 g in a liter of distilled water. Allow this to stand for 2 or 3 days, then siphon it carefully through clean glass tubes or filter it through a Gooch crucible into the glass container in which it is to be kept, discarding the first 25 mL and allowing the last inch of liquid to remain in the bottle. In this way any dust or reducing substance in the water is oxidized, and the MnO_2 formed is removed. Permanganate solutions should never be allowed to come into contact with rubber, filter paper, or any other organic matter, and should be stored away from light. To standardize the $KMnO_4$, weigh accurately samples of about 0.3 g of primary standard grade $Na_2C_2O_4$ into Erlenmeyer flasks, add 150 mL of distilled water and 4 mL of concentrated H_2SO_4, and heat to 70°C and maintain at this temperature throughout the titration with the permanganate solution. The end point is a faint, permanent pink color throughout the solution. Equivalent weight of $Na_2C_2O_4/2$ is 67.000 g.

Sodium thiosulfate, 0.1*N*. Weigh 24.818 g of fresh crystals of $Na_2S_2O_3 \cdot 5H_2O$, dissolve in distilled water. Add 0.5 g of Na_2CO_3 and 0.5 mL of chloroform as preservative. Dilute to 1 L.

Equations for the principal methods for the redox determinations of the elements are given in Table 11.29. Volumetric factors in redox titrations for the common titrants are given in Table 11.28.

11.6.4 Indicators for Redox Titrations

A selected list of redox indicators will be found in Table 8.26. A redox indicator should be selected so that its E^0 is approximately equal to the electrode potential at the equivalent point, or so that the color change will occur at an appropriate part of the titration curve. If n is the number of electrons involved in the transition from the reduced to the oxidized form of the indicator, the range in which the color change occurs is approximately given by $E^0 \pm 0.06/n$ volt (V) for a two-color indicator whose forms are equally intensely colored. Since hydrogen ions are involved in the redox equilibria of many indicators, it must be recognized that the color change interval of such an indicator will vary with pH.

In Table 8.26, E^0 represents the redox potential at which the color change of the indicator would normally be perceived in a solution containing approximately 1*M* H^+. For a one-color indicator this is the potential at which the concentration of the colored form is just large enough to impart a visible color to the solution and depends on the total concentration of indicator added to the solution. If it is the reduced form of the indicator that is colorless, the potential at which the first visible color

appears becomes less positive as the total concentration of indicator increases. For a two-color indicator, the potential at which the middle tint appears is independent of the total indicator concentration, but may differ from the potentiometrically determined formal potential of the indicator in either direction, depending on which of the two forms is more intensely colored. If the reduced form is the more intense color, the middle tint will appear at a potential more positive than the potentiometrically measured formal potential, which is the potential at which the two forms are present at equal concentrations.

In addition to those indicators listed in Table 8.26, there are indicators for bromometric and iodometric titrations:

Specific reagents for titrations with bromine or bromate

Methyl orange or methyl red	Use acid-base indicator solutions. Oxidation causes bleaching of indicator to colorless
Bordeaux acid red 17	Dissolve 2 g dye in 1 L water. The red solution is oxidized to pale yellowish green or colorless.
Naphthol blue black	Dissolve 2 g dye in 1 L water. The blue solution is oxidized to pale red.

Specific reagents for iodometric titrations

Organic solvents such as CCl_4, $CHCl_3$	Up to 5 mL solvent is usually added per titration. Near the end point the mixture is shaken vigorously after each addition of titrant, and the appearance or disappearance of the I_2 color in the organic layer is observed.
Starch	Suspend 5 g of soluble starch in 50 mL of saturated NaCl solution, and stir slowly into 500 mL of boiling saturated NaCl solution. Cool and bottle. Free iodine produces a blue-black color.

TABLE 11.29 Equations for the Redox Determinations of the Elements with Equivalent Weights

Al	$Al(C_9H_6NO)_3 + 3\ HCl = AlCl_3 + 3\ C_9H_7NO$ (8-hydroxyquinoline) $3\ C_9H_7NO + 6\ Br_2 = 3\ C_9H_5Br_2NO + 6\ HBr$ $Al/12 = 2.2485$; $Al_2O_3/24 = 4.2483$
As^0	$As + 5\ Ce(IV) + 4\ H_2O = H_3AsO_4 + 5\ Ce(III) + 5\ H^+$ $As/5 = 14.9843$
As(III)	$5\ H_3AsO_3 + 2\ KMnO_4 + 6\ HCl = 5\ H_3AsO_4 + 2\ MnCl_2 + 3\ H_2O$ $H_3AsO_3 + 2\ Ce(SO_4)_2 + H_2O = H_3AsO_4 + Ce_2(SO_4)_3 + H_2SO_4$ $As/2 = 37.4608$; $As_2O_3/4 = 49.460$
	$3\ H_3AsO_3 + KBrO_3\ (+\ HCl) = 3\ H_3AsO_4 + KBr$ $H_3AsO_3 + I_2 + 2\ H_2O = H_3AsO_4 + 2\ I^- + 2\ H^+$ $As/2 = 37.4608$; $As_2O_3/4 = 49.460$
As(V)	$H_3AsO_4 + 2\ KI\ (excess) + 2\ HCl = H_3AsO_3 + I_2 + 2\ KCl + H_2O$ $I_2 + 2\ Na_2S_2O_3 = 2\ NaI + Na_2S_4O_6$ $As/2 = 37.4608$; $As_2O_3/4 = 49.460$

TABLE 11.29 Equations for the Redox Determinations of the Elements with Equivalent Weights (*Continued*)

Ba	$BaCrO_4 + 6\ KI\ (excess) + 16\ HCl = 2\ BaCl_2 + 3\ I_2 + 6\ KCl + 2\ CrCl_3 + 8\ H_2O$ $I_2 + 2\ Na_2S_2O_3 = 2\ NaI + Na_2S_4O_6$ $\quad Ba/3 = 45.78$ $BaCrO_4 + 3\ Fe^{2+}\ (excess) + 8\ H^+ = Ba^{2+} + Cr^{3+} + 3\ Fe^{3+} + 4\ H_2O$ Titrate excess Fe^{2+} with permanganate or dichromate; $Ba/3 = 45.78$
Br_2	$Br_2 + 2\ KI\ (excess) = 2\ KBr + I_2$ $I_2 + 2\ Na_2S_2O_3 \rightarrow 2\ NaI = Na_2S_4O_6$ $\quad Br_2/2 = 79.904$
Br^-	$Br^- + 3\ HClO = BrO_3^- + 3\ Cl^- + 3\ H^+$ $Br/6 = 13.317$
BrO_3^-	$BrO_3^- + 6\ I^-\ (excess) + 6\ H^+ = Br^- + 3\ I_2 + 3H_2O$ $I_2 + 2\ Na_2S_2O_3 = 2\ NaI + Na_2S_4O_6$ $KBrO_3/6 = 27.835$
CO	$5\ CO + I_2O_5 = 5\ CO_2 + I_2$ (at 125°C; adsorbed and measured colorimetrically) $5/2\ CO = 70.02$
$C_2O_4^{2-}$	Titrate as for CaC_2O_4
$C_2O_6^{2-}$	Acidify and titrate as for H_2O_2; $C_2O_6^{2-} + 2\ H^+ = H_2O_2 + CO_2$ $K_2C_2O_6/2 = 99.11$
Ca	$5\ CaC_2O_4 + 2\ KMnO_4 + 8\ H_2SO_4 = 5\ CaSO_4 + 10\ CO_2 + K_2SO_4 + 2\ MnSO_4 + 8\ H_2O$ $Ca/2 = 20.039$; $CaO/2 = 28.04$
Cd	$Cd(anthranilate)_2 + 4\ Br_2 = 2\ NH_2C_6H_2Br_2COOH + 4\ Br^-$ Titrate with $KBrO_3$—KBr until color of indigo changes to yellow. Add KI and back-titrate iodine liberated with thiosulfate. $Cd/8 = 14.05$
Ce	Oxidize Ce(III) to Ce(IV) with $(NH_4)_2S_2O_8$ plus Ag^+; destroy excess by boiling. $2\ Ce(SO_4)_2 + 2\ FeSO_4 = Ce_2(SO_4)_3 + Fe_2(SO_4)_3$ $Ce/1 = 140.12$; $Ce_2O_3/2 = 164.12$
Cl_2	Same as for Br_2; $Cl_2/2 = 35.453$
ClO^-	$ClO^- + 2\ I^- + 2\ H = Cl^- + I_2 + H_2O$ Titrate liberated I_2 with thiosulfate; $HClO/2 = 26.230$
ClO_2^-	$ClO_2^- + 4\ I^- + 4\ H^+ = Cl^- + 2\ I_2 + 2\ H_2O$ Titrate liberated I_2 with thiosulfate; $HClO/2 = 26.230$
ClO_3^-	$ClO_3^- + 6\ I^- + 6\ H_2O = Cl^- + 3\ I_2 + 3\ H_2O$ Titrated liberated I_2 with thiosulfate; $HClO_2/4 = 17.115$ $ClO_3^- + 3\ H_3AsO_3\ (excess;\ boil\ with\ strong\ HCl) = Cl^- + 3\ H_3AsO_4$ Titrate excess H_3AsO_3 with bromate; $HClO_3/6 = 14.077$
Co	$Co(NH_3)_6^{2+} + Fe(CN)_6^{3-}$ [Citrate-NH_3 buffer] $= Co(NH_3)_6^{3+} + Fe(CN)_6^{4-}$ $Co/1 = 58.9332$ Precipitate Co anthranilate and treat as for cadmium; $Co/8 = 7.3667$
Cr	$Cr_2O_7^{2-} + 6\ Fe^{2+} + 14\ H^+ = 2\ Cr^{3+} + 6\ Fe^{3+} + 7\ H_2O$ $Cr/3 = 17.332$; $Cr_2O_3/6 = 25.337$
Cu	$2\ Cu^{2+} + 2\ I^- + 2SCN^- = 2CuSCN + I_2$ Titrate the liberated iodine with thiosulfate; $Cu/1 = 63.546$ $4\ CuSCN + 7\ IO_3^- + 14\ H^+ + 7\ Cl^- = 4\ Cu^{2+} + 4\ SO_4^{2-} + 7\ ICl + 4\ HCN + 5\ H_2O$ Precipitate and wash CuSCN. Titrate with standard KIO_3 solution with 5 mL $CHCl_3$ until a definite I_2 color appears in the organic layer. Back-titrate the excess I_2 with standard thiosulfate solution. $Cu/7 = 9.078$; $KIO_3/4 = 53.505$
Fe(II)	$5\ Fe^{2+} + MnO_4^- + 8\ H^+ = 5\ Fe^{3+} + Mn^{2+} + 4\ H_2O$ $Fe^{2+} + Ce(IV) = Fe^{3+} + Ce(III)$; use 1,10-phenanthroline iron(II) indicator. $6\ Fe^{2+} + Cr_2O_7^{2-} + 14\ H^+ = 6\ Fe^{3+} + 2\ Cr^{3+} + 7\ H_2O$; use diphenylamine sulfonate indicator. $Fe/1 = 55.847$; $Fe_2O_3/2 = 79.845$

TABLE 11.29 Equations for the Redox Determinations of the Elements with Equivalent Weights (*Continued*)

Fe(III)	$Fe^{3+} + 4\ SCN^- = Fe(SCN)_4^-$; $Fe(SCN)_4^- + Ti(III) = Fe^{2+} + Ti(IV) + 4\ SCN^-$ Fe/1 = 55.847; $Fe_2O_3/2$ = 79.845
	$2\ Fe^{3+} + Zn = 2\ Fe^{2+} + Zn^{2+}$; then proceed by a method under Fe(II).
	$Fe^{3+} + Ag + Cl^- = Fe^{2+} + AgCl$; then proceed by a method under Fe(II).
	$2\ Fe^{3+} + SnCl_2$(slight excess) $+ 4\ Cl^- = 2\ Fe^{2+} + SnCl_6^{2-}$ $2\ HgCl_2 + SnCl_2 + 2\ Cl^- = Hg_2Cl_2 + SnCl_6^{2-}$ Pour above mixture into an H_3PO_4 plus $MnSO_4$ solution and titrate with $KMnO_4$ as under Fe(II). Fe/1 = 55.847; $Fe_2O_3/2$ = 79.845
	$2\ Fe^{3+} + 2\ I^- = Fe^{2+} + I_2$ Titrate liberated iodine with thiosulfate; Fe/1 = 55.847; $Fe_2O_3/2$ = 79.845
I_2	$I_2 + 2\ S_2O_3^{2-} = 2\ I^- + S_4O_6^{2-}$ [titrate solution (pH ∘ 7.0) with thiosulfate until color is pale yellow. Add KI and starch and continue titration to disappearance of blue color. $I_2/2$ = 126.9045 $I_2 + H_3AsO_3 + H_2O = 2\ I^- + H_3AsO_4 + 2\ H^+$; use starch and KI as indicator. $I_2/2$ = 126.9045
I^-	$2\ I^- + Br_2$(excess) $= I_2 + 2Br^-$ Remove excess Br_2 formic acid and titrate I_2 with thiosulfate. $I_2/2$ = 126.9045
IO_3^-	$IO_3^- + 5\ I^-$(excess) $+ 6\ H^+ = 3\ I_2 + 3\ H_2O$; titrate I_2 with thiosulfate. $KIO_3/6$ = 35.67
IO_4^-	$IO_4^- + 7\ I^-$(excess) $+ 8\ H^+ = 4\ I_2 + 4\ H_2O$; use a neutral buffered solution. Titrate I_2 with thiosulfate. $KIO_4/2$ = 115.00
K	$K_2Na[Co(NO_2)_6]$; dissolve in H_2SO_4 and titrate with either $KMnO_4$ or Ce(IV). ca. K/5.5 but use an empirical factor.
Mg	$Mg(oxine)_2$; dissolve precipitate and use procedure for Al(8-hydroxyquinoline)$_3$. Mg/8 = 3.0381
Mn(II)	$2\ Mn^{2+} + 5\ BiO_3^- + 14\ H^+ = 2\ MnO_4^- + 5\ Bi^{3+} + 7\ H_2O$ $2\ MnO_4^- + 5\ AsO_3^{3-} + 6\ H^+ = 2\ Mn^{2+} + 5\ AsO_4^{3-} + 3\ H_2O$; Mn/5 = 10.9876
	$2\ Mn^{2+} + 5\ S_2O_8^{2-} + 8\ H_2O$ (Ag^+ catalyst) $= 2\ MnO_4^- + 10\ SO_4^{2-} + 16\ H^+$ Titrate the permanganate formed with iron(II) as under iron(II); Mn/5 = 10.9876
	$2\ Mn^{2+} + 5\ IO_4^- + 3\ H_2O = 2\ MnO_4^- + 5\ IO_3^- + 6\ H^+$ Slowly precipitate excess KIO_4 with $Hg(NO_3)_2$. Filter, add excess Fe^{2+} and titrate excess with standard $KMnO_4$ solution; Mn/5 = 10.9876
	$MnO_4^- + 4\ Mn^{2+} + 15\ H_2P_2O_7^{2-}$ [pH range 4 to 7] $= 5\ Mn(H_2P_2O_7)_3^{3-} + 4\ H_2O$ Use Pt—SCE indicator system; Mn/1 = 54.9380
Mn(IV)	$MnO_2 + 2\ Fe^{2+}$(excesss standard) $+ 4\ H^+ = Mn^{2+} + 2\ Fe^{3+} + 2\ H_2O$ (use CO_2 atmosphere)
	$MnO_2 + H_2C_2O_4$(excess standard) $+ 2\ H^+ = Mn^{2+} + 2\ CO_2 + 2\ H_2O$ (use CO_2 atmosphere)
	In either of the above, titrate excess with $KMnO_4$. Mn/2 = 27.469; $MnO_2/2$ = 43.47
Mn(VI)	$MnO_4^{2-} + 2H_2C_2O_4 + 4\ H^+ = Mn^{2+} + 4\ CO_2 + 4\ H_2O$ Add excess oxalate and back-titrate with permanganate. Mn/4 = 13.7345
Mn(VII)	$2\ MnO_4^- + 5H_2C_2O_4\ 6\ H^+ = 2\ Mn^{2+} + 10\ CO_2 + 3\ H_2O$; Mn/5 = 10.9876
Mo	Mo(VI) + Zn = Mo(III) + Zn^{2+}; catch eluate in excess $Fe_2(SO_4)_3$ solution Mo(III) $+ 3\ Fe^{3+} + 4\ H_2O = MoO_4^{2+} + 3\ Fe^{2+}\ 8\ H^+$; titrate Fe(II) with $KMnO_4$ Mo/3 = 31.98
	Mo(VI) + Ag + Cl^- = Mo(V) + AgCl; pass through Ag reductor at 60–80°C. Mo(V) + Ce(IV) = Mo(VI) + Ce(III); Mo/l = 95.94
N_2H_4	$3\ N_2H_4 + 2\ BrO_3^-$(excess) $= 3\ N_2 + 2\ Br^- + 6\ H_2O$; add excess KI and titrate I_2 with thiosulfate. $N_2H_4/4$ = 8.01
NH_2OH	$NH_2OH + BrO_3^- = NO_3^- + Br^- + H^+ + H_2O$; proceed as above for N_2H_4. $NH_2OH/6$ = 5.505

TABLE 11.29 Equations for the Redox Determinations of the Elements with Equivalent Weights (*Continued*)

HN_3	$2\ HN_3 + 2\ Ce(IV)(excess) = 3\ N_2 + 2\ Ce(III) + 2\ H^+$; done under inert atmosphere. Add excess KI and titrate with thiosulfate. $HN_3/1 = 43.03$
NO_2^-	$5\ NO_2^- + 2\ MnO_4^-(excess) + 6\ H^+ = 5\ NO_3^- + 2\ Mn^{2+} + 3\ H_2O$; determine excess $KMnO_4$ standard $Na_2C_2O_4$ solution. $NaNO_2/1 = 69.00$
	$NO_2^- + 2\ Ce(IV)(excess) + H_2O = NO_3^- + 2\ Ce(III) + 2\ H^+$; warmed to 50°C. Add excess standard Fe(II) solution and back-titrate with standard Ce(IV) using erioglaucine indicator. $NaNO_2/1 = 69.00$
NO_3^-	NO_3^- + excess Fe^{2+} (Mo catalyst) + $4H^+ = NO + Fe^{3+}$. Add H_3PO_4 and back-titrate excess Fe(II) with $K_2Cr_2O_7$. $NaNO_3/3 = 28.34$
Nb(V)	$Nb(V) + Zn = Nb(III) + Zn^{2+}$; catch reduced solution under excess Fe(III). $Nb(III) + 2\ Fe^{3+} = Nb(V) + 2\ Fe^{2+}$; titrate Fe(II) with MnO_4 solution using 1,10-phenanthroline as indicator. $Nb/2 = 46.453$; $Nb_2O_5 = 66.455$
Ni	Precipitate $Ni(anthranilate)_2$ and proceed as under Cd. $Ni/8 = 7.336$
O_2	$O_2 + 2\ Mn^{2+} + 2\ OH^- = 2\ MnO_2 + 2\ H^+$; stoppered flask plus KI $MnO_2 + 2\ I^- + 4\ H^+ = Mn^{2+} + I_2\ 2H_2O$; titrate I_2 released with thiosulfate. $O_2/4 = 7.007$
O_3	$O_3 + 2\ I^- + H_2O = O_2 + I_2 + 2\ OH^-$; acidify and titrate with thiosulfate. $O_3/2 = 24.00$
H_2O_2	$5\ H_2O_2 + 2\ MnO_4^- + 6\ H^+ = 5\ O_2 + 2\ Mn^{2+} + 8\ H_2O$; $H_2O_2/2 = 17.01$
	$H_2O_2 + 2\ Ce(IV) + 2\ H^+ = 2\ Ce(III) + 2\ H_2O$; use 1,10-phenanthroline indicator $H_2O_2/1 = 34.02$
	$H_2O_2 + 2\ I^- + 2\ H^+ = I_2 + 2\ H_2O$; titrate I_2 with thiosulfate. $H_2O_2/2 = 17.01$
	$H_2O_2 + 2\ Ti(III) + 2H^+ = 2\ Ti(IV) + 2H_2O$; end point is disappearance of the yellow color of peroxotitanic acid. $H_2O_2/2 = 17.01$
P	The yellow precipitate of $(NH_4)_3[P(Mo_3O_{10})_4]$ is dissolved in NH_4OH, then solution is strongly acidified with H_2SO_4. See molybdenum; 12 moles Mo per P. $P/36 = 0.86038$
HPH_2O_2	$HPH_2O_2 + 2\ I_2(excess) + 2\ H_2O = H_3PO_4 + 4\ I^- + 4\ H^+$ (let stand 10 h) Make solution alkaline with $NaHCO_3$ and titrate excess I_2 with standard arsenite solution. $HPH_2O_2/4 = 16.499$
H_3PO_3	$H_3PO_3 + I_2(excess) + H_2O = H_3PO_4 + 2\ I^- + 2\ H^+$ (use $CO_2/NaHCO_3$ buffer; let stand 40–60 min in stoppered flask). Titrate excess I_2 with standard arsenite solution. $H_3PO_3/2 = 41.00$
Pb	Isolate Pb as $PbSO_4$, dissolve it in NaOAc and precipitate with $K_2Cr_2O_7$. Dissolve K_2CrO_4 in NaCl—HCl solution, add KI, and titrate I_2 with thiosulfate solution. $2\ PbCrO_4 + 6\ I^- + 16\ H^+ = 2\ Pb^{2+} + 2\ Cr^{3+} + 3\ I_2 + 8\ H_2O$ $Pb/3 = 69.1$; $PbO/3 = 74.4$
S^{2-}	$H_2S + I_2(excess) = S + 2\ I^- + 2\ H^+$ Back-titrate excess I_2 with standard thiosulfate solution. $S/2 = 16.03$; $H_2S/2 = 17.04$
	$H_2S + 4\ Br_2 + 4\ H_2O = SO_4^{2-} + 8\ Br^- + 10\ H^+$ Use excess KBr and standard $KBrO_3$ solution. Let stand until clear, add excess KI, and titrate with standard thiosulfate solution. $H_2S/8 = 4.260$; $SO_2/2 = 32.03$; $SCN/6 = 9.681$
SO_2, SO_3^{2-}	$SO_2 + I_2 + 2\ H_2O = SO_4^{2-} + 2\ I^- + 4\ H^+$ (Titrate excess I_2 with standard thiosulfate) $SO_2/2 = 32.03$
	$SO_2 + 4\ Br_2 + 2\ H_2O = SO_4^{2-} + 2\ Br^- + 4\ H^+$ (Titrate with standard $KBrO_3$—KBr solution until methyl orange is bleached.) $SO_2/2 = 32.03$
$S_2O_3^{2-}$	$2\ S_2O_3^{2-} + I_2 = S_4O_6^{2-} + 2\ I^-$ (Use starch indicator) $Na_2S_2O_3/1 = 158.11$
H_2SO_5	$SO_5^{2-} + H_3AsO_3 = SO_4^{2-} + H_3AsO_4$ $H_2SO_5/2 = 57.04$
$S_2O_8^{2-}$	$S_2O_8^{2-} + H_3AsO_3 + H_2O = 2\ SO_4^{2-} + H_3AsO_4 + 2\ H^+$ $H_2S_2O_8/2 = 97.07$
	$S_2O_8^{2-} + 2\ Fe^{2+} = 2\ SO_4^{2-} + 2\ Fe^{3+}$ $H_2S_2O_8/2 = 97.07$

TABLE 11.29 Equations for the Redox Determinations of the Elements with Equivalent Weights (*Continued*)

Sb	$5\ Sb(III) + 2\ MnO_4^- + 16\ H^+ = 5\ Sb(V) + 2\ Mn^{2+} + 8\ H_2O$
	$3\ Sb(III) + BrO_3^- + 6\ H^+ = 3\ Sb(V) + Br^- + 3\ H_2O$
	$Sb(III) + I_2$ [tartrate buffer, pH >7] $= Sb(V) + 2\ I^-$
	$Sb(III) + 2\ Ce(IV) = Sb(V) + 2\ Ce(III)$ For all four methods: $Sb/2 = 60.88$; $Sb_2O_3/4 = 72.88$
SeO_3^{2-}	$5\ H_2SeO_3 + 2\ MnO_4^- + 6\ H^+ = 5\ H_2SeO_4 + 2\ Mn^{2+} + 3\ H_2O$ $Na_2SeO_3/2 = 86.47$
	$H_2SeO_3 + 4\ I^- + 4\ H^+ = Se + 2\ I_2 + 3\ H_2O$ (titrate I_2 with standard thiosulfate solution) $Na_2SeO_3/2 = 86.47$
	$H_2SeO_3 + 4\ S_2O_3^{2-} + 4\ H^+ = SeS_4O_6^{2-} + S_4O_6^{2-} + 3\ H_2O$ (add small excess of thiosulfate and back-titrate with standard iodine solution) $Na_2SeO_3/4 = 47.23$
SeO_4^{2-}	$SeO_4^{2-} + 2\ H^+ + 2\ Cl^- = SeO_3^{2-} + Cl_2 + H_2O$ (absorb Cl_2 in KI solution) $Cl_2 + 2\ I^- = 2\ Cl^- + I_2$ (titrate I_2 with standard thiosulfate) $Na_2SeO_4/2 = 94.47$
Sn(IV)	$SnCl_6^{2-} + Pb = Sn^{2+} + Pb^{2+} + 6\ Cl^-$ (in CO_2 atmosphere boil 40 min) $Sn^{2+} + I_2 + 6\ Cl^- = SnCl_6^{2-} + 2\ I^-$ (at 0–3°C) $Sn/2 = 59.35$; $SnO_2/2 = 67.35$
Sn(II)	$Sn(II) + 2\ Ce(IV) = Sn(IV) + 2\ Ce(III)$ $Sn/2 = 59.35$
Te(IV)	$3\ H_2TeO_3 + Cr_2O_7^{2-} + 8\ H^+ = 3\ H_2TeO_4 + 2\ Cr^{3+} + 4\ H_2O$ $Te/2 = 63.80$
Te(VI)	$H_2TeO_4 + 2\ Cl^- + 2\ H^+ = H_2TeO_3 + Cl_2 + H_2O$ (see SeO_4^{2-}) $Te/2 = 63.80$
Ti	$2\ Ti(IV) + Zn(reductor) = 2Ti(III) + Zn(II)$ $Ti(III) + Fe^{3+} = Ti(IV) + Fe^{2+}$ (in CO_2 atmosphere; use KSCN as indicator) $Ti/1 = 47.88$ or Ti(III) + Methylene blue = Ti(IV) + colorless leuco base (in CO_2 atmosphere) $Ti/1 = 47.88$
Tl	$2\ Tl^+ + MnO_4^- + 8\ H^+ = 2\ Tl^{3+} + Mn^{2+} + 4\ H_2O$ $Tl/2 = 102.19$
	$Tl^+ + 2\ Ce^{3+} = Tl^{3+} + 2\ Ce^{3+}$ (to a yellow color or use 1,10-phenanthroline) $Tl/2 = 102.19$
U	$U(VI) + Zn = U(III) + U(IV) + Zn(II)$ [pass air through solution to oxidize U(III) to U(IV)] $5\ U^{4+} + 2\ MnO_4^- + 2\ H_2O = 5\ UO_2^{2+} + 2\ Mn^{2+} + 4\ H^+$ $U/2 = 119.01$; $U_3O_8/6 = 140.35$
V	Oxidize V(IV) to V(V) with permanganate. Destroy excess with sodium azide and boiling. $VO_2^+ + Fe^{2+} + 2\ H^+ = VO^{2+} + Fe^{3+} + H_2O$ (diphenyaminesulfonic acid indicator) $V/1 = 50.94$
	Reduce V(V) with SO_2 and bubble CO_2 through boiling solution to remove excess SO_2. $5\ VO^{2+} + MnO_4^- + H_2O = 5\ VO_2^+ + Mn^{2+} + 2\ H^+$ $V/1 = 50.94$
	Reduce V(V) to V(II) with Zn; catch eluate in excess Fe^{3+}. $V^{2+} + 2\ Fe^{3+} + H_2O = VO^{2+} + 2\ Fe^{2+} + 2\ H^+$ Titrate VO^{2+}—Fe^{2+} mixture with permanganate to VO_2^+—Fe^{3+} $V/3 = 16.98$; $V_2O_5/6 = 30.32$
Zn	Dissolve precipitate of $Zn[Hg(SCN)_4]$ in 4*M* HCl in stoppered flask, add $CHCl_3$. $2\ SCN^- + 3\ IO_3^- + 2\ H^+ + CN^- = 2\ SO_4^{2-} + 3\ ICN + H_2O$ $Zn/24 = 2.725$
	$2\ Fe(CN)_6^{3-} + 2\ I^- + 3\ Zn^{2+} + 2\ K^{2+} = K_2Zn_3[Fe(CN)_6]_2 + I_2$ Remove I_2 as formed by standard thiosulfate solution. $3Zn/2 = 98.07$ but empirical value of 99.07 is recommended.
	Precipitate $Zn(anthranilate)_2$; proceed as with Cd. $Zn/8 = 8.174$

Note: Additional procedural information plus interferences and general remarks will be found in J. A. Dean, ed., *Analytical Chemistry Handbook*, McGraw-Hill, New York, 1995.

11.6.5 Precipitation Titrations

Many precipitation reactions that are useful as separation techniques for gravimetric analysis fail to meet one or both of two requirements for titrimetry:

1. The reaction rate must be sufficiently rapid, particularly in the titration of dilute solutions and in the immediate vicinity of the end point. To increase the precipitation rate, it is sometimes beneficial to change solvents or to raise the temperature. By adding an excess of reagent and back-titrating, it may be possible to take advantage of a more rapid precipitation in the reverse direction. By choosing an end-point detection method that does not require equilibrium to be reached in the immediate vicinity of the end point, advantage may be taken of a faster reaction rate at points removed from the end point. Examples are: amperometric titrations, conductometric titrations, and photometric titrations.
2. The stoichiometry must be exact. Coprecipitation by solid-solution formation, foreign ion entrapment, and adsorption are possible sources of error.

Table 11.30 lists standard solutions for precipitation titrations and Table 11.31 lists specific reagents as indicators, adsorption indicators, and protective colloids for precipitation titrations.

11.6.6 Complexometric Titrations

A complexometric titration is based on the essentially stoichiometric reaction of a complexing agent (*chelon*) with another species to form a complex species (*chelonate*) that is only slightly dissociated and is soluble in the titration medium. In such a titration, either the chelon or the chelonate may serve as the limiting reagent (that is, as the titrant). The end point is detected by measuring or observing some property that reflects the change, in the vicinity of the equivalence point, in the concentration of the chelon or the chelonate. Examples of the application of metal-ion indicators are listed in Table 11.32. For a metal indicator to be useful, a proper sequence of effective stabilities must be met. On the one hand, the metal-indicator complex must be sufficiently stable to maintain itself in extremely dilute solution; otherwise the end-point color change will be spread over a broad interval of the titration, owing to the extended dissociation. On the other hand, the metal-indicator complex must be less stable than the metal chelonate; otherwise a sluggish end point, a late end point, or no end point at all will be obtained. Furthermore, the metal-indicator complex must react rapidly with the chelon. Only a limited number of the numerous chromogenic agents for metals allow this sequence and have useful indicator properties in chelometric titrations.

Among the complexing agents that find use as titrating agents, ethylenediamine-*N,N,N′,N′*-tetraacetic acid (acronym EDTA, and equation abbreviation, H_4Y) is by far the more important, and it is used in the vast majority of complexometric titrations. The successive acid pK_a values of H_4Y are $pK_1 = 2.0$, $pK_2 = 2.67$, $pK_3 = 6.16$, $pK_4 = 10.26$ at 20°C and an ionic strength of 0.1. The fraction α_4 present as the tetravalent anion is of particular importance in equilibrium calculations. Its magnitude at various pH values is given in Table 11.33.

The formation constants of EDTA complexes are gathered in Table 11.34. Based on their stability, the EDTA complexes of the most common metal ions may be roughly divided into three groups:

$\log K > 20$	Tri- and tetravalent cations including Bi, Fe(III), Ga, Hg(II), In, Sc, Th, U(IV), V(III), and Zr
$\log K = 15$ to 18	Divalent transition metals, rare earths, and Al
$\log K = 8$ to 11	Alkaline earths and Mg

The more stable the metal complex, the lower the pH at which it can be quantitatively formed. Elements in the first group may be titrated with EDTA at pH 1 to 3 without interference from cations of the last two groups, while cations of the second group may be titrated at pH 4 to 5 without interference from the alkaline earths.

In practice, an auxiliary complexing (masking) agent is usually added during EDTA titrations to prevent the precipitation of heavy metals as hydroxides or basic salts. The concentration of auxiliary complexing agents is generally high compared with the metal-ion concentration, and the solution is sufficiently well buffered so that the hydrogen ions produced during complexing of a metal ion by H_4Y do not cause an appreciable change in pH. Many EDTA titrations are carried out in ammonia–ammonium chloride buffers, which serve also to provide ammonia as an auxiliary complexing agent. The cumulative formation constants of ammine complexes are listed in Table 11.35.

11.6.6.1 Types of Chelometric Titrations. Chelometric titrations may be classified according to their manner of performance: direct titrations, back titrations, substitution titrations, redox titrations, or indirect methods.

11.6.6.1.1 Direct Titrations. The most convenient and simplest manner is the measured addition of a standard chelon solution to the sample solution (brought to the proper conditions of pH, buffer, etc.) until the metal ion is stoichiometrically chelated. Auxiliary complexing agents such as citrate, tartrate, or triethanolamine are added, if necessary, to prevent the precipitation of metal hydroxides or basic salts at the optimum pH for titration. For example, tartrate is added in the direct titration of lead. If a pH range of 9 to 10 is suitable, a buffer of ammonia and ammonium chloride is often added in relatively concentrated form, both to adjust the pH and to supply ammonia as an auxiliary complexing agent for those metal ions which form ammine complexes. A few metals, notably iron(III), bismuth, and thorium, are titrated in acid solution.

Direct titrations are commonly carried out using disodium dihydrogen ethylenediaminetetraacetate, Na_2H_2Y, which is available in pure form. The reaction of the chelon with the indicator must be rapid for a practical, direct titration. Where it is slow, heating of the titration medium is often expedient, or another indicator is employed.

11.6.6.1.2 Back Titrations. In the performance of a back titration, a known, but excess quantity of EDTA or other chelon is added, the pH is now properly adjusted, and the excess of the chelon is titrated with a suitable standard metal salt solution. Back titration procedures are especially useful when the metal ion to be determined cannot be kept in solution under the titration conditions or where the reaction of the metal ion with the chelon occurs too slowly to permit a direct titration, as in the titration of chromium(III) with EDTA. Back titration procedures sometimes permit a metal ion to be determined by the use of a metal indicator that is blocked by that ion in a direct titration. For example, nickel, cobalt, or aluminum form such stable complexes with Eriochrome Black T that the direct titration would fail. However, if an excess of EDTA is added before the indicator, no blocking occurs in the back titration with a magnesium or zinc salt solution. These metal ion titrants are chosen because they form EDTA complexes of relatively low stability, thereby avoiding the possible titration of EDTA bound by the sample metal ion.

In a back titration, a slight excess of the metal salt solution must sometimes be added to yield the color of the metal-indicator complex. Where metal ions are easily hydrolyzed, the complexing agent is best added at a suitable, low pH and only when the metal is fully complexed is the pH adjusted upward to the value required for the back titration. In back titrations, solutions of the following metal ions are commonly employed: Cu(II), Mg, Mn(II), Pb(II), Th(IV), and Zn. These solutions are usually prepared in the approximate strength desired from their nitrate salts (or the solution of the metal or its oxide or carbonate in nitric acid), and a minimum amount of acid is added to repress hydrolysis of the metal ion. The solutions are then standardized against an EDTA solution (or other chelon solution) of known strength.

11.6.6.1.3 Substitution Titrations. Upon the introduction of a substantial or equivalent amount of the chelonate of a metal that is less stable than that of the metal being determined, a substitution occurs, and the metal ion displaced can be titrated by the chelon in the same solution. This is a direct titration with regard to its performance, but in terms of the mechanism it can be considered as a substitution titration (or replacement titration).

In principle any ion can be used if it forms a weaker EDTA complex than the metal ion being determined. Still weaker metal-EDTA complexes would not interfere. Exchange reactions are also possible with other metal complexes to permit application of the chelometric titration to non-titrable cations and anions. The exchange reagent can be added and the titration performed in the sample solution without prior removal of the excess reagent. A most important example is the exchange of silver ion with an excess of the tetracyanonickelate ion according to the equation:

$$2\ Ag^{+} + Ni(CN)_4^{2-} \rightleftarrows 2\ Ag(CN)_2^{-} + Ni^{2+}$$

The nickel ion freed may then be determined by an EDTA titration. Note that two moles of silver are equivalent to one mole of nickel and thus to one mole of EDTA.

11.6.6.1.4 Redox Titrations. Redox titrations can be carried out in the presence of excess EDTA. Here EDTA acts to change the oxidation potential by forming a more stable complex with one oxidation state than with the other. Generally the oxidized form of the metal forms a more stable complex than the reduced form, and the couple becomes a stronger reducing agent in the presence of excess EDTA. For example, the Co(III)–Co(II) couple is shifted about 1.2 volts, so that Co(II) can be titrated with Ce(IV). Alternatively, Co(III) can be titrated to Co(II), with Cr(II) as a reducing agent.

Manganese(II) can be titrated directly to Mn(III) using hexacyanoferrate(III) as the oxidant. Alternatively, Mn(III), prepared by oxidation of the Mn(II)–EDTA complex with lead dioxide, can be determined by titration with standard iron(II) sulfate.

11.6.6.1.5 Indirect Procedures. Numerous inorganic anions that do not form complexes with a complexing agent are accessible to a chelatometric titration by indirect procedures. Frequently the anion can be precipitated as a compound containing a stoichiometric amount of a titrable cation. Another indirect approach employing replacement mechanism is the reduction of a species with the liquid amalgam of a metal that can be determined by a chelometric titration after removal of excess amalgam. For example:

$$2\ Ag^{+} + Cd(Hg) = Cd^{2+} + 2\ Ag(Hg)$$

The equivalent amount of cadmium ion exchanged for the silver ion can readily be determined by EDTA titration procedures.

11.6.6.2 Preparation of Standard Solutions

11.6.6.2.1 Standard EDTA Solutions. Disodium dihydrogen ethylenediaminetetraacetate dihydrate is available commercially of analytical reagent purity. After drying at 80°C for at least 24 hr, its composition agrees exactly with the dihydrate formula (molecular weight 372.25). It may be weighed directly. If an additional check on the concentration is required, it may be standardized by titration with nearly neutralized zinc chloride or zinc sulfate solution.

11.6.6.2.2 Standard Magnesium Solution. Dissolve 24.647 g of magnesium sulfate heptahydrate in water and dilute to 1 L for 0.1*M* solution.

11.6.6.2.3 Standard Manganese(II) Solution. Dissolve exactly 16.901 g ACS reagent grade manganese(II) sulfate hydrate in water and dilute to 1 L.

11.6.6.2.4 Standard Zinc Solution. Dissolve exactly 13.629 g of zinc chloride, ACS reagent grade, or 28.754 g of zinc sulfate heptahydrate, and dilute to 1 L for 0.1000*M* solution.

11.6.6.2.5 Buffer Solution, pH 10. Add 142 mL of concentrated ammonia solution (sp. grav. 0.88–0.90) to 17.5 g of analytical reagent ammonium chloride, and dilute to 250 mL.

11.6.6.2.6 Water. Distilled water must be (a) redistilled in an all-Pyrex glass apparatus or (b) purified by passage through a column of cation exchange resin in the sodium form. For storage, polyethylene bottles are most satisfactory, particularly for very dilute (0.001*M*) EDTA solutions.

11.6.6.2.7 Murexide Indicator. Suspend 0.5 g of powdered murexide in water, shake thoroughly, and allow the undissolved solid to settle. Use 5–6 drops of the supernatant liquid for each titration. Decant the old supernatant liquid daily and treat the residue with water to provide a fresh solution of the indicator.

Alternatively, grind 0.1 g of murexide with 10 g of ACS reagent grade sodium chloride; use about 50 mg of the mixture for each titration.

11.6.6.2.8 Pyrocatechol Violet Indicator Solution. Dissolve 0.1 g of the solid dyestuff in 100 mL of water.

11.6.7 Masking Agents

Masking (and demasking) techniques are widely used in analytical chemistry because they frequently provide convenient and elegant methods by which to avoid the effects of unwanted components of a system without having to resort to physical separation. The best molecules or ligands to use as masking agents are those that are chemically stable and nontoxic and react rapidly to form strong, colorless complexes with the ions to be masked, but form only relatively weak complexes with other ions that are present. Tables 11.36 and 11.37 are intended as qualitative guides to the types of masking agents likely to be suitable for particular analytical problems.

Masking must not be identified solely with complex formation. There are numerous complex compounds in which solutions show no masking effects. On the other hand, examples can be cited in which the product of soluble principal valence compounds may lead to masking. This latter category includes the annulment of the base action of NH_2— groups in carboxylic acids by the addition of formaldehyde, the masking of the iodometric oxidation of sulfites by formaldehyde, as well as the masking of almost all reactions of molybdenum(VI), tungsten(VI), and vanadium(V) by hydrogen peroxide or fluoride ion. Sometimes the masking agent changes the valence state of the metal ion. Examples include the reduction of Fe(III) to Fe(II) with hydrazine, hydroxylamine hydrochloride, or tin(II) chloride. Hydroxylamine also reduces Ce(IV) to Ce(III), Cu(II) to Cu(I), and Hg(II) to free Hg. Ascorbic acid reduces Cu(II) to Cu(I) in the presence of the chloride ion.

The reaction of the hydrogen sulfite ion in an alkaline solution with ketones and aldehydes is:

$$H_2C{=}O + HSO_3^- \rightleftarrows H_2C(OH)SO_3^-$$

The carbon-oxygen double bond of the carbonyl group is opened, and the hydrogen sulfite radical is added. An increase in temperature reverses the reaction more easily for ketones than for aldehydes.

Certain organic substances have no charge at any pH but form complexes with substances that do have a charge. The sugars and polyalcohols form such complexes in the pH range between 9 and 10 with a number of anions; including borate, molybdate, and arsenite. Elegant ion exchange methods have been devised for the sugars.

Probably the most extensively applied masking agent is cyanide ion. In alkaline solution, cyanide forms strong cyano complexes with the following ions and masks their action toward EDTA: Ag, Cd, Co(II), Cu(II), Fe(II), Hg(II), Ni, Pd(II), Pt(II), Tl(III), and Zn. The alkaline earths, Mn(II), Pb, and the rare earths are virtually unaffected; hence, these latter ions may be titrated with EDTA with the former ions masked by cyanide. Iron(III) is also masked by cyanide. However, as the hexacyanoferrate(III) ion oxidizes many indicators, ascorbic acid is added to form hexacyanoferrate(II) ion. Moreover, since the addition of cyanide to an acidic solution results in the formation of deadly

hydrogen cyanide, the solution must first be made alkaline, with hydrous oxide formation prevented by the addition of tartrate. Zinc and cadmium may be demasked from their cyanide complexes by the action of formaldehyde.

Masking by oxidation or reduction of a metal ion to a state which does not react with EDTA is occasionally of value. For example, Fe(III) ($\log K_{MY} = 24.23$) in acidic media may be reduced to Fe(II) ($\log K_{MY} = 14.33$) by ascorbic acid; in this state iron does not interfere in the titration of some trivalent and tetravalent ions in strong acidic medium (pH 0 to 2). Similarly, Hg(II) can be reduced to the metal. In favorable conditions, Cr(III) may be oxidized by alkaline peroxide to chromate which does not complex with EDTA.

In resolving complex metal-ion mixtures, more than one masking or demasking process may be utilized with various aliquots of the sample solution, or applied simultaneously or stepwise with a single aliquot. In favorable cases, even four or five metals can be determined in a mixture by the application of direct and indirect masking processes. Of course, not all components of the mixture need be determined by chelometric titrations. For example, redox titrimetry may be applied to the determination of one or more of the metals present.

11.6.8 Demasking

For the major part, masking reactions that occur in solutions and lead to soluble compounds are equilibrium reactions. They usually require the use of an excess of the masking agent and can be reversed again by removal of the masking agent. The freeing of previously masked ionic or molecular species has been called *demasking*. This merits consideration in regard to its use in analysis. Masking never completely removes certain ionic or molecular species, but only reduces their concentrations. The extent of this lowering determines which color or precipitation reactions can be prevented. A system masked against a certain reagent is not necessarily masked against another but more aggressive reagent. It is therefore easy to see that masked reaction systems can also function as reagents at times (e.g., Fehling's solution, Nessler's reagent).

The methods used in demasking are varied. One approach is to change drastically the hydrogen ion concentration of the solution. The conditional stability constants of most metal complexes depend greatly on pH, so that simply raising or lowering the pH is frequently sufficient for selective demasking. In most cases a strong mineral acid is added, and the ligand is removed from the coordination sphere of the complex through the formation of a slightly ionized acid, as with the polyprotic (citric, tartaric, EDTA, and nitriloacetic) acids.

Another type of demasking involves formation of new complexes or other compounds that are more stable than the masked species. For example, boric acid is used to demask fluoride complexes of tin(IV) and molybdenum(VI). Formaldehyde is often used to remove the masking action of cyanide ions by converting the masking agent to a nonreacting species through the reaction:

$$CN^- + HCHO \rightleftarrows OCH_2CN$$

which forms glycollic nitrile. Pertinent instances are the demasking of $Ni(CN)_4^{2-}$ ions to Ni^{2+} ions by formaldehyde and the demasking of dimethylglyoxime (dmg) from $Pd(dmg)_2^{2-}$ ions by cyanide. Selectivity is evident in that $Zn(CN)_4^{2-}$ is demasked whereas $Cu(CN)_3^{2-}$ is not.

Destruction of the masking ligand by chemical reaction may be possible, as in the oxidation of EDTA in acid solutions by permanganate or another strong oxidizing agent. Hydrogen peroxide and Cu(II) ion destroy the tartrate complex of aluminum.

Demasking methods for a number of masking agents are enumerated in Table 11.38.

TABLE 11.30 Standard Solutions for Precipitation Titrations

The list given below includes the substances that are most used and most useful for the standardization of solutions for precipitation titrations. Primary standard solutions are denoted by the letter (P) in Column 1.

Standard	Formula weight	Preparation
$AgNO_3$ (P)	169.89	Weigh the desired amount of ACS reagent grade* $AgNO_3$, dried at 105°C for 2 hr, and dissolve in double distilled water. Store in amber container and away from light. Check against NaCl.
$BaCl_2 \cdot 2H_2O$	244.28	Dissolve clear crystals of the salt in distilled water. Standardize against K_2SO_4 or Na_2SO_4.
$Hg(NO_3)_2 \cdot H_2O$	342.62	Dissolve the reagent grade salt in distilled water and dilute to desired volume. Standardize against NaCl.
KBr	119.01	The commercial reagent (ACS) may contain 0.2% chloride. Prepare an aqueous solution of approximately the desired concentration and standardize it against $AgNO_3$.
$K_4[Fe(CN)]_6 \cdot 3H_2O$	422.41	Dissolve the high-purity commercial salt in distilled water containing 0.2 g/L of Na_2CO_3. Kept in an amber container and away from direct sunlight, solutions are stable for a month or more. Standardize against zinc metal.
KSCN	97.18	Prepare aqueous solutions having the concentration desired. Standardize against $AgNO_3$ solution. Protect from direct sunlight.
K_2SO_4 (P)	174.26	Dissolve about 17.43 g, previously dried at 150°C and accurately weighed, in distilled water and dilute exactly to 1 L.
NaCl (P)	58.44	Dry at 130–150°C and weigh accurately, from a closed container, 5.844 g, dissolve in water, and dilute exactly to 1 L.
NaF (P)	41.99	Dry at 110°C and weigh the appropriate amount of ACS reagent. Dissolve in water and dilute exactly to 1 L.
Na_2SO_4 (P)	142.04	Weigh accurately 14.204 g, dried at 150°C, and dissolve in distilled water. Dilute to exactly 1 L.
$Th(NO_3)_4 \cdot 4H_2O$	552.12	Weigh the appropriate amount of crystals and dissolve in water. Standardize against NaF.

* Meets standards of purity (and impurity) set by the American Chemical Society.

TABLE 11.31 Indicators for Precipitation Titrations

Indicator	Preparation and use
	Specific reagents
$NH_4Fe(SO_4)_2 \cdot 12H_2O$	Use reagent (ACS)* grade salt, low in chloride. Dissolve 175 g in 100 mL 6 *M* HNO_3 which has been gently boiled for 10 min to expel nitrogen oxides. Dilute with 500 mL water. Use 2 mL per 100 mL of end-point volume.
K_2CrO_4	Use reagent (ACS)* grade salt, low in chloride. Prepare 0.1*M* aqueous solution (19.421 g/L). Use 2.5 mL per 100 mL of end-point volume.
Tetrahydroxy-1,4-benzoquinone (THQ)	Prepare fresh as required by dissolving 15 mg in 5 mL of water. Use 10 drops for each titration.
	Adsorption indicators
Bromophenol blue	Dissolve 0.1 g of the acid in 200 mL 95% ethanol.
2′,7′-Dichlorofluorescein	Dissolve 0.1 g of the acid in 100 mL 70% ethanol. Use 1 mL for 100 mL of initial solution.
Eosin, tetrabromofluorescein	See Dichlorofluorescein.
Fluorescein	Dissolve 0.4 g of the acid in 200 mL 70% ethanol. Use 10 drops.
Potassium rhodizonate, $C_4O_4(OK)_2$	Prepare fresh as required by dissolving 15 mg in 5 mL of water. Use 10 drops for each titration.
Rhodamine 6G	Dissolve 0.1 g in 200 mL 70% ethanol.
Sodium 3-alizarinsulfonate	Prepare a 0.2% aqueous solution. Use 5 drops per 120 mL end-point volume.
Thorin	Prepare a 0.025% aqueous solution. Use 5 drops.
	Protective colloids
Dextrin	Use 5 mL of 2% aqueous solution of chloride-free dextrin per 25 mL of 0.1*M* halide solution.
Polyethylene glycol 400	Prepare a 50% (v/v) aqueous solution of the surfactant. Use 5 drops per 100 mL end-point volume.

*Meets standards as set forth in *Reagent Chemicals*, American Chemical Society, Washington, D.C.; revised periodically.

TABLE 11.32 Properties and Applications of Selected Metal Ion Indicators

Indicator	Chemical name	Dissociation constants and colors of free indicator species	Colors of metal-indicator complexes	Applications
Calmagite 0.05 g/100 mL water; stable 1 year	1-(6-Hydroxy-*m*-tolylazo)-2-naphthol-4-sulfonic acid	H_2In^- (red); $pK_2 = 8.1$ HIn^{2-} (blue); $pK_3 = 12.4$ In^{3-} (orange)	Wine-red	Titrations performed with Eriochrome Black T as indicator may be carried out equally well with Calmagite
Eriochrome Black T 0.1 g/100 mL water; prepare fresh daily	1-(2-Hydroxy-1-naphthyl-azo)-6-nitro-2-naphthol-4-sulfonic acid	H_2In^- (red); $pK_2 = 6.3$ HIn^{2-} (blue); $pK_3 = 11.5$ In^{3-} (yellow-orange)	Wine-red	*Direct titration*: Ba, Ca, Cd, In, Mg, Mn, Pb, Sc, Sr, Tl, Zn, and lanthanides *Back titration*: Al, Ba, Bi, Ca, Co, Cr, Fe, Ga, Hg, Mn, Ni, Pb, Pd, Sc, Tl, V *Substitution titration*: Au, Ba, Ca, Cu, Hg, Pb, Pd, Sr
Murexide Suspend 0.5 g in water; use fresh supernatent liquid each day	5-[(Hexahydro-2,4,6-trioxo-5-pyrimidinyl)imino]-2,4,6(1*H*,3*H*,5*H*)-pyrimidinetrione monoammonium salt	H_4In^- (red-violet); $pK_2 = 9.2$ H_3In^{2-} (violet); $pK_3 = 10.9$ H_2In^{3-} (blue)	Red with Ca^{2+} Yellow with Co^{2+}, Ni^{2+}, and Cu^{2+}	*Direct titration*: Ca, Co, Cu, Ni *Back titration*: Ca, Cr, Ga *Substitution titration*: Ag, Au, Pd
PAN	1-(2-Pyridylazo)-2-naphthol	HIn (orange-red); $pK_1 = 12.3$ In^- (pink)	Red	*Direct titration*: Cd, Cu, In, Sc, Tl, Zn *Back titration*: Cu, Fe, Ga, Ni, Pb, Sc, Sn, Zn *Substitution titration*: Al, Ca, Co, Fe, Ga, Hg, In, Mg, Mn, Ni, Pb, V, Zn
Pyrocatechol Violet 0.1 g/100 mL; stable several weeks	Pyrocatecholsulfonephthalein	H_4In (red); $pK_1 = 0.2$ H_3In^- (yellow): $pK_2 = 7.8$ H_2In^{2-} (violet); $pK_3 = 9.8$ HIn^{3-} (red-purple); $pK_4 = 11.7$	Blue, except red with Th(IV)	*Direct titration*: Al, Bi, Cd, Co, Fe, Ga, Mg, Mn, Ni, Pb, Th, Zn *Back titration*: Al, Bi, Fe, Ga, In, Ni, Pd, Sn, Th, Ti
Salicylic acid	2-Hydroxybenzoic acid	H_2In; $pK_1 = 2.98$ HIn^-; $pK_2 = 12.38$	$FeSCN^{2+}$ at pH 3 is reddish-brown	Typical uses: Fe(III) titrated with EDTA to colorless iron-EDTA complex
Xylenol orange	3,3'-Bis[*N*,*N*-di(carboxy-ethyl)aminomethyl]-*o*-cresolsulfonephthalein	—COOH groups: $pK_3 = 0.76$; $pK_4 = 1.15$; $pK_5 = 2.58$; $pK_6 = 3.23$		Typical uses: Bi, Pb, Th

Source: J. A. Dean, ed., *Analytical Chemistry Handbook*, McGraw-Hill, New York, 1995.

TABLE 11.33 Variation of α_4 with pH

pH	$-\log \alpha_4$	pH	$-\log \alpha_4$
2.0	13.44	7.0	3.33
2.5	11.86	8.0	2.29
3.0	10.60	9.0	1.29
4.0	8.48	10.0	0.46
5.0	6.45	11.0	0.07
6.0	4.66	12.0	0.00

TABLE 11.34 Formation Constants of EDTA Complexes at 25°C, Ionic Strength Approaching Zero

Metal ion	$\log K_{MY}$	Metal ion	$\log K_{MY}$
Co(III)	36	V(IV)	18.0
V(III)	25.9	U(IV)	17.5
In	24.95	Ti(IV)	17.3
Fe(III)	24.23	Ce(III)	16.80
Th	23.2	Zn	16.4
Sc	23.1	Cd	16.4
Cr(III)	23	Co(II)	16.31
Bi	22.8	Al	16.13
Tl(III)	22.5	La	16.34
Sn(II)	22.1	Fe(II)	14.33
Ti(III)	21.3	Mn(II)	13.8
Hg(II)	21.80	Cr(II)	13.6
Ga	20.25	V(II)	12.7
Zr	19.40	Ca	11.0
Cu(II)	18.7	Be	9.3
Ni	18.56	Mg	8.64
Pd(II)	18.5	Sr	8.80
Pb(II)	18.3	Ba	7.78
V(V)	18.05	Ag	7.32

TABLE 11.35 Cumulative Formation Constants of Ammine Complexes at 20°C, Ionic Strength 0.1

Cation	$\log K_1$	$\log K_2$	$\log K_3$	$\log K_4$	$\log K_5$	$\log K_6$
Cadmium	2.65	4.75	6.19	7.12	6.80	5.14
Cobalt(II)	2.11	3.74	4.79	5.55	5.73	5.11
Cobalt(III)	6.7	14.0	20.1	25.7	30.8	35.2
Copper(I)	5.93	10.86				
Copper(II)	4.31	7.98	11.02	13.32	12.66	
Iron(II)	1.4	2.2				
Manganese(II)	0.8	1.3				
Mercury(II)	8.8	17.5	18.5	19.28		
Nickel	2.80	5.04	6.77	7.96	8.71	8.74
Platinum(II)						35.3
Silver(I)	3.24	7.05				
Zinc	2.37	4.81	7.31	9.46		

TABLE 11.36 Masking Agents for Various Elements

Element	Masking agent
Ag	Br^-, citrate, Cl^-, CN^-, I^-, NH_3, SCN^-, $S_2O_3^{2-}$, thiourea, thioglycolic acid, diethyldithiocarbamate, thiosemicarbazide, bis(2-hydroxyethyl)dithiocarbamate
Al	Acetate, acetylacetone, BF_4^-, citrate, $C_2O_4^{2-}$, EDTA, F^-, formate, 8-hydroxyquinoline-5-sulfonic acid, mannitol, 2,3-mercaptopropanol, OH^-, salicylate, sulfosalicylate, tartrate, triethanolamine, tiron
As	Citrate, 2,3-dimercaptopropanol, $NH_2OH \cdot HCl$, OH^-, S_2^{2-}, $S_2O_3^{2-}$, tartrate
Au	Br^-, CN^-, NH_3, SCN^-, $S_2O_3^{2-}$, thiourea
Ba	Citrate, cyclohexanediaminetetraacetic acid, *N*,*N*-dihydroxyethylglycine, EDTA, F^-, SO_4^{2-}, tartrate
Be	Acetylacetone, citrate, EDTA, F^-, sulfosalicylate, tartrate
Bi	Br^-, citrate, Cl^-, 2,3-dimercaptopropanol, dithizone, EDTA, I^-, OH^-, $Na_5P_3O_{10}$, SCN^-, tartrate, thiosulfate, thiourea, triethanolamine
Ca	BF_4^-, citrate, *N*,*N*-dihydroxyethylglycine, EDTA, F^-, polyphosphates, tartrate
Cd	Citrate, CN^-, 2,3-dimercaptopropanol, dimercaptosuccinic acid, dithizone, EDTA, glycine, I^-, malonate, NH_3, 1,10-phenanthroline, SCN^-, $S_2O_3^{2-}$, tartrate
Ce	Citrate, *N*,*N*-dihydroxyethylglycine, EDTA, F^-, PO_4^{3-}, reducing agents (ascorbic acid), tartrate, tiron
Co	Citrate, CN^-, diethyldithiocarbamate, 2,3-dimercaptopropanol, dimethylglyoxime, ethylenediamine, EDTA, F^-, glycine, H_2O_2, NH_3, NO_2^-, 1,10-phenanthroline, $Na_5P_3O_{10}$, SCN^-, $S_2O_3^{2-}$, tartrate
Cr	Acetate, (reduction with) ascorbic acid + KI, citrate, *N*,*N*-dihydroxyethylglycine, EDTA, F^-, formate, NaOH + H_2O_2, oxidation to CrO_4^{2-}, $Na_5P_3O_{10}$, sulfosalicylate, tartrate, triethylamine, tiron
Cu	Ascorbic acid + KI, citrate, CN^-, diethyldithiocarbamate, 2,3-dimercaptopropanol, ethylenediamine, EDTA, glycine, hexacyanocobalt(III)(3−), hydrazine, I^-, NaH_2PO_2, $NH_2OH \cdot HCl$, NH_3, NO_2^-, 1,10-phenanthroline, S^{2-}, SCN^- + SO_3^{2-}, $S_2O_3^{2-}$, sulfosalicylate, tartrate, thioglycolic acid, thiosemicarbazide, thiocarbohydrazide, thiourea
Fe	Acetylacetone, (reduction with) ascorbic acid, $C_2O_4^{2-}$, citrate, CN^-, 2,3-dimercaptopropanol, EDTA, F^-, NH_3, $NH_2OH \cdot HCl$, OH^-, oxine, 1,10-phenanthroline, 2,2'-bipyridyl, PO_4^{3-}, $P_2O_7^{4-}$, S^{2-}, SCN^-, $SnCl_2$, $S_2O_3^{2-}$, sulfamic acid, sulfosalicylate, tartrate, thioglycolic acid, thiourea, tiron, triethanolamine, trithiocarbonate
Ga	Citrate, Cl^-, EDTA, OH^-, oxalate, sulfosalicylate, tartrate
Ge	F^-, oxalate, tartrate
Hf	See Zr
Hg	Acetone, (reduction with) ascorbic acid, citrate, Cl^-, CN^-, 2,3-dimercaptopropan-1-ol, EDTA, formate, I^-, SCN^-, SO_3^{2-}, tartrate, thiosemicarbazide, thiourea, triethanolamine
In	Cl^-, EDTA, F^-, SCN^-, tartrate, thiourea, triethanolamine
Ir	Citrate, CN^-, SCN^-, tartrate, thiourea
La	Citrate, EDTA, F^-, oxalate, tartrate, tiron
Mg	Citrate, $C_2O_4^{2-}$, cyclohexane-1,2-diaminetetraacetic acid, *N*,*N*-dihydroxyethylglycine, EDTA, F^-, glycol, hexametaphosphate, OH^-, $P_2O_7^{4-}$, triethanolamine
Mn	Citrate, CN^-, $C_2O_4^{2-}$, 2,3-dimercaptopropanol, EDTA, F^-, $Na_5P_3O_{10}$, oxidation to MnO_4^-, $P_2O_7^{4-}$, reduction to Mn(II) with $NH_2OH \cdot HCl$ or hydrazine, sulfosalicylate, tartrate, triethanolamine, triphosphate, tiron
Mo	Acetylacetone, ascorbic acid, citrate, $C_2O_4^{2-}$, EDTA, F^-, H_2O_2, hydrazine, mannitol, $Na_5P_3O_{10}$, $NH_2OH \cdot HCl$, oxidation to molybdate, SCN^-, tartrate, tiron, triphosphate

TABLE 11.36 Masking Agents for Various Elements (*Continued*)

Element	Masking agent
Nb	Citrate, $C_2O_4^{2-}$, F^-, H_2O_2, OH^-, tartrate
Nd	EDTA
NH_4^+	HCHO
Ni	Citrate, CN^-, *N*,*N*-dihydroxyethylglycine, dimethylglyoxime, EDTA, F^-, glycine, malonate, $Na_5P_3O_{10}$, NH_3, 1,10-phenanthroline, SCN^-, sulfosalicylate, thioglycolic acid, triethanolamine, tartrate
Np	F^-
Os	CN^-, SCN^-, thiourea
Pa	H_2O_2
Pb	Acetate, $(C_6H_5)_4AsCl$, citrate, 2,3-dimercaptopropanol, EDTA, I^-, $Na_5P_3O_{10}$, SO_4^{2-}, $S_2O_3^{2-}$, tartrate, tiron, tetraphenylarsonium chloride, triethanolamine, thioglycolic acid
Pd	Acetylacetone, citrate, CN^-, EDTA, I^-, NH_3, NO_2^-, SCN^-, $S_2O_3^{2-}$, tartrate, triethanol amine
Pt	Citrate, CN^-, EDTA, I^-, NH_3, NO_2^-, SCN^-, $S_2O_3^{2-}$, tartrate, urea
Pu	Reduction to Pu(IV) with sulfamic acid
Rare earths	$C_2O_4^{2-}$, citrate, EDTA, F^-, tartrate
Re	Oxidation to perrhenate
Rh	Citrate, tartrate, thiourea
Ru	CN^-, thiourea
Sb	Citrate, 2,3-dimercaptopropanol, EDTA, F^-, I^-, OH^-, oxalate, S^{2-}, S_2^{2-}, $S_2O_3^{2-}$, tartrate, triethanolamine
Sc	Cyclohexane-1,2-diaminetetraacetic acid, F^-, tartrate
Se	Citrate, F^-, I^-, reducing agents, S^{2-}, SO_3^{2-}, tartrate
Sn	Citrate, $C_2O_3^{2-}$, 2,3-dimercaptopropanol, EDTA, F^-, I^-, OH^-, oxidation with bromine water, phosphate(3−), tartrate, triethanolamine, thioglycolic acid
Sr	Citrate, *N*,*N*-dihydroxyethylglycine, EDTA, F^-, SO_4^{2-}, tartrate
Ta	Citrate, F^-, H_2O_2, OH^-, oxalate, tartrate
Te	Citrate, F^-, I^-, reducing agents, S^{2-}, sulfite, tartrate
Th	Acetate, acetylacetone, citrate, EDTA, F^-, SO_4^{2-}, 4-sulfobenzenearsonic acid, sulfosalicylic acid, tartrate, triethanolamine
Ti	Ascorbic acid, citrate, F^-, gluconate, H_2O_2, mannitol, $Na_5P_3O_{10}$, OH^-, SO_4^{2-}, sulfosalicylic acid, tartrate, triethanolamine, tiron
Tl	Citrate, Cl^-, CN^-, EDTA, HCHO, hydrazine, $NH_2OH \cdot HCl$, oxalate, tartrate, triethanolamine
U	Citrate, $(NH_4)_2CO_3$, $C_2O_4^{2-}$, EDTA, F^-, H_2O_2, hydrazine + triethanolamine, phosphate(3−), tartrate
V	(Reduction with) ascorbic acid, hydrazine, or $NH_2OH \cdot HCl$, CN^-, EDTA, F^-, H_2O_2, mannitol, oxidation to vanadate, triethanolamine, tiron
W	Citrate, F^-, H_2O_2, hydrazine, $Na_5P_3O_{10}$, $NH_2OH \cdot HCl$, oxalate, SCN^-, tartrate, tiron, triphosphate, oxidation to tungstate(VI)
Y	Cyclohexane-1,2-diaminetetraacetic acid, F^-
Zn	Citrate, CN^-, *N*,*N*-dihydroxyethylglycine, 2,3-dimercaptopropanol, dithizone, EDTA, F^-, glycerol, glycol, hexacyanoferrate(II)(4−), $Na_5P_3O_{10}$, NH_3, OH^-, SCN^-, tartrate, triethanolamine
Zr	Arsenazo, carbonate, citrate, $C_2O_4^{2-}$, cyclohexane-1,2-diaminetetraacetic acid, EDTA, F^-, H_2O_2, PO_4^{3-}, $P_2O_7^{4-}$, pyrogallol, quinalizarinesulfonic acid, salicylate, SO_4^{2-} + H_2O_2, sulfosalicylate, tartrate, triethanolamine

TABLE 11.37 Masking Agents for Anions and Neutral Molecules

Anion or neutral molecule	Masking agent
Boric acid	F^-, glycol, mannitol, tartrate, and other hydroxy acids
Br^-	Hg(II)
Br_2	Phenol, sulfosalicylic acid
BrO_3^-	Reduction with arsenate(III), hydrazine, sulfite, or thiosulfate
Chromate(VI)	Reduction with arsenate(III), ascorbic acid, hydrazine, hydroxylamine, sulfite, or thiosulfate
Citrate	Ca(II)
Cl^-	Hg(II), Sb(III)
Cl_2	Sulfite
ClO_3^-	Thiosulfate
ClO_4^-	Hydrazine, sulfite
CN^-	HCHO, Hg(II), transition metal ions
EDTA	Cu(II)
F^-	Al(III), Be(II), boric acid, Fe(III), Th(IV), Ti(IV), Zr(IV)
$Fe(CN)_6^{3-}$	Arsenate(III), ascorbic acid, hydrazine, hydroxylamine, thiosulfate
Germanic acid	Glucose, glycerol, mannitol
I^-	Hg(II)
I_2	Thiosulfate
IO_3^-	Hydrazine, sulfite, thiosulfate
IO_4^-	Arsenate(III), hydrazine, molybdate(VI), sulfite, thiosulfate
MnO_4^-	Reduction with arsenate(III), ascorbic acid, azide, hydrazine, hydroxylamine, oxalic acid, sulfite, or thiosulfate
MoO_4^{2-}	Citrate, F^-, H_2O_2, oxalate, thiocyanate + Sn(II)
NO_2^-	Co(II), sulfamic acid, sulfanilic acid, urea
Oxalate	Molybdate(VI), permanganate
Phosphate	Fe(III), tartrate
S	CN^-, S^{2-}, sulfite
S^{2-}	Permanganate + sulfuric acid, sulfur
Sulfate	Cr(III) + heat
Sulfite	HCHO, Hg(II), permanganate + sulfuric acid
SO_5^{2-}	Ascorbic acid, hydroxylamine, thiosulfate
Se and its anions	Diaminobenzidine, sulfide, sulfite
Te	I^-
Tungstate	Citrate, tartrate
Vanadate	Tartrate

TABLE 11.38 Common Demasking Agents

Abbreviations: DPC, diphenylcarbazide; HDMG, dimethylglyoxime; PAN, 1-(2-pyridylazo)-2-naphthol.

Complexing agent	Ion demasked	Demasking agent	Application
CN^-	Ag^+	H^+	Precipitation of Ag
	Cd^{2+}	H^+	Free Cd^{2+}
		$HCHO + OH^-$	Detection of Cd (with DPC) in presence of Cu
	Cu^+	H^+	Precipitation of Cu
	Cu^{2+}	HgO	Determination of Cu
	Fe^{2+}	Hg^{2+}	Free Fe^{2+}
	Fe^{3+}	HgO	Determination of Fe

TABLE 11.38 Common Demasking Agents (*Continued*)

Complexing agent	Ion demasked	Demasking agent	Application
CN^- (*continued*)	HDMG	Pd^{2+}	Detection of CN^- (with Ni^{2+})
	Hg^{2+}	Pd^{2+}	Detection of Pd (with DPC)
	Ni^{2+}	HCHO	Detection of Ni (with HDMG)
		H^+	Free Ni^{2+}
		HgO	Determination of Ni
		Ag^+	Detection and determination of Ni (with HDMG) in presence of Co
		Ag^+, Hg^{2+}, Pb^{2+}	Detection of Ag, Hg, Pb (with HDMG)
	Pd^{2+}	H^+	Precipitation of Pd
		HgO	Determination of Pd
	Zn^{2+}	$Cl_3CCHO \cdot H_2O$	Titration of Zn with EDTA
		H^+	Free Zn
CO_3^{2-}	Cu^{2+}	H^+	Free Cu^{2+}
$C_2O_4^{2-}$	Al^{3+}	OH^-	Precipitation of $Al(OH)_3$
Cl^- (concentrated)	Ag^+	H_2O	Precipitation of AgCl
Ethylenediamine	Ag^+	SiO_2 (amorphous)	Differentiation of crystalline and amorphous SiO_2 (with CrO_4^{2-})
EDTA	Al^{3+}	F^-	Titration of Al
	Ba^{2+}	H^+	Precipitation of $BaSO_4$ (with SO_4^{2-})
	Co^{2+}	Ca^{2+}	Detection of Co (with diethyldithiocarbamate)
	Mg^{2+}	F^-	Titration of Mg, Mn
	Th(IV)	SO_4^{2-}	Titration of Th
	Ti(IV)	Mg^{2+}	Precipitation of Ti (with NH_3)
	Zn^{2+}	CN^-	Titration of Mg, Mn, Zn
	Many ions	KMO_4^-	Free ions
F^-	Al(III)	Be(II)	Precipitation of Al (with 8-hydroxylquinoline)
		OH^-	Precipitation of $Al(OH)_3$
	Fe(III)	OH^-	Precipitation of $Fe(OH)_3$
	Hf(IV)	Al(III) or Be(II)	Detection of Hg (with xylenol orange)
	Mo(VI)	H_3BO_3	Free molybdate
	Sn(IV)	H_3BO_3	Precipitation of Sn (with H_2S)
	U(VI)	Al(III)	Detection of U (with dibenzoylmethane)
	Zr(IV)	Al(III) or Be(II)	Detection of Zr (with xylenol orange)
		Ca(II)	Detection of Ca (with alizarin S)
		OH^-	Precipitation of $Zr(OH)_4$
H_2O_2	Hf(IV), Ti(IV), or Zr	Fe(III)	Free ions
NH_3	Ag^+	Br^-	Detection of Br^-
		H^+	Detection of Ag
		I^-	Detection of I and Br
		SiO_2 (amorphous)	Differentiation of crystalline and amorphous SiO_2 (with CrO_4^{2-})
NO_2^-	Co(III)	H^+	Free Co
PO_4^{3-}	Fe(III)	OH^-	Precipitation of $FePO_4$
	UO_2^{2-}	Al(III)	Detection of U (with dibenzoylmethane)
SCN^-	Fe(III)	OH^-	Precipitation of $Fe(OH)_3$
SO_4^{2-} (conc. H_2SO_4)	Ba^{2+}	H_2O	Precipitation of $BaSO_4$
$S_2O_3^{2-}$	Ag^+	H^+	Free Ag^+
	Cu^{2+}	OH^-	Detection of Cu (with PAN)
Tartrate	Al(III)	$H_2O_2 + Cu^{2+}$	Precipitation of $Al(OH)_3$

TABLE 11.39 Amino Acids pI and pK_a Values

This table lists the pK_a and pI (pH at the isoelectric point) values of α-amino acids commonly found in proteins along with their abbreviations. The dissociation constants refer to aqueous solutions at 25°C.

Name	Abbreviations		pK_a values			pI values
	3 Letter	1 Letter	—COOH	$-NH_3^+$	Other groups	
Alanine	Ala	A	2.34	9.69		6.00
Arginine	Arg	R	2.17	9.04	12.48	10.76
Asparagine	Asn	N	2.01	8.80		5.41
Aspartic acid	Asp	D	1.89	9.60	3.65	2.77
Cysteine	Cys	C	1.96	10.28	8.18	5.07
Glutamine	Gln	Q	2.17	9.13		5.65
Glutamic acid	Glu	E	2.19	9.67	4.25	3.22
Glycine	Gly	G	2.34	9.60		5.97
Histidine	His	H	1.82	9.17	6.00	7.59
Isoleucine	Ile	I	2.36	9.60		6.02
Leucine	Leu	L	2.36	9.60	5.98	
Lysine	Lys	K	2.18	8.98	10.53	9.74
Methionine	Met	M	2.28	9.21		5.74
Phenylalanine	Phe	F	1.83	9.13		5.48
Proline	Pro	P	1.99	10.60		6.30
Serine	Ser	S	2.21	9.15		5.68
Threonine	Thr	T	2.09	9.10		5.60
Tryptophan	Trp	W	2.83	9.39		5.89
Tyrosine	Tyr	Y	2.20	9.11	10.07	5.66
Valine	Val	V	2.32	9.62		5.96

Source: E. L. Smith, et al., *Principles of Biochemistry*, 7th ed., McGraw-Hill, New York, 1983; H. J. Hinz, ed., *Thermodynamic Data for Biochemistry and Biotechnology*, Springer-Verlag, Heidelberg, 1986.

TABLE 11.40 Tolerances of Volumetric Flasks

Capacity, mL	Tolerances,* ±mL		Capacity, mL	Tolerances,* ±mL	
	Class A	Class B		Class A	Class B
5	0.02	0.04	200	0.10	0.20
10	0.02	0.04	250	0.12	0.24
25	0.03	0.06	500	0.20	0.40
50	0.05	0.10	1000	0.30	0.60
100	0.08	0.16	2000	0.50	1.00

*Accuracy tolerances for volumetric flasks at 20°C are given by ASTM standard E288.

TABLE 11.41 Pipet Capacity Tolerances

Volumetric transfer pipets			Measuring and serological pipets	
	Tolerances,* ±mL			Tolerances,† ±mL
Capacity, mL	Class A	Class B	Capacity, mL	Class B
0.5	0.006	0.012	0.1	0.005
1	0.006	0.012	0.2	0.008
2	0.006	0.012	0.25	0.008
3	0.01	0.02	0.5	0.01
4	0.01	0.02	0.6	0.01
5	0.01	0.02	1	0.02
10	0.02	0.04	2	0.02
15	0.03	0.06	5	0.04
20	0.03	0.06	10	0.06
25	0.03	0.06	25	0.10
50	0.05	0.10		
100	0.08	0.16		

* Accuracy tolerances for volumetric transfer pipets are given by ASTM standard E969 and Federal Specification NNN-P-395.

† Accuracy tolerances for measuring pipets are given by Federal Specification NNN-P-350 and for serological pipets by Federal Specification NNN-P-375.

TABLE 11.42 Tolerances of Micropipets (Eppendorf)

Capacity, μL	Accuracy, %	Precision, %	Capacity, μL	Accuracy, %	Precision, %
10	1.2	0.4	100	0.5	0.2
40	0.6	0.2	250	0.5	0.15
50	0.5	0.2	500	0.5	0.15
60	0.5	0.2	600	0.5	0.15
70	0.5	0.2	900	0.5	0.15
80	0.5	0.2	1000	0.5	0.15

TABLE 11.43 Buret Accuracy Tolerances

		Accuracy, ±mL	
Capacity, mL	Subdivision, mL	Class A* and precision grade	Class B and standard grade
10	0.05	0.02	0.04
25	0.10	0.03	0.06
50	0.10	0.05	0.10
100	0.20	0.10	0.20

* Class A conforms to specifications in ASTM E694 for standard taper stopcocks and to ASTM E287 for Teflon or polytetrafluoroethylene stopcock plugs. The 10-mL size meets the requirements for ASTM D664.

TABLE 11.44 Factors for Simplified Computation of Volume

The volume is determined by weighing the water, having a temperature of t°C, contained or delivered by the apparatus at the same temperature. The weight of water, w grams, is obtained with brass weights in air having a density of 1.20 mg/mL.

For apparatus made of soft glass, the volume contained or delivered at 20°C is given by

$$\nu_{20} = wf_{20} \text{ mL}$$

where ν_{20} is the volume at 20° and f_{20} is the factor (apparent specific volume) obtained from the table below for the temperature t at which the calibration is performed. The volume at any other temperature t' may then be obtained from

$$\nu' = \nu_{20}[1 + 0.00002(t' - 20)] \text{ mL}$$

For apparatus made of any other material, the volume contained or delivered at the temperature t is

$$\nu_t = wf_t \text{ mL}$$

where w is again the weight in air obtained with brass weights (in grams), and f_t is the factor given in the third column of the table for the temperature t. The volume at any temperature t' may then be obtained from

$$\nu'_t = \nu_t[1 + \beta(t' - t)] \text{ mL}$$

where β is the cubical coefficient of thermal expansion of the material from which the apparatus is made. Approximate values of β for some frequently encountered materials are given in Table 11.45.

t, °C	f_{20}	f_t	t, °C	f_{20}	f_t
0	1.001 62	1.001 22	20	1.002 86	1.002 86
1	54	16	21	1.003 05	1.003 07
2	48	12	22	26	30
3	43	09	23	47	53
4	41	09	24	69	77
5	1.001 39	1.001 09	25	1.003 93	1.004 03
6	40	12	26	1.004 17	29
7	42	16	27	42	56
8	45	21	28	68	84
9	50	28	29	95	1.005 13
10	1.001 56	1.001 36	30	1.005 23	1.005 43
11	63	45	31	1.005 52	1.005 74
12	72	56	32	1.005 82	1.006 06
13	82	68	33	1.006 13	1.006 39
14	93	81	34	1.006 44	1.006 72
15	1.002 06	1.001 96	35	1.006 77	1.007 07
16	20	1.002 12	36	1.007 10	1.007 42
17	35	29	37	1.007 44	1.007 78
18	51	47	38	1.007 79	1.008 15
19	68	66	39	1.008 15	1.008 53
			40	1.008 52	1.008 91

TABLE 11.45 Cubical Coefficients of Thermal Expansion

This table lists values of β, the cubical coefficient of thermal expansion, taken from "Essentials of Quantitative Analysis," by Benedetti-Pichler, and from various other sources. The value of β represents the relative increases in volume for a change in temperature of 1°C at temperatures in the vicinity of 25°C, and is equal to 3α, where α is the linear coefficient of thermal expansion. Data are given for the types of glass from which volumetic apparatus is most commonly made, and also for some other materials which have been or may be used in the fabrication of apparatus employed in analytical work.

Material	β
Glasses	
Alkali-resistant, Corning 728	1.90×10^{-5}
Gerateglas, Schott G20	1.47
Kimble KG-33 (borosilicate)	0.96
N-51A ("Resistant")	1.47
R-6 (soft)	2.79
Pyrex, Corning 744	0.96
Vitreous silica	0.15
Vycor, Corning 790	0.24
Metals	
Brass	*ca.* 5.5
Copper	5.0
Gold	4.3
Monel metal	4.0
Platinum	2.7
Silver	5.7
Stainless steel	*ca.* 5.3
Tantalum	*ca.* 2.0
Tungsten	1.3
Plastics and other materials	
Hard rubber	24×10^{-5}
Polyethylene	45–90
Polystyrene	18–24
Porcelain	*ca.* 1.2
Teflon (polytetrafluoroethylene)	16.5

TABLE 11.46 General Solubility Rules for Inorganic Compounds

Nitrates	All nitrates are soluble.
Acetates	All acetates are soluble; silver acetate is moderately soluble.
Chlorides	All chlorides are soluble except AgCl, $PbCl_2$, and Hg_2Cl_2. $PbCl_2$ is soluble in hot water, slightly soluble in cold water.
Sulfates	All sulfates are soluble except barium and lead. Silver, mercury(I), and calcium are only slightly soluble.
Hydrogen sulfates	The hydrogen sulfates are more soluble than the sulfates.
Carbonates, phosphates, chromates, silicates	All carbonates, phosphates, chromates, and silicates are insoluble, except those of sodium, potassium, and ammonium. An exception is $MgCrO_4$ which is soluble.
Hydroxides	All hydroxides (except lithium, sodium, potassium, cesium, rubidium, and ammonia) are insoluble; $Ba(OH)_2$ is moderately soluble; $Ca(OH)_2$ and $Sr(OH)_2$ are slightly soluble.
Sulfides	All sulfides (except alkali metals, ammonium, magnesium, calcium, and barium) are insoluble. Aluminum and chromium sulfides are hydrolyzed and precipitate as hydroxides.
Sodium, potassium, ammonium	All sodium, potassium, and ammonium salts are soluble. Exceptions: $Na_4Sb_2O_7$, $K_2NaCo(NO_2)_6$, K_2PtCl_6, $(NH_4)_2PtCl_6$, and $(NH_4)_2NaCo(NO_2)_6$.
Silver	All silver salts are insoluble. Exceptions: $AgNO_3$ and $AgClO_4$; $AgC_2H_3O_2$ and Ag_2SO_4 are moderately soluble.

11.7 LABORATORY SOLUTIONS

TABLE 11.47 Concentrations of Commonly Used Acids and Bases

Freshly opened bottles of these reagents are generally of the concentrations indicated in the table. This may not be true of bottles long opened and this is especially true of ammonium hydroxide, which rapidly loses its strength. In preparing volumetric solutions, it is well to be on the safe side and take a little more than the calculated volume of the concentrated reagent, since it is much easier to dilute a concentrated solution than to strengthen one that is too weak.

A concentrated C.P. reagent usually comes to the laboratory in a bottle having a label which states its molecular weight w, its density (or its specific gravity) d, and its percentage assay p. When such a reagent is used to prepare an aqueous solution of desired molarity M, a convenient formula to employ is

$$V = \frac{100\ wM}{pd}$$

where V is the number of milliliters of concentrated reagent required for 1 liter of the dilute solution.

Example: Sulfuric acid has the molecular weight 98.08. If the concentrated acid assays 95.5% and has the specific gravity 1.84, the volume required for 1 liter of a 0.1 molar solution is

$$V = \frac{100 \times 98.08 \times 0.1}{95.5 \times 1.84} = 5.58 \text{ mL}$$

Reagent	Formula Weight	Density, g · mL^{-1} (20°C)	Weight % (approx)	Molarity	V, mL*
Acetic acid	60.05	1.05	99.8	17.45	57.3
Ammonium hydroxide	35.05	0.90	56.6	14.53	60.0
(as NH_3)	17.03		28.0		
Ethylenediamine	60.10	0.899	100	15.0	66.7
Formic acid	46.03	1.20	90.5	23.6	42.5
Hydrazine	32.05	1.011	95	30.0	33.3
Hydriodic acid	127.91	1.70	57	7.6	132
Hydrobromic acid	80.92	1.49	48	8.84	113
Hydrochloric acid	36.46	1.19	37.2	12.1	82.5
Hydrofluoric acid	20.0	1.18	49.0	28.9	34.5
Nitric acid	63.01	1.42	70.4	15.9	63.0
Perchloric acid	100.47	1.67	70.5	11.7	85.5
Phosphoric acid	97.10	1.70	85.5	14.8	67.5
Pyridine	79.10	0.982	100	12.4	80.6
Potassium hydroxide (soln)	56.11	1.46	45	11.7	85.5
Sodium hydroxide (soln)	40.00	1.54	50.5	19.4	51.5
Sulfuric acid	98.08	1.84	96.0	18.0	55.8
Triethanolamine	149.19	1.124	100	7.53	132.7

* V, mL = volume in milliliters needed to prepare 1 liter of 1 molar solution.

TABLE 11.48 Standard Stock Solutions*

Element	Procedure
Aluminum	Dissolve 1.000 g Al wire in minimum amount of 2 *M* HCl; dilute to volume.
Antimony	Dissolve 1.000 g Sb in (1) 10 ml HNO_3 plus 5 ml HCl, and dilute to volume when dissolution is complete; or (2) 18 ml HBr plus 2 ml liquid Br_2; when dissolution is complete add 10 ml $HClO_4$, heat in a well-ventilated hood while swirling until white fumes appear and continue for several minutes to expel all HBr, then cool and dilute to volume.
Arsenic	Dissolve 1.3203 g of As_2O_3 in 3 ml 8 *M* HCl and dilute to volume; or treat the oxide with 2 g NaOH and 20 ml water; after dissolution dilute to 200 ml, neutralize with HCl (pH meter), and dilute to volume.
Barium	(1) Dissolve 1.7787 g $BaCl_2 \cdot 2H_2O$ (fresh crystals) in water and dilute to volume. (2) Dissolve 1.516 g $BaCl_2$ (dried at 250°C for 2 hr) in water and dilute to volume. (3) Treat 1.4367 g $BaCO_3$ with 300 ml water, slowly add 10 ml of HCl and, after the CO_2 is released by swirling, dilute to volume.
Beryllium	(1) Dissolve 19.655 g $BeSO_4 \cdot 4H_2O$ in water, add 5 ml HCl (or HNO_3), and dilute to volume. (2) Dissolve 1.000 g Be in 25 ml 2 *M* HCl, then dilute to volume.
Bismuth	Dissolve 1.000 g Bi in 8 ml of 10 *M* HNO_3, boil gently to expel brown fumes, and dilute to volume.
Boron	Dissolve 5.720 g fresh crystals of H_3BO_3 and dilute to volume.
Bromine	Dissolve 1.489 g KBr (or 1.288 g NaBr) in water and dilute to volume.
Cadmium	(1) Dissolve 1.000 g Cd in 10 ml of 2 *M* HCl; dilute to volume. (2) Dissolve 2.282 g $3CdSO_4 \cdot 8H_2O$ in water; dilute to volume.
Calcium	Place 2.4973 g $CaCO_3$ in volumetric flask with 300 ml water, carefully add 10 ml HCl; after CO_2 is released by swirling, dilute to volume.
Cerium	(1) Dissolve 4.515 g $(NH_4)_4Ce(SO_4)_4 \cdot 2H_2O$ in 500 ml water to which 30 ml H_2SO_4 had been added, cool, and dilute to volume. Advisable to standardize against As_2O_3. (2) Dissolve 3.913 g $(NH_4)_2Ce(NO_3)_6$ in 10 ml H_2SO_4, stir 2 min, cautiously introduce 15 ml water and again stir 2 min. Repeat addition of water and stirring until all the salt has dissolved, then dilute to volume.
Cesium	Dissolve 1.267 g CsCl and dilute to volume. Standardize: Pipette 25 ml of final solution to Pt dish, add 1 drop H_2SO_4, evaporate to dryness, and heat to constant weight at $\gtrsim$ 800°C. Cs (in μg/ml) = (40)(0.734)(wt of residue)
Chlorine	Dissolve 1.648 g NaCl and dilute to volume.
Chromium	(1) Dissolve 2.829 g $K_2Cr_2O_7$ in water and dilute to volume. (2) Dissolve 1.000 g Cr in 10 ml HCl, and dilute to volume.
Cobalt	Dissolve 1.000 g Co in 10 ml of 2 *M* HCl, and dilute to volume.
Copper	(1) Dissolve 3.929 g fresh crystals of $CuSO_4 \cdot 5H_2O$, and dilute to volume. (2) Dissolve 1.000 g Cu in 10 ml HCl plus 5 ml water to which HNO_3 (or 30%H_2O_2) is added dropwise until dissolution is complete. Boil to expel oxides of nitrogen and chlorine, then dilute to volume.
Dysprosium	Dissolve 1.1477 g Dy_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Erbium	Dissolve 1.1436 g Er_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Europium	Dissolve 1.1579 g Eu_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Fluorine	Dissolve 2.210 g NaF in water and dilute to volume.
Gadolinium	Dissolve 1.152 g Gd_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Gallium	Dissolve 1.000 g Ga in 50 ml of 2 *M* HCl; dilute to volume.
Germanium	Dissolve 1.4408 g GeO_2 with 50 g oxalic acid in 100 ml of water; dilute to volume.

* 1000 μg/mL as the element in a final volume of 1 liter unless stated otherwise.

From J. A. Dean and T. C. Rains, "Standard Solutions for Flame Spectrometry," in *Flame Emission and Atomic Absorption Spectrometry*, J. A. Dean and T. C. Rains (Eds.), Vol. 2, Chap. 13, Marcel Dekker, New York, 1971.

TABLE 11.48 Standard Stock Solutions (*Continued*)

Element	Procedure
Gold	Dissolve 1.000 g Au in 10 ml of hot HNO_3 by dropwise addition of HCl, boil to expel oxides of nitrogen and chlorine, and dilute to volume. Store in amber container away from light.
Hafnium	Transfer 1.000 g Hf to Pt dish, add 10 ml of 9 *M* H_2SO_4, and then slowly add HF dropwise until dissolution is complete. Dilute to volume with 10% H_2SO_4.
Holmium	Dissolve 1.1455 g Ho_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Indium	Dissolve 1.000 g In in 50 ml of 2 *M* HCl; dilute to volume.
Iodine	Dissolve 1.308 g Kl in water and dilute to volume.
Iridium	(1) Dissolve 2.465 g Na_3IrCl_6 in water and dilute to volume. (2) Transfer 1.000 g Ir sponge to a glass tube, add 20 ml of HCl and 1 ml of $HClO_4$. Seal the tube and place in an oven at 300°C for 24 hr. Cool, break open the tube, transfer the solution to a volumetric flask, and dilute to volume. Observe all safety precautions in opening the glass tube.
Iron	Dissolve 1.000 g Fe wire in 20 ml of 5 *M* HCl; dilute to volume.
Lanthanum	Dissolve 1.1717 g La_2O_3 (dried at 110°C) in 50 ml of 5 *M* HCl, and dilute to volume.
Lead	(1) Dissolve 1.5985 g $Pb(NO_3)_2$ in water plus 10 ml HNO_3, and dilute to volume. (2) Dissolve 1.000 g Pb in 10 ml HNO_3, and dilute to volume.
Lithium	Dissolve a slurry of 5.3228 g Li_2CO_3 in 300 ml of water by addition of 15 ml HCl; after release of CO_2 by swirling, dilute to volume.
Lutetium	Dissolve 1.6079 g $LuCl_3$ in water and dilute to volume.
Magnesium	Dissolve 1.000 g Mg in 50 ml of 1 *M* HCl and dilute to volume.
Manganese	(1) Dissolve 1.000 g Mn in 10 ml HCl plus 1 ml HNO_3, and dilute to volume. (2) Dissolve 3.0764 g $MnSO_4 \cdot H_2O$ (dried at 105°C for 4 hr) in water and dilute to volume. (3) Dissolve 1.5824 g MnO_2 in 10 HCl in a good hood, evaporate to gentle dryness, dissolve residue in water and dilute to volume.
Mercury	Dissolve 1.000 g Hg in 10 ml of 5 *M* HNO_3 and dilute to volume.
Molybdenum	(1) Dissolve 2.0425 g $(NH_4)_2MoO_4$ in water and dilute to volume. (2) Dissolve 1.5003 g MoO_3 in 100 ml of 2 *M* ammonia, and dilute to volume.
Neodymium	Dissolve 1.7373 g $NdCl_3$ in 100 ml 1 *M* HCl and dilute to volume.
Nickel	Dissolve 1.000 g Ni in 10 ml hot HNO_3, cool, and dilute to volume.
Niobium	Transfer 1.000 g Nb (or 1.4305 g Nb_2O_5) to Pt dish, add 20 ml HF, and heat gently to complete dissolution. Cool, add 40 ml H_2SO_4, and evaporate to fumes of SO_3. Cool and dilute to volume with 8 *M* H_2SO_4.
Osmium	Dissolve 1.3360 g OsO_4 in water and dilute to 100 ml. Prepare only as needed as solution loses strength on standing unless Os is reduced by SO_2 and water is replaced by 100 ml 0.1 *M* HCl.
Palladium	Dissolve 1.000 g Pd in 10 ml of HNO_3 by dropwise addition of HCl to hot solution; dilute to volume.
Phosphorus	Dissolve 4.260 g $(NH_4)_2HPO_4$ in water and dilute to volume.
Platinum	Dissolve 1.000 g Pt in 40 ml of hot aqua regia, evaporate to incipient dryness, add 10 ml HCl and again evaporate to moist residue. Add 10 ml HCl and dilute to volume.
Potassium	Dissolve 1.9067 g KCl (or 2.8415 g KNO_3) in water and dilute to volume.
Praseodymium	Dissolve 1.1703 g Pr_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Rhenium	Dissolve 1.000 g Re in 10 ml of 8 *M* HNO_3 in an ice bath until initial reaction subsides, then dilute to volume.
Rhodium	Dissolve 1.000 g Rh by the sealed-tube method described under iridium.
Rubidium	Dissolve 1.4148 g RbCl in water. Standardize as described under cesium. Rb (in μg/ml) = (40)(0.320)(wt of residue).
Ruthenium	Dissolve 1.317 g RuO_2 in 15 ml of HCl; dilute to volume.
Samarium	Dissolve 1.1596 g Sm_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Scandium	Dissolve 1.5338 g Sc_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.

TABLE 11.48 Standard Stock Solutions (*Continued*)

Element	Procedure
Selenium	Dissolve 1.4050 g SeO_2 in water and dilute to volume or dissolve 1.000 g Se in 5 ml of HNO_3, then dilute to volume.
Silicon	Fuse 2.1393 g SiO_2 with 4.60 g Na_2CO_3, maintaining melt for 15 min in Pt crucible. Cool, dissolve in warm water, and dilute to volume. Solution contains also 2000 μg/ml sodium.
Silver	(1) Dissolve 1.5748 g $AgNO_3$ in water and dilute to volume. (2) Dissolve 1.000 g Ag in 10 ml of HNO_3; dilute to volume. Store in amber glass container away from light.
Sodium	Dissolve 2.5421 g NaCl in water and dilute to volume.
Strontium	Dissolve a slurry of 1.6849 g $SrCO_3$ in 300 ml of water by careful addition of 10 ml of HCl; after release of CO_2 by swirling, dilute to volume.
Sulfur	Dissolve 4.122 g $(NH_4)_2SO_4$ in water and dilute to volume.
Tantalum	Transfer 1.000 g Ta (or 1.2210 g Ta_2O_5) to Pt dish, add 20 ml of HF, and heat gently to complete the dissolution. Cool, add 40 ml of H_2SO_4 and evaporate to heavy fumes of SO_3. Cool and dilute to volume with 50% H_2SO_4.
Tellurium	(1) Dissolve 1.2508 g TeO_2 in 10 ml of HCl; dilute to volume. (2) Dissolve 1.000 g Te in 10 ml of warm HCl with dropwise addition of HNO_3, then dilute to volume.
Terbium	Dissolve 1.6692 g of $TbCl_3$ in water, add 1 ml of HCl, and dilute to volume.
Thallium	Dissolve 1.3034 g $TlNO_3$ in water and dilute to volume.
Thorium	Dissolve 2.3794 g $Th(NO_3)_4 \cdot 4H_2O$ in water, add 5 ml HNO_3, and dilute to volume.
Thulium	Dissolve 1.142 g Tm_2O_3 in 50 ml of 2 *M* HCl; dilute to volume.
Tin	Dissolve 1.000 g Sn in 15 ml of warm HCl; dilute to volume.
Titanium	Dissolve 1.000 g Ti in 10 ml of H_2SO_4 with dropwise addition of HNO_3; dilute to volume with 5% H_2SO_4.
Tungsten	Dissolve 1.7941 g of $Na_2WO_4 \cdot 2H_2O$ in water and dilute to volume.
Uranium	Dissolve 2.1095 g $UO_2(NO_3)_2 \cdot 6H_2O$ (or 1.7734 g uranyl acetate dihydrate) in water and dilute to volume.
Vanadium	Dissolve 2.2963 g NH_4VO_3 in 100 ml of water plus 10 ml of HNO_3; dilute to volume.
Ytterbium	Dissolve 1.6147 g $YbCl_3$ in water and dilute to volume.
Yttrium	Dissolve 1.2692 g Y_2O_3 in 50 ml of 2 *M* HCl and dilute to volume.
Zinc	Dissolve 1.000 g Zn in 10 ml of HCl; dilute to volume.
Zirconium	Dissolve 3.533 g $ZrOCl_2 \cdot 8H_2O$ in 50 ml of 2 *M* HCl, and dilute to volume. Solution should be standardized.

11.7.1 General Reagents, Indicators, and Special Solutions

Unless otherwise stated, the term *g per liter* signifies grams of the formula indicated dissolved in water and made up to a liter of solution.

Acetic acid, $HC_2H_3O_2$—6*N*: 350 mL glacial acetic acid per liter.

Alcohol, amyl, $C_5H_{11}OH$: use as purchased.

Alcohol, ethyl, C_2H_5OH; 95% alcohol, as purchased.

Alizarin, dihydroxyanthraquinone (indicator): dissolve 0.1 g in 100 mL alcohol; pH range yellow 5.5–6.8 red.

Alizarin yellow R, sodium *p*-nitrobenzeneazosalicylate (indicator): dissolve 0.1 g in 100 mL water; pH range yellow 10.1–violet 12.1.

Alizarin yellow GG, salicyl yellow, sodium *m*-nitrobenzeneazosalicylate (indicator): dissolve 0.1 g in 100 mL 50% alcohol; pH range yellow 10.0–12.0 lilac.

Alizarin S, alizarin carmine, sodium alizarin sulfonate (indicator): dissolve 0.1 g in 100 mL water; pH range yellow 3.7–5.2 violet.

Aluminon (qualitative test for aluminum). The reagent consists of 0.1% solution of the ammonium salt of aurin tricarboxylic acid. A bright red precipitate, persisting in alkaline solution, indicates aluminum.

Aluminum chloride, $AlCl_3$—0.5*N*: 22 g per liter.

Aluminum nitrate, $Al(NO_3)_3 \cdot 7.5H_2O$—0.5*N*: 58 g per liter.

Aluminum sulfate, $Al_2(SO_4)_3 \cdot 18H_2O$—0.5*N*: 55 g per liter.

Ammonium acetate, $NH_4C_2H_3O_2$—3*N*: 231 g per liter.

Ammonium carbonate, $(NH_4)_2CO_3 \cdot H_2O$—3*N*: 171 g per liter; for the anhydrous salt: 144 g per liter.

Ammonium chloride, NH_4Cl—3*N*: 161 g per liter.

Ammonium hydroxide, NH_4OH—15*N*: the concentrated solution which contains 28% NH_3; for 6*N*: 400 mL per liter.

Ammonium molybdate, $(NH_4)_2MoO_4$—*N*: dissolve 88.3 g of solid $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$ in 100 mL 6*N* NH_4OH. Add 240 g of solid NH_4NO_3 and dilute to 1 liter. Another method is to take 72 g of MoO_3, add 130 mL of water and 75 mL of 15*N* NH_4OH; stir mechanically until nearly all has dissolved, then add it to a solution of 240 mL concentrated HNO_3 and 500 mL of water; stir continuously while solutions are being mixed; allow to stand 3 days, filter, and use the clear filtrate.

Ammonium nitrate, NH_4NO_3—*N*: 80 g per liter.

Ammonium oxalate, $(NH_4)_2C_2O_4 \cdot H_2O$—0.5*N*: 40 g per liter.

Ammonium polysulfide (yellow ammonium sulfide), $(NH_4)_2S_x$: allow the colorless $(NH_4)_2S$ to stand, or add sulfur.

Ammonium sulfate, $(NH_4)_2SO_4$—0.5*N*: 33 g per liter; saturated: dissolve 780 g of $(NH_4)_2SO_4$ in water and make up to a liter.

Ammonium sulfide (colorless), $(NH_4)_2S$—saturated: pass H_2S through 200 mL of concentrated NH_4OH in the cold until no more gas is dissolved, add 200 mL NH_4OH and dilute with water to a liter; the addition of 15 g of sulfur is sufficient to make the polysulfide.

Antimony pentachloride, $SbCl_5$—0.5*N*: 39 g per liter.

Antimony trichloride, $SbCl_3$—0.5*N*: 38 g per liter.

Aqua regia: mix 3 parts of concentrated HCl and 1 part of concentrated HNO_3 just before ready to use.

Arsenic acid, $H_3AsO_4 \cdot 0.5H_2O$—0.5*N* (= $\frac{1}{2}H_3AsO_4 \div 5$): 15 g per liter.

Arsenous oxide, As_2O_3—0.25*N*: 8 g per liter for saturation.

Aurichloric acid, $HAuCl_4 \cdot 3H_2O$: dissolve in ten parts of water.

Aurin, *see* rosolic acid.

Azolitmin solution (indicator); make up a 1% solution of azolitmin by boiling in water for 5 minutes; it may be necessary to add a small amount of NaOH to make the solution neutral; pH range red 4.5–8.3 blue.

Bang's reagent (for glucose estimation): dissolve 100 g of K_2CO_3, 66 g of KCl, and 160 of $KHCO_3$ in the order given in about 700 mL of water at 30°C. Add 4.4 g of copper sulfate and dilute to 1 liter after the CO_2 is evolved. This solution should be shaken only in such a manner as not to allow the entry of air. After 24 hours 300 mL diluted to a liter with saturated KCl solution, shaken gently and used after 24 hours; 50 mL ≡ 10 mg glucose.

Barfoed's reagent (test for glucose): dissolve 66 g of cupric acetate and 10 mL of glacial acetic acid in water and dilute to 1 liter.

Barium chloride, $BaCl_2 \cdot 2H_2O$—0.5*N*: 61 g per liter.

Barium hydroxide, $Ba(OH)_2 \cdot 8H_2O$—0.2*N*: 32 g per liter for saturation.

Barium nitrate, $Ba(NO_3)_2$—0.5*N*: 65 g per liter.

Baudisch's reagent: *see* cupferron.

Benedict's qualitative reagent (for glucose): dissolve 173 g of sodium citrate and 100 g of anhydrous sodium carbonate in about 600 mL of water, and dilute to 850 mL; dissolve 17.3 g of $CuSO_4 \cdot 5H_2O$ in 100 mL of water and dilute to 150 mL; this solution is added to the citrate-carbonate solution with constant stirring. *See also* the quantitative reagent below.

Benedict's quantitative reagent (sugar in urine): This solution contains 18 g copper sulfate, 100 g of anhydrous sodium carbonate, 200 g of potassium citrate, 125 g of potassium thiocyanate, and 0.25 g of potassium ferrocyanide per liter; 1 mL of this solution ≡ 0.002 g sugar.

Benzidine hydrochloride solution (for sulfate determination): mix 6.7 g of benzidine $[C_{12}H_8(NH_2)_2]$ or 8.0 g of the hydrochloride $[C_{12}H_8(NH_2)_2 \cdot 2HCl]$ into a paste with 20 mL of water; add 20 mL of HCl (sp. gr. 1.12) and dilute the mixture to 1 liter with water; each mL of this solution is equivalent to 0.00357 g H_2SO_4.

Benzopurpurine 4B (indicator): dissolve 0.1 g in 100 mL water; pH range blue-violet 1.3–4.0 red.

Benzoyl auramine (indicator): dissolve 0.25 g in 100 mL methyl alcohol; pH range violet 5.0–5.6 pale yellow. Since this compound is not stable in aqueous solution, hydrolyzing slowly in neutral medium, more rapidly in alkaline, and still more rapidly in acid solution, the indicator should not be added until one is ready to titrate. The acid quinoid form of the compound is dichroic, showing a red-violet in thick layers and blue in thin. At a pH of 5.4 the indicator appears a neutral gray color by daylight or a pale red under tungsten light. The change to yellow is easily recognized in either case. Cf. Scanlan and Reid, *Ind. Eng. Chem., Anal. Ed.* **7:**125 (1935).

Bertrand's reagents (glucose estimation): (*a*) 40 g of copper sulfate diluted to 1 liter; (*b*) rochelle salt 200 g, NaOH 150 g, and sufficient water to make 1 liter; (*c*) ferric sulfate 50 g, H_2SO_4 200 g, and sufficient water to make 1 liter; (*d*) $KMnO_4$ 5 g and sufficient water to make 1 liter.

Bial's reagent (for pentoses): dissolve 1 g of orcinol in 500 mL of 30% HCl to which 30 drops of a 10% ferric chloride solution have been added.

Bismuth chloride, $BiCl_3$—0.5*N*: 52 g per liter, using 1:5 HCl in place of water.

Bismuth nitrate, $Bi(N_2O_3)_3 \cdot 5H_2O$—0.25*N*: 40 g per liter, using 1:5 HNO_3 in place of water.

Bismuth standard solution (quantitative color test for Bi): dissolve 1 g of bismuth in a mixture of 3 mL of concentrated HNO_3 and 2.8 mL of H_2O and make up to 100 mL with glycerol. Also dissolve 5 g of KI in 5 mL of water and make up to 100 mL with glycerol. The two solutions are used together in the colorimetric estimation of Bi.

Boutron-Boudet solution: *see* soap solution.

Bromchlorophenol blue, dibromodichlorophenol-sulfonphthalein (indicator): dissolve 0.1 g in 8.6 mL 0.02 *N* NaOH and dilute with water to 250 mL; pH range yellow 3.2–4.8 blue.

Bromcresol green, tetrabromo-*m*-cresol-sulfonphthalein (indicator): dissolve 0.1 g in 7.15 mL 0.02 *N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL 20% alcohol; pH range yellow 4.0–5.6 blue.

Bromcresol purple, dibromo-*o*-cresol-sulfonphthalein (indicator): dissolve 0.1 g in 9.5 mL 0.02 *N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL 20% alcohol; pH range yellow 5.2–6.8 purple.

Bromine water, saturated solution: to 400 mL water add 20 mL of bromine; use a glass stopper coated with petrolatum.

Bromphenol blue, tetrabromophenol-sulfonphthalein (indicator): dissolve 0.1 g in 7.45 mL 0.02 *N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL 20% alcohol; pH range yellow 3.6–4.6 violet-blue.

Bromphenol red, dibromophenol-sulfonphthalein (indicator): dissolve 0.1 g in 9.75 mL 0.02 *N* NaOH and dilute with water to 250 mL; pH range yellow 5.2–7.0 red.

Bromthymol blue, dibromothymol-sulfonphthalein (indicator): dissolve 0.1 g in 8.0 mL 0.02 *N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL of 20% alcohol; pH range yellow 6.0–7.6 blue.

Brucke's reagent (protein precipitant): dissolve 50 g of KI in 500 mL of water, saturate with HgI_2 (about 120 g), and dilute to 1 liter.

Cadmium chloride, $CdCl_2$—0.5*N*: 46 g per liter.

Cadmium nitrate, $Cd(NO_3)_2 \cdot 4H_2O$—0.5*N*: 77 g per liter.

Cadmium sulfate, $CdSO_4 \cdot 4H_2O$—0.5*N*: 70 g per liter.

Calcium chloride, $CaCl_2 \cdot 6H_2O$—0.5*N*: 55 g per liter.

Calcium hydroxide, $Ca(OH)_2$—0.04*N*: 10 g per liter for saturation.

Calcium nitrate, $Ca(NO_3)_2 \cdot 4H_2O$—0.5*N*: 59 g per liter.

Calcium sulfate, $CaSO_4 \cdot 2H_2O$—0.03*N*: mechanically stir 10 g in a liter of water for 3 hours; decant and use the clear liquid.

Carbon disulfide, CS_2: commercial grade which is colorless.

Chloride reagent: dissolve 1.7 g of $AgNO_3$ and 25 g KNO_3 in water, add 17 mL of concentrated NH_4OH and make up to 1 liter with water.

Chlorine water, saturated solution: pass chlorine gas into small amounts of water as needed; solutions deteriorate on standing.

Chloroform, $CHCl_3$: commercial grade.

Chloroplatinic acid, $H_2PtCl_6 \cdot 6H_2O$—10% solution: dissolve 1 g in 9 mL of water; keep in a dropping bottle.

Chlorphenol red, dichlorophenol-sulfonphthalein (indicator): dissolve 0.1 g in 11.8 mL 0.02 *N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL 20% alcohol; pH range yellow 5.2–6.6 red.

Chromic chloride, $CrCl_3$—0.5*N*: 26 g per liter.

Chromic nitrate, $Cr(NO_3)_3$—0.5*N*: 40 g per liter.

Chromic sulfate, $Cr_2(SO_4)_3 \cdot 18H_2O$—0.5*N*: 60 g per liter.

Cobaltous nitrate, $Co(NO_3)_2 \cdot 6H_2O$—0.5*N*: 73 g per liter.

Cobaltous sulfate, $CoSO_4 \cdot 7H_2O$—0.5*N*: 70 g per liter.

Cochineal (indicator): triturate 1 g with 75 mL alcohol and 75 mL water, let stand for two days and filter; pH range red 4.8–6.2 violet.

Congo red, sodium tetrazodiphenyl-naphthionate (indicator): dissolve 0.1 g in 100 mL water; pH range blue 3.0–5.2 red.

Corallin (indicator): *see* rosolic acid.

Cresol red, *o*-cresol-sulfonphthalein (indicator): dissolve 0.1 g in 13.1 mL 0.02*N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL 20% alcohol; pH range yellow 7.2–8.8 red.

***o*-Cresolphthalein** (indicator): dissolve 0.1 g in 250 mL alcohol; pH range colorless 8.2–10.4 red.

Cupferron (iron analysis): dissolve 6 g of ammonium nitrosophenyl-hydroxylamine (cupferron) in water and dilute to 100 mL. This solution is stable for about one week if protected from light.

Cupric chloride, $CuCl_2 \cdot 2H_2O$—0.5*N*: 43 g per liter.

Cupric nitrate, $Cu(NO_3)_2 \cdot 6H_2O$—0.5*N*: 74 g per liter.

Cupric sulfate, $CuSO_4 \cdot 5H_2O$—0.5*N*: 62 g per liter.

Cuprous chloride, CuCl—0.5*N*: 50 g per liter, using 1 : 5 HCl in place of water.

Cuprous chloride, acid (for gas analysis, absorption of CO): cover the bottom of a 2-liter bottle with a layer of copper oxide ⅜ inch deep, and place a bundle of copper wire an inch thick in the bottle so that it extends from the top to the bottom. Fill the bottle with HCl (sp. gr. 1.10). The bottle is shaken occasionally, and when the solution is colorless or nearly so, it is poured into half-liter bottles containing copper wire. The large bottle may be filled with hydrochloric acid, and by adding the oxide or wire when either is exhausted, a constant supply of the reagent is available.

Cuprous chloride, ammoniacal: this solution is used for the same purpose and is made in the same manner as the acid cuprous chloride above, except that the acid solution is treated with ammonia until a faint odor of ammonia is perceptible. Copper wire should be kept with the solution as in the acid reagent.

Curcumin (indicator): prepare a saturated aqueous solution; pH range yellow 6.0–8.0 brownish red.

Dibromophenol-tetrabromophenol-sulfonphthalein (indicator): dissolve 0.1 g in 1.21 mL 0.1*N* NaOH and dilute with water to 250 mL; pH range yellow 5.6–7.2 purple.

Dimethyl glyoxime, $(CH_3CNOH)_2$—0.01*N*: 6 g in 500 mL of 95% alcohol.

2,4-Dinitrophenol (indicator): dissolve 0.1 g in a few mL alcohol, then dilute with water to 100 mL; pH range colorless 2.6–4.0 yellow.

2,5-Dinitrophenol (indicator): dissolve 0.1 g in 20 mL alcohol, then dilute with water to 100 mL; pH range colorless 4–5.8 yellow.

2,6-Dinitrophenol (indicator): dissolve 0.1 g in a few mL alcohol, then dilute with water to 100 mL; pH range colorless 2.4–4.0 yellow.

Esbach's reagent (estimation of proteins): dissolve 10 g of picric acid and 20 g of citric acid in water and dilute to 1 liter.

Eschka's mixture (sulfur in coal): mix 2 parts of porous calcined MgO with 1 part of anhydrous Na_2CO_3; not a solution but a dry mixture.

Ether, $(C_2H_5)_2O$—use commercial grade.

***p*-Ethoxychrysoidine,** *p*-ethoxybenzeneazo-*m*-phenylenediamine (indicator): dissolve 0.1 g of the base in 100 mL 90% alcohol; or, 0.1 g of the hydrochloride salt in 100 mL water; pH range red 3.5–5.5 yellow.

Ethyl bis-(2,4-dinitrophenyl) acetate (indicator): the stock solution is prepared by saturating a solution containing equal volumes of alcohol and acetone with the indicator; pH range colorless 7.4–9.1 deep blue. This compound is available commercially. The preparation of this compound is described by Fehnel and Amstutz, *Ind. Eng. Chem., Anal. Ed.* **16:**53 (1944), and by von Richter, *Ber*. **21:**2470 (1888), who recommended it for the titration of orange- and red-colored solutions or dark oils in which the endpoint of phenol-phthalein is not easily visible. The indicator is an orange solid which after crystallization from benzene gives pale yellow crystals melting at 150–153.5°C, uncorrected.

Fehling's solution (sugar detection and estimation): (*a*) Copper sulfate solution: dissolve 34.639 g of $CuSO_4 \cdot 5H_2O$ in water and dilute to 500 mL. (b) Alkaline tartrate solution: dissolve 173 g of rochelle salts ($KNaC_4O_6 \cdot 4H_2O$) and 125 g of KOH in water and dilute to 500 mL. Equal volumes of the two solutions are mixed just prior to use. The Methods of the Assoc. of Official Agricultural Chemists give 50 g of NaOH in place of the 125 g KOH.

Ferric chloride, $FeCl_3$—0.5*N*: 27 g per liter.

Ferric nitrate, $Fe(NO_3)_3 \cdot 9H_2O$—0.5*N*: 67 g per liter.

Ferrous ammonium sulfate, Mohr's salt, $FeSO_4 \cdot (NH_4)_2SO_4 \cdot 6H_2O$—0.5*N*: 196 g per liter.

Ferrous sulfate, $FeSO_4 \cdot 7H_2O$—0.5*N*: 80 g per liter; add a few drops of H_2SO_4.

Folin's mixture (for uric acid): dissolve 500 g of ammonium sulfate, 5 g of uranium acetate, and 6 mL of glacial acetic acid, in 650 mL of water. The volume is about a liter.

Formal or Formalin: use the commercial 40% solution of formaldehyde.

Froehde's reagent (gives characteristic colorations with certain alkaloids and glycosides): dissolve 0.01 g of sodium molybdate in 1 mL of concentrated H_2SO_4; use only a freshly prepared solution.

Gallein (indicator): dissolve 0.1 g in 100 mL alcohol; pH range light brown-yellow 3.8–6.6 rose.

Glyoxylic acid solution (protein detection): cover 10 g of magnesium powder with water and slowly add 250 mL of a saturated oxalic solution, keeping the mixture cool; filter off the magnesium oxalate, acidify the filtrate with acetic acid and make up to a liter with water.

Guaiacum tincture: dissolve 1 g of guaiacum in 100 mL of alcohol.

Gunzberg's reagent (detection of HCl in gastric juice): dissolve 4 g of phloroglucinol and 2 g of vanillin in 100 mL of absolute alcohol; use only a freshly prepared solution.

Hager's reagent (for alkaloids): this reagent is a saturated solution of picric acid in water.

Hanus solution (for determination of iodine number): dissolve 13.2 g of iodine in a liter of glacial acetic acid that will not reduce chromic acid; add sufficient bromine to double the halogen content determined by titration (3 mL is about the right amount). The iodine may be dissolved with the aid of heat, but the solution must be cold when the bromine is added.

Hematoxylin (indicator): dissolve 0.5 g in 100 mL alcohol; pH range yellow 5.0–6.0.

Heptamethoxy red, 2,4,6,2′,4′,2″,4″-heptamethoxytriphenyl carbinol (indicator): dissolve 0.1 g in 100 mL alcohol; pH range red 5.0–7.0 colorless.

Hydriodic acid, HI—0.5*N*: 64 g per liter.

Hydrobromic acid, HBr—0.5*N*: 40 g per liter.

Hydrochloric acid, HCl—5*N*: 182 g per liter; sp. gr. 1.084.

Hydrofluoric acid, H_2F_2—48% solution: use as purchased, and keep in the special container.

Hydrogen peroxide, H_2O_2—3% solution: use as purchased.

Hydrogen sulfide, H_2S: prepare a saturated aqueous solution.

Indicator solutions: a number of indicator solutions are listed in this section under the names of the indicators; e.g., alizarin, aurin, azolitmin, et al., which follow alphabetically. *See also* various index entries.

Indigo carmine, sodium indigodisulfonate (indicator): dissolve 0.25 g in 100 mL 50% alcohol; pH range blue 11.6–14.0 yellow.

Indo-oxine, 5,8-quinolinequinone-8-hydroxy-5-quinoyl-5-imide (indicator): dissolve 0.05 g in 100 mL alcohol; pH range red 6.0–8.0 blue. Cf. Berg and Becker, *Z. Anal. Chem.* **119:**81 (1940).

Iodeosin, tetraiodofluorescein (indicator): dissolve 0.1 g in 100 mL ether saturated with water; pH range yellow 0–about 4 rose-red; *see also* under methyl orange.

Iodic acid, HIO_3—0.5*N* (HIO_3/12): 15 g per liter.

Iodine: *see* tincture of iodine.

Lacmoid (indicator): dissolve 0.5 g in 100 mL alcohol; pH range red 4.4–6.2 blue.

Lead acetate, $Pb(C_2H_3O_2)_2 \cdot 3H_2O$—0.5*N*: 95 g per liter.

Lead chloride, $PbCl_2$—saturated solution is 1/7*N*.

Lead nitrate, $Pb(NO_3)_2$—0.5*N*: 83 g per liter.

Lime water: *see* calcium hydroxide.

Litmus (indicator): powder the litmus and make up a 2% solution in water by boiling for 5 minutes; pH range red 4.5–8.3 blue.

Magnesia mixture: 100 g of $MgSO_4$, 200 g of NH_4Cl, 400 mL of NH_4Cl, 800 mL of water; each mL $\equiv$ 0.01 g phosphorus (P).

Magnesium chloride, $MgCl_2 \cdot 6H_2O$—0.5*N*: 50 g per liter.

Magnesium nitrate, $Mg(NO_3)_2 \cdot 6H_2O$—0.5*N*: 64 g per liter.

Magnesium sulfate, epsom salts, $MgSO_4 \cdot 7H_2O$—0.5*N*: 62 g per liter; saturated solution dissolve 600 g of the salt in water and dilute to 1 liter.

Manganous chloride, $MnCl_2 \cdot 4H_2O$—0.5*N*: 50 g per liter.

Manganous nitrate, $Mn(NO_3)_2 \cdot 6H_2O$—0.5*N*: 72 g per liter.

Manganous sulfate, $MnSO_4 \cdot 7H_2O$—0.5*N*: 69 g per liter.

Marme's reagent (gives yellowish-white precipitate with salts of alkaloids): saturate a boiling solution of 4 parts of KI in 12 parts of water with CdI_2; then add an equal volume of cold saturated KI solution.

Marquis reagent (gives a purple-red coloration, then violet, then blue with morphine, codeine, dionine, and heroine): mix 3 mL of concentrated H_2SO_4 with 3 drops of a 35% formaldehyde solution.

Mayer's reagent (gives white precipitate with most alkaloids in a slightly acid solution): dissolve 13.55 g of $HgCl_2$ and 50 g of KI in a liter of water.

Mercuric chloride, $HgCl_2$—0.5*N*: 68 g per liter.

Mercuric nitrate, $Hg(NO_3)_2$—0.5*N*: 81 g per liter.

Mercuric sulfate, $HgSO_4$—0.5*N*: 74 g per liter.

Mercurous nitrate, $HgNO_3$: mix 1 part of $HgNO_3$, 20 parts of H_2O, and 1 part of HNO_3.

Metacresol purple, *m*-cresol-sulfonphthalein (indicator): dissolve 0.1 g in 13.6 mL 0.02*N* NaOH and dilute with water to 250 mL; acid pH range red 0.5–2.5 yellow, alkaline pH range yellow 7.4–9.0 purple.

Metanil yellow, diphenylaminoazo-*m*-benzene sulfonic acid (indicator): dissolve 0.25 g in 100 mL alcohol; pH range red 1.2–2.3 yellow.

Methyl green, hexamethylpararosaniline hydroxymethylate (component of mixed indicator): dissolve 0.1 g in 100 mL alcohol; when used with equal parts of hexamethoxytriphenyl carbinol gives color change from violet to green at a titration exponent (pI) of 4.0.

Methyl orange, orange III, tropeolin D, sodium *p*-dimethylaminoazobenzenesulfonate (indicator): dissolve 0.1 g in 100 mL water; pH range red 3.0–4.4 orange-yellow. If during a titration where methyl yellow is being used a precipitate forms which tends to remove the indicator from the aqueous phase, methyl orange will be found to be a more suitable indicator. This occurs, for example, in titrations of soaps with acids. The fatty acids, liberated by the titration, extract the methyl yellow so that the endpoint cannot be perceived. Likewise methyl orange is more suitable for titrations in the presence of immiscible organic solvents such as carbon tetrachloride or ether used in the extraction of alkaloids for analysis. Iodeosin (*q.v.*) has also been proposed as an indicator for such cases. Cf. Mylius and Foerster, *Ber.* **24:**1482 (1891); *Z. Anal. Chem.* **31:**240 (1892).

Methyl red, *p*-dimethylaminoazobenzene-*o′*-carboxylic acid (indicator): dissolve 0.1 g in 18.6 mL of 0.02*N* NaOH and dilute with water to 250 mL; or, 0.1 g in 60% alcohol; pH range red 4.4–6.2 yellow.

Methyl violet (indicator): dissolve 0.25 g in 100 mL water, pH range blue 1.5–3.2 violet.

Methyl yellow, *p*-dimethylaminoazobenzene, benzeneazodimethylaniline (indicator): dissolve 0.1 g in 200 mL alcohol; pH range red 2.9–4.0 yellow. The color change from yellow to orange can be perceived somewhat more sharply than the change of methyl orange from orange to rose, so that methyl yellow seems to deserve preference in many cases. *See also* under methyl orange.

Methylene blue, *N,N,N′,N′*-tetramethylthionine (component of mixed indicator): dissolve 0.1 g in 100 mL alcohol; when used with equal part of methyl yellow gives color change from blue-violet to green at a titration exponent (pI) of 3.25; when used with equal part of 0.2% methyl red in alcohol gives color change from red-violet to green at a titration exponent (pI) of 5.4; when used with an equal part of neutral red gives color change from violet-blue to green at a titration exponent (pI) of 7.0.

Millon's reagent (gives a red precipitate with certain proteins and with various phenols): dissolve 1 part of mercury in 1 part of HNO_3 (sp. gr. 1.40) with gentle heating, then add 2 parts of water; a few crystals of KNO_3 help to maintain the strength of the reagent.

Mohr's salt: *see* ferrous ammonium sulfate.

α-Naphthol solution: dissolve 144 g of α-naphthol in enough alcohol to make a liter of solution.

α-Naphtholbenzein (indicator): dissolve 0.1 g in 100 mL 70% alcohol; pH range colorless 9.0–11.0 blue.

α-Naphtholphthalein (indicator): dissolve 0.1 g in 50 mL alcohol and dilute with water to 100 mL; pH range pale yellow-red 7.3–8.7 green.

Nessler's reagent (for free ammonia): dissolve 50 g of KI in the least possible amount of cold water; add a saturated solution of $HgCl_2$ until a very slight excess is indicated; add 400 mL of a 50% solution of KOH; allow to settle, make up to a liter with water, and decant.

Neutral red, toluylene red, dimethyldiaminophenazine chloride, aminodimethylaminotoluphenazine hydrochloride (indicator): dissolve 0.1 g in 60 mL alcohol and dilute with water to 100 mL; pH range red 6.8–8.0 yellow-orange.

Nickel chloride, $NiCl_2 \cdot 6H_2O$—0.5*N*: 59 g per liter.

Nickel nitrate, $Ni(NO_3)_2 \cdot 6H_2O$—0.5*N*: 73 g per liter.

Nickel sulfate, $NiSO_4 \cdot 6H_2O$—0.5*N*: 66 g per liter.

Nitramine, picrylmethylnitramine, 2,4,6-trinitrophenylmethyl nitramine (indicator): dissolve 0.1 g in 60 mL alcohol and dilute with water to 100 mL; pH range colorless 10.8–13.0 red-brown; the solution should be kept in the dark as nitramine is unstable; on boiling with alkali it decomposes quickly. Fresh solutions should be prepared every few months.

Nitric acid, HNO_3—5*N*: 315 g per liter; sp. gr. 1.165.

Nitrohydrochloric acid: *see* aqua regia.

***p*-Nitrophenol** (indicator): dissolve 0.2 g in 100 mL water; pH range colorless at about 5–7 yellow.

Nitroso-*β*-naphthol, $HOC_{10}H_6NO$—saturated solution: saturate 100 mL of 50% acetic acid with the solid.

Nylander's solution (detection of glucose): dissolve 40 g of rochelle salt and 20 g of bismuth subnitrate in 1000 mL of an 8% NaOH solution.

Obermayer's reagent (detection of indoxyl in urine): dissolve 4 g of $FeCl_3$ in a liter of concentrated HCl.

Orange III (indicator): *see* under methyl orange.

Oxalic acid, $H_2C_2O_4 \cdot 2H_2O$: dissolve in ten parts of water.

Pavy's solution (estimation of glucose): mix 120 mL of Fehling's solution and 300 mL of ammonium hydroxide (sp. gr. 0.88), and dilute to a liter with water.

Perchloric acid, $HClO_4$—60%: use as purchased.

Phenol red, phenol-sulfonphthalein (indicator): dissolve 0.1 g in 14.20 mL 0.02*N* NaOH and dilute with water to 250 mL; or, 0.1 g in 100 mL 20% alcohol; pH range yellow 6.8–8.0 red.

Phenol solution: dissolve 20 g of phenol (carbolic acid) in a liter of water.

Phenol sulfonic acid (determination of nitrogen as nitrate; water analysis for nitrate): dissolve 25 g pure, white phenol in 150 mL of pure concentrated H_2SO_4, add 75 mL of fuming H_2SO_4 (15% SO_3), stir well and heat for two hours at 100°C.

Phenolphthalein (indicator): dissolve 1 g in 60 mL of alcohol and dilute with water to 100 mL; pH range colorless 8.2–10.0 red.

Phosphoric acid, *ortho,* H_3PO_4—0.5*N*: 16 g per liter.

Poirrer blue C4B (indicator): dissolve 0.2 g in 100 mL water; pH range blue 11.0–13.0 red.

Potassium acid antimonate, KH_2SbO_4—0.1*N*: boil 23 g of the salt with 950 mL of water for 5 minutes, cool rapidly and add 35 mL of 6*N* KOH; allow to stand for one day, filter dilute filtrate to a liter.

Potassium arsenate, K_3AsO_4—0.5*N* (K_3AsO_4/10): 26 g per liter.

Potassium arsenite, $KAsO_2$—0.5*N* ($KAsO_2$/6): 24 g per liter.

Potassium bromate, $KBrO_3$—0.5*N* ($KBrO_3$/12): 14 g per liter.

Potassium bromide, KBr—0.5*N*: 60 g per liter.

Potassium carbonate, K_2CO_3—3*N*: 207 g per liter.

Potassium chloride, KCl—0.5*N*: 37 g per liter.

Potassium chromate, K_2CrO_4—0.5*N*: 49 g per liter.

Potassium cyanide, KCN—0.5*N*: 33 g per liter.

Potassium dichromate, $K_2Cr_2O_7$—0.5*N* ($K_2Cr_2O_7$/8): 38 g per liter.

Potassium ferricyanide, $K_3Fe(CN)_6$—0.5*N*: 55 g per liter.

Potassium ferrocyanide, $K_4Fe(CN)_6 \cdot 3H_2O$—0.5*N*: 53 g per liter.

Potassium hydroxide, KOH—5*N*: 312 g per liter.

Potassium iodate, KIO_3—0.5*N* (KIO_3/12): 18 g per liter.

Potassium iodide, KI—0.5*N*: 83 g per liter.

Potassium nitrate, KNO_3—0.5*N*: 50 g per liter.

Potassium nitrate, KNO_2—6*N*: 510 g per liter.

Potassium permanganate, $KMnO_4$—0.5*N* ($KMnO_4$/10): 16 g per liter.

Potassium pyrogallate (oxygen in gas analysis): weigh out 5 g of pyrogallol (pyrogallic acid), and pour upon it 100 mL of a KOH solution. If the gas contains less than 28% of oxygen, the KOH solution should be 500 g KOH in a liter of water; if there is more than 28% of oxygen in the gas, the KOH solution should be 120 g of KOH in 100 mL of water.

Potassium sulfate, K_2SO_4—0.5*N*: 44 g per liter.

Potassium thiocyanate, KCNS—0.5*N*: 49 g per liter.

Precipitating reagent (for group II, anions): dissolve 61 g of $BaCl_2 \cdot 2H_2O$ and 52 g of $CaCl_2 \cdot 6H_2O$ in water and dilute to 1 liter. If the solution becomes turbid, filter and use filtrate.

Quinaldine red (indicator): dissolve 0.1 g in 100 mL alcohol; pH range colorless 1.4–3.2 red.

Quinoline blue, cyanin (indicator): dissolve 1 g in 100 mL alcohol; pH range colorless 6.6–8.6 blue.

Rosolic acid, aurin, corallin, corallinphthalein, 4,4′-dihydroxy-fuchsone, 4,4′-dihydroxy-3-methyl-fuchsone (indicator): dissolve 0.5 g in 50 mL alcohol and dilute with water to 100 mL.

Salicyl yellow (indicator): *see* alizarin yellow GG.

Scheibler's reagent (precipitates alkaloids, albumoses and peptones): dissolve sodium tungstate in boiling water containing half its weight of phosphoric acid (sp. gr. 1.13); on evaporation of this solution, crystals of phosphotungstic acid are obtained. A 10% solution of phosphotungstic acid in water constitutes the reagent.

Schweitzer's reagent (dissolves cotton, linen, and silk, but not wool); add NH_4Cl and NaOH to a solution of copper sulfate. The blue precipitate is filtered off, washed, pressed, and dissolved in ammonia (sp. gr. 0.92).

Silver nitrate, $AgNO_3$—0.25*N*: 43 g per liter.

Silver sulfate, Ag_2SO_4—*N*/13 (saturated solution): stir mechanically 10 g of the salt in a liter of water for 3 hours; decant and use the clear liquid.

Soap solution (for hardness in water): (*a*) *Clark's or A.P.H.A. Stand. Methods*—prepare stock solution of 100 g of pure powdered castile soap in a liter of 80% ethyl alcohol; allow to stand over night and decant. Titrate against $CaCl_2$ solution (0.5 g $CaCO_3$ dissolved in a concentrated HCl, neutralized with NH_4OH to slight alkalinity using litmus as the indicator, make up to 500 mL; 1 mL of this solution is equivalent to 1 mg $CaCO_3$) and dilute with 80% alcohol until 1 mL of the resulting solution is equivalent to 1 mL of the standard $CaCl_2$ making due allowance

for the lather factor (the lather factor is that amount of standard soap solution required to produce a permanent lather in a 50-mL portion of distilled water). One milliliter of this solution after subtracting the lather factor is equivalent to 1 mg of $CaCO_3$. (*b*) *Boutron-Boudet*—dissolve 100 g of pure castile soap in about 2500 mL of 56% ethyl alcohol and adjust so that 2.4 mL will give a permanent lather with 40 mL of a solution containing 0.59 g $Ba(NO_3)_2$ per liter of water; 2.4 mL of this solution is equivalent to 22 French degrees or 220 parts per million of hardness (as $CaCO_3$) on a 40-mL sample of water.

Sodium acetate, $NaC_2H_3O_2 \cdot 3H_2O$: dissolve 1 part of the salt in 10 parts of water.

Sodium acetate, acid: dissolve 100 g of sodium acetate and 30 mL of glacial acetic acid in water and dilute to 1 liter.

Sodium bismuthate (oxidation of manganese): heat 20 parts of NaOH nearly to redness in an iron or nickel crucible, and add slowly 10 parts of basic bismuth nitrate which has been previously dried. Add 2 parts of sodium peroxide, and pour the brownish-yellow fused mass on an iron plate to cool. When cold break up in a mortar, extract with water, and collect on an asbestos filter.

Sodium carbonate, Na_2CO_3—3*N*: 159 g per liter; one part Na_2CO_3, or 2.7 parts of the crystalline $Na_2CO_3 \cdot 10H_2O$ in 5 parts of water.

Sodium chloride, NaCl—0.5*N*: 29 g per liter.

Sodium chloroplatinite, Na_2PtCl_4: dissolve 1 part of the salt in 12 parts of water.

Sodium cobaltinitrite, $Na_2Co(NO_2)_6$—0.3*N*: dissolve 230 g of $NaNO_2$ in 500 mL of water, add 160 mL of 6*N* acetic acid and 35 g of $Co(NO_3)_2 \cdot 6H_2O$. Allow to stand one day, filter, and dilute the filtrate to a liter.

Sodium hydrogen phosphate, $Na_2HPO_4 \cdot 12H_2O$—0.5*N*: 60 g liter.

Sodium hydroxide, NaOH—5*N*: 220 g per liter.

Sodium hydroxide, alcoholic: dissolve 20 g of NaOH in alcohol and dilute to 1 liter with alcohol.

Sodium hypobromite: dissolve 100 g of NaOH in 250 mL of water and add 25 mL of bromine.

Sodium nitrate, $NaNO_3$—0.5*N*: 43 g per liter.

Sodium nitroprusside (for sulfur detection): dissolve about 1 g of sodium nitroprusside in 10 mL of water; as the solution deteriorates on standing, only freshly prepared solutions should be used. This compound is also called sodium nitroferricyanide and has the formula $Na_2Fe(NO)(CN)_5 \cdot 2H_2O$.

Sodium polysulfide, Na_2S_x: dissolve 480 g of $Na_2S \cdot 9H_2O$ in 500 mL of water, add 40 g of NaOH and 18 g of sulfur, stir mechanically and dilute to 1 liter with water.

Sodium sulfate, Na_2SO_4—0.5*N*: 35 g per liter.

Sodium sulfide, Na_2S: saturate NaOH solution with H_2S, then add as much NaOH as was used in the original solution.

Sodium sulfite, $Na_2SO_3 \cdot 7H_2O$—0.5*N*: 63 g per liter.

Sodium sulfite, acid (saturated): dissolve 600 g of $NaHSO_3$ in water and dilute to 1 liter; for the preparation of addition compounds with aldehydes and ketones: prepare a saturated solution of sodium carbonate in water and saturate with sulfur dioxide.

Sodium tartrate, acid, $NaHC_4H_4O_6$: dissolve 1 part of the salt in 10 parts of water.

Sodium thiosulfate, $Na_2S_2O_3 \cdot 5H_2O$: one part of the salt in 40 parts of water.

Sonnenschein's reagent (alkaloid detection): a nitric acid solution of ammonium molybdate is treated with phosphoric acid. The precipitate so produced is washed and boiled with aqua regia

until the ammonium salt is decomposed. The solution is evaporated to dryness and the residue is dissolved in 10% HNO_3.

Stannic chloride, $SnCl_4$—0.5*N*: 33 g per liter.

Stannous chloride, $SnCl_2 \cdot 2H_2O$—0.5*N*: 56 g per liter. The water should be acid with HCl and some metallic tin should be kept in the bottle.

Starch solution (iodine indicator): dissolve 5 g of soluble starch in cold water, pour the solution into 2 liters of water and boil for a few minutes. Keep in a glass-stoppered bottle.

Starch solution (other than soluble): make a thin paste of the starch with cold water, then stir in 200 times its weight of boiling water and boil for a few minutes. A few drops of chloroform added to the solution acts as a preservative.

Stoke's reagent: dissolve 30 g of ferrous sulfate and 20 g of tartaric acid in water and dilute to 1 liter. When required for use, add strong ammonia until the precipitate first formed is dissolved.

Strontium chloride, $SrCl_2 \cdot 6H_2O$—0.5*N*: 67 g per liter.

Strontium nitrate, $Sr(NO_3)_2$—0.5*N*: 53 g per liter.

Strontium sulfate, $SrSO_4$: prepare a saturated solution.

Sulfanilic acid (for detection of nitrites): dissolve 8 g of sulfanilic acid in 1 liter of acetic acid (sp. gr. 1.04).

Sulfuric acid, H_2SO_4—5*N*: 245 g per liter, sp. gr. 1.153.

Sulfurous acid, H_2SO_3: saturate water with sulfur dioxide.

Tannic acid: dissolve 1 g tannic acid in 1 mL alcohol and make up to 10 mL with water.

Tartaric acid, $H_2C_4H_4O_6$: dissolve one part of the acid in 3 parts of water; for a saturated solution dissolve 750 g of tartaric acid in water and dilute to 1 liter.

Tetrabromophenol blue, tetrabromophenol-tetrabromosulfonphthalein (indicator): dissolve 0.1 g in 5 mL 0.02*N* NaOH and dilute with water to 250 mL; pH range yellow 3.0–4.6 blue.

Thymol blue, thymol-sulfonphthalein (indicator): dissolve 0.1 g in 10.75 mL 0.02*N* NaOH and dilute with water to 250 mL; or dissolve 0.1 g in 20 mL warm alcohol and dilute with water to 100 mL; pH range (acid) red 1.2–2.8 yellow, and (alkaline) yellow 8.0–9.6 blue.

Thymolphthalein (indicator): dissolve 0.1 g in 100 mL alcohol; pH range colorless 9.3–10.5 blue.

Tincture of iodine (antiseptic): add 70 g of iodine and 50 g of KI to 50 mL of water; make up to 1 liter with alcohol.

***o*-Tolidine solution** (for residual chlorine in water analysis): dissolve 1 g of pulverized *o*-tolidine, m.p. 129°C., in 1 liter of dilute hydrochloric acid (100 mL conc. HCl diluted to 1 liter).

Toluylene red (indicator): *see* neutral red.

Trichloroacetic acid: dissolve 100 g of the acid in water and dilute to 1 liter.

Trinitrobenzene, 1,3,5-trinitrobenzene (indicator): dissolve 0.1 g in 100 mL alcohol; pH range colorless 11.5–14.0 orange.

Trinitrobenzoic acid, 2,4,6-trinitrobenzoic acid (indicator): dissolve 0.1 g in 100 mL water; pH range colorless 12.0–13.4 orange-red.

Tropeolin D (indicator): *see* methyl orange.

Tropeolin O, sodium 2,4-dihydroxyazobenzene-4-sulfonate (indicator): dissolve 0.1 g in 100 mL water; pH range yellow 11.0–13.0 orange-brown.

Tropeolin OO, orange IV, sodium *p*-diphenylamino-azobenzene sulfonate, sodium 4′-anilino-azobenzene-4-sulfonate (indicator): dissolve 0.1 g in 100 mL water; pH range red 1.3–3.2 yellow.

Tropeolin OOO, sodium α-naphtholazobenzene sulfonate (indicator): dissolve 0.1 g in 100 mL water; pH range yellow 7.6–8.9 red.

Turmeric paper (gives a rose-brown coloration with boric acid): wash the ground root of turmeric with water and discard the washings. Digest with alcohol and filter, using the clear filtrate to impregnate white, unsized paper, which is then dried.

Uffelmann's reagent (gives a yellow coloration in the presence of lactic acid): add a ferric chloride solution to a 2% phenol solution until the solution becomes violet in color.

Wagner's solution (phosphate rock analysis): dissolve 25 g citric acid and 1 g salicylic acid in water, and make up to 1 liter. Twenty-five to fifty milliliters of this reagent prevents precipitation of iron and aluminum.

Wijs solution (for iodine number): dissolve 13 g resublimed iodine in 1 liter of glacial acetic acid (99.5%), and pass in washed and dried (over or through H_2SO_4) chlorine gas until the original thio titration of the solution is not quite doubled. There should be only a slight excess of iodine and no excess of chlorine. Preserve the solution in amber colored bottles sealed with paraffin. Do not use the solution after it has been prepared for more than 30 days.

Xylene cyanole-methyl orange indicator, Schoepfle modification (for partially color blind operators): dissolve 0.75 g xylene cyanole FF (Eastman No. T 1579) and 1.50 g methyl orange in 1 liter of water.

***p*-Xylenol blue,** 1,4-dimethyl-5-hydroxybenzene-sulfonphthalein (indicator): dissolve 0.1 g in 250 mL alcohol; pH range (acid) red 1.2–2.8 yellow, and (alkaline) yellow 8.0–9.6 blue.

Zinc chloride, $ZnCl_2$—0.5*N*: 34 g per liter.

Zinc nitrate, $Zn(NO_3)_2 \cdot 6H_2O$—0.5*N*: 74 g per liter.

Zinc sulfate, $ZnSO_4 \cdot 7H_2O$—0.5*N*: 72 g per liter.

TABLE 11.49 TLV Concentration Limits for Gases and Vapors

Exposure limits (threshold limit value or TLV) are those set by the Occupational Safety and Health Administration and represent conditions to which most workers can be exposed without adverse effects. The TLV value is expressed as a time weighted average airborne concentration over a normal 8-hour workday and 40-hour workweek.

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Acetaldehyde	25	45	carcinogen
Acetic acid	10	25	
Acetic anhydride	5	21	
Acetone	750	1780	
Acetonitrile	40	67	
Acetophenone	10	49	
Acetylene			slightly narcotic
Acrolein	0.1	0.23	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Acrylic acid	2	5.9	
Acrylonitrile	2	4.3	
Acrylonitrile	20	45	
Allyl alcohol	2	4.8	
Allyl chloride	1	3	
Allyl glycidyl ether	5	22	
Ammonia	25	18	toxic
Aniline	2	7.6	carcinogen
Arsine	0.05	0.2	highly toxic
Benzene	10	32	carcinogen
Benzenethiol	0.5	2.3	
p-Benzoquinone	0.1		
Benzoyl chloride	0.5		
Benzoyl peroxide		5	
Benzyl acetate	10		
Benzyl chloride	1		carcinogen
Biphenyl	0.2		
Bis(2-aminoethyl)amine	1		
Bis(2-chloroethyl) ether	5	29	
Bis(2-chloromethyl) ether	0.001		carcinogen
Bis(2-ethylhexyl) phthalate		5	
Boron tribromide	1		
Boron trichloride			toxic
Boron trifluoride	1	3	highly toxic
Bromine	0.1	0.7	
Bromine pentafluoride	0.1		highly toxic
Bromine trifluoride			highly toxic
Bromochloromethane (Halon 1011)	200	1060	
Bromoethane	5	22	carcinogen
Bromoethylene	5	22	slightly toxic
Bromoform	0.5	5	
Bromomethane	5	19	highly toxic, carcinogen
1,3-Butadiene	2		slightly anesthetic, carcinogen
Butane	800	1900	slightly anesthetic
1-Butanethiol	0.5	1.8	
1-Butanol	50	152	
2-Butanol	100	303	
2-Butanone	200	590	
2-Butoxyethanol	25	121	
Butyl acetate	150	710	
sec-Butyl acetate	200	950	
tert-Butyl acetate	200	950	
Butyl acrylate	10		
tert-Butyl alcohol	100	300	
Butylamine	5	15	
tert-Butyl chromate (as CrO_3)		0.1	
Butyl glycidyl ether	50	270	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Butyl mercaptan	0.5	1.5	
p-tert-Butyltoluene	10		
(+)-Camphor	2	12	
Caprolactam	5		
Carbon dioxide	5000	9000	
Carbon disulfide	10	31	
Carbon monoxide	25	28	toxic
Carbon tetrachloride	10	65	
Carbonyl chloride	0.1		
Carbonyl fluoride	2		toxic
Chlordane		0.5	
Chlorine	0.5	1.5	highly toxic
Chlorine dioxide	0.1	0.3	
Chlorine trifluoride	0.1	0.4	highly toxic
Chloroacetaldehyde	1	3	
α-Chloroacetophenone	0.05	0.3	
Chloroacetyl chloride	0.05		
Chlorobenzene	10	46	
2-Chloro-1,3-butadiene	10		carcinogen
Chlorodifluoromethane (CFC 22)	1000	3540	
Chloroethane	100	264	low toxicity
2-Chloroethanol	1	3.3	
Chloroethylene (vinyl chloride)	5	13	toxic, carcinogen
Chloroform (trichloromethane)	10	49	
Chloromethane	50	103	toxic, carcinogen
1-Chloro-1-nitropropane	20	100	
Chloropentafluoroethane (CFC 115)	1000	6320	
3-Chloro-1-propene (allyl chloride)	1	3	carcinogen
o-Chlorotoluene	50	259	
Chlorotrifluoroethylene			toxic
Chromyl chloride (CrO_2Cl_2)	0.025		carcinogen
o-Cresol (also *m*-, *p*-)	5	22	
trans-Crotonaldehyde	2	5.7	
Cyanogen	10	20	highly toxic
Cyanogen chloride	0.3		
Cyclohexane	300	1030	
Cyclohexanol	50	206	
Cyclohexanone	25	100	
Cyclohexene	300	1015	
Cyclohexylamine	10	41	
1,3-Cyclopentadiene	75		
Cyclopentane	600	1720	
Cyclopropane			anesthetic
2,4-D		10	
DDT		1	
Decaborane	0.05	0.3	
Diacetone alcohol	50	238	
2,2'-Diaminodiethylamine	1	4.2	
Diazomethane	0.2		carcinogen

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Diborane	0.1	0.1	
Dibromodifluoromethane	100	860	
1,2-Dibromoethane			carcinogen
Dibutyl phthalate		5	
Dichloroacetylene	0.1		
o-Dichlorobenzene	25	150	
p-Dichlorobenzene	10	60	carcinogen
Dichlorodifluoromethane (Freon 12)	1000	4950	
1,1-Dichloroethane	100	405	
1,2-Dichloroethane	10	40	carcinogen
1,1-Dichloroethylene	5	20	carcinogen
cis-1,2-Dichloroethylene	200	793	
trans-1,2-Dichloroethylene	200	793	
Dichlorofluoromethane (Freon 21)	10	42	
Dichloromethane	50	174	carcinogen
1,1-Dichloro-1-nitroethane	10	60	
1,2-Dichloropropane	75	347	carcinogen
1,3-Dichloropropene	1		carcinogen
Dichlorosilane			highly toxic
1,2-Dichlorotetrafluoroethane (Freon 114)	1000	7000	
Dieldrin		0.25	
Diethanolamine	0.46		
Diethylamine	5	15	
Diethyl ether	400	1210	
Diglycidyl ether	0.5	2.8	
Diisobutyl ketone	25	150	
Diisopropylamine	5	20	
Diiopropyl ether	250	1040	
Dimethoxymethane	1000	3110	
N,*N*-Dimethylacetamide	10	35	
Dimethylamine	5	9.2	highly toxic
N,*N*-Dimethylaniline	5	25	
Dimethyl 1,2-dibromo-2,2-dichloroethylphosphate		3	
Dimethyl ether			slightly toxic, anesthetic
1-(1,1-Dimethylethyl)-4-methylbenzene	1	6.1	
N,*N*-Dimethylformamide	10	30	
2,6-Dimethyl-4-heptanone	25		
1,1-Dimethylhydrazine	0.5	1	carcinogen
Dimethyl phthalate		5	
2,2-Dimethylpropane			probably anesthetic
Dimethyl sulfate	0.1	0.5	carcinogen
Dinitrobenzene	0.15	1	
Dinitro-*o*-cresol		0.2	
Dinitrotoluene		1.5	
1,4-Dioxane	25	90	carcinogen
Diphenyl	0.2	1	
Diphenyl ether	1	7	
Dipropylene glycol methyl ether—skin	100	600	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Endrin—skin		0.1	
Epichlorohydrin	2	7.6	carcinogen
2,3-Epoxy-1-propanol (glycidol)	50	150	
1,2-Ethanediamine	10	25	
Ethanethiol	0.5		
Ethanol	1000	1880	
Ethanolamine	3	7.5	
2-Ethoxyethanol (Cellosolve)	5	18	
2-Ethoxyethyl acetate	5	27	
Ethyl acetate	400	1400	
Ethyl acrylate	5	20	
Ethylamine	5	9.2	highly toxic
Ethylbenzene	100	435	
Ethylene			anesthetic
Ethylene glycol	39		
Ethylene glycol dinitrate	0.2		
Ethyleneimine	0.05		carcinogen
Ethylene oxide	1		toxic, carcinogen
Ethyl formate	100	300	
Ethyl mercaptan	0.1	1	
Ethyl silicate	100	850	
Fluorine	1	2	highly toxic
Fluorotrichloromethane (Freon 11)	1000	5600	
Formaldehyde	0.3		carcinogen
Formamide	10	18	
Formic acid	5	9.4	
2-Furancarboxaldehyde (furfural)	2	7.9	
2-Furanmethanol	10	40	
Glycerol		10	
Heptachlor		0.5	
Heptane	400	1640	
2-Heptanone	50	233	
3-Heptanone	50	234	
Hexachloro-1,3-butadiene	0.02		carcinogen
Hexachlorocyclohexane (lindane)		0.5	
Hexachloroethane	1		carcinogen
Hexachloronaphthalene		0.2	
Hexamethylphosphoric triamide			carcinogen
Hexane	50	176	
2-Hexanone	5	20	
sec-Hexyl acetate	50	300	
Hexylene glycol	25		
Hydrazine	0.01	0.1	carcinogen
Hydrogen bromide	3	10	highly toxic
Hydrogen chloride	5	7	highly toxic
Hydrogen cyanide	4.7		highly toxic
Hydrogen fluoride	3	2	highly toxic
Hydrogen iodide			highly toxic
Hydrogen peroxide (90%)	1	1.4	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Hydrogen selenide	0.05	0.2	highly toxic
Hydrogen sulfide	10	15	highly toxic
4-Hydroxy-4-methyl-2-pentanone	50	238	
Indene	10		
Iodine	0.1	1	
Iodine pentafluoride			highly toxic
Iodomethane	2	12	
Isobutyl acetate	150	700	
Isobutyl alcohol	50	150	
Isopentyl acetate	100	525	
Isopentyl alcohol	100	360	
Isophorone	5	28	
Isopropyl acetate	250	1040	
Isopropylamine	5	12	
Isopropylbenzene (cumene)	50	246	
Isopropyl glycidyl ether	50	240	
Ketene	0.5	0.9	
Lindane		0.5	
Liquified petroleum gas	1000	1800	
Malathion		10	
Maleic anhydride	0.25	1	
Malononitrile	0.05	0.4	
Mesityl oxide	15	60	
Methacrylic acid	20	70	
Methanethiol	0.5		
Methanol	200	262	
2-Methoxyaniline (also 4-)	0.1		carcinogen
2-Methoxyethanol	5	16	
2-Methoxyethyl acetate	5	24	
Methyl acetate	200	610	
Methyl acetylene-propadiene (MAPP)	1000	1800	
Methyl acrylate	10	35	
Methylacrylonitrile	1		
Methylamine	5	6.4	highly toxic
o-Methylaniline (also *p*-)	2		carcinogen
m-Methylaniline	2		
N-Methylaniline	0.5	2.2	
3-Methyl-1-butanol	100	361	
Methyl *tert*-butyl ether	40		
Methylcyclohexane	400	1600	
1-Methylcyclohexanol	50	234	
cis-2-Methylcyclohexanol	50	234	
trans-2-Methylcyclohexanol	50	234	
cis-3-Methylcyclohexanol	50	234	
trans-3-Methylcyclohexanol	50	234	
cis-4-Methylcyclohexanol	50	234	
trans-4-Methylcyclohexanol	50	234	
Methyl formate	100	250	
5-Methyl-2-hexanone	50	234	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	$mg \cdot m^{-3}$	
Methyl hydrazine	0.01		
Methyl isocyanate	0.02	0.05	
Methyl mercaptan	0.5	1	highly toxic
Methyl methacrylate	100	410	
Methyl oxirane	20		carcinogen
4-Methyl-2-pentanol	25	104	
4-Methyl-2-pentanone	50	205	
2-Methyl-2,4-pentanediol	25	121	
2-Methyl-1-propanol	50	152	
2-Methyl-2-propanol	100	303	
2-Methyl-2-propenenitrile	1	2.7	
o-Methylstyrene (also *m*-, *p*-)	50		
Morpholine	20	70	
Naphthalene	10	50	
Nickel carbonyl [$Ni(CO)_4$]	0.05	0.35	carcinogen
Nicotine		0.5	
Nitric acid	2	5	
Nitric oxide	25	30	highly toxic
Nitrobenzene	1	5	
p-Nitrochlorobenzene		1	
Nitroethane	100	310	
Nitrogen dioxide	3		highly toxic
Nitrogen trifluoride	10		
Nitrogen trioxide	10	29	highly toxic
Nitroglycerine	0.2	2	
Nitromethane	100	250	
1-Nitropropane	25	90	
2-Nitropropane	10	36	
Nitrosyl chloride			highly toxic
o-Nitrotoluene (also *m*-, *p*-)	2		
Nonane	200	1050	
Octachloronaphthalene		0.1	
Octane	300	1450	
Oxalic acid		1	
2-Oxetanone	0.05		carcinogen
Oxygen difluoride	0.05	0.1	
Ozone	0.1	0.2	
Parathion		0.1	
Pentaborane	0.005	0.01	
Pentachloronaphthalene		0.5	
Pentachlorophenol		0.5	
Pentanal	50		
Pentane	600	1770	
2-Pentanone	200	700	
3-Pentanone	200	700	
Pentyl acetate	100	530	
Perchloroethylene	100	670	
Perchloromethyl mercaptan	0.1	0.8	
Perchloryl fluoride	3	14	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	mg · m^{-3}	
Perfluoroacetone	0.1		
Phenol	5	19	
p-Phenylenediamine		0.1	
Phenylhydrazine	0.1		carcinogen
Phosgene	0.1	0.4	highly toxic
Phosphine	0.3	0.4	highly toxic
Phosphoric acid		1	
Phosphorus pentachloride		1	
Phosphorus pentafluoride			highly toxic
Phosphorus pentasulfide		1	
Phosphorus trichloride	0.5	3	
Phosphoryl chloride	0.1		
Phthalic anhydride	1	6	
Picric acid—skin		0.1	
Propane	1000	1800	low toxicity
Propanoic acid	10	30	
1-Propanol	200	500	
2-Propanol	400	980	
Propenal	0.1		
Propenenitrile	2		carcinogen
Propenoic acid	2		
Propyl acetate	200	835	
Propyleneimine	2	5	carcinogen
Propylene oxide	100	240	toxic
Propyl nitrate	25	110	
Propyne	1000	1650	
2-Propyn-1-ol	1	2.3	
Pyridine	5	15	
Quinone	0.1	0.4	
Selenium compounds (as Se)		0.2	
Selenium hexafluoride	0.05	0.4	
Silane	5	7	highly toxic
Silicon tetrafluoride			highly toxic
Stibine	0.1		
Stoddard solvent	100	575	
Strychnine		0.15	
Styrene	50	213	carcinogen
Sulfur dioxide	2		highly toxic
Sulfur hexafluoride	1000	6000	low toxicity
Sulfuric acid		1	
Sulfur monochloride	1	6	
Sulfur pentafluoride	0.01		
Sulfur tetrafluoride	0.1	0.4	
Sulfuryl fluoride	5	20	highly toxic
Tellurium hexafluoride	0.02	0.2	
Terphenyls	1	9	
1,1,2,2-Tetrabromoethane	1	14	

TABLE 11.49 TLV Concentration Limits for Gases and Vapors (*Continued*)

Substance	Maximum allowable exposure		Toxicity
	ppm	mg · m^{-3}	
Tetrabromomethane	0.1		
1,1,1,2-Tetrachloro-2,2-difluoroethane	500	4170	
1,1,2,2-Tetrachloro-1,2-difluoroethane	500	4170	
1,1,2,2-Tetrachloroethane	1	6.9	carcinogen
Tetrachloroethylene	25	170	carcinogen
Tetrachloromethane	5	31	carcinogen
1,2,3,4-Tetrachloronaphthalene		2	
Tetraethyllead (as Pb)		0.100	
Tetrafluoromethane			low toxicity
Tetrahydrofuran	200	590	
Tetramethyllead (as Pb)		0.150	
Tetramethylsuccinonitrile	0.5	3	
Tetranitromethane	1	8	
Thionyl chloride	1		
Thiram		5	
Toluene	50	188	
Toluene-2,4-diisocyanate	0.02	0.14	
o-Toluidine (also *m*-, *p*-)	2	8.8	
Tribromomethane	0.5	5.2	
Tributyl phosphate	0.2	2.2	
1,2,4-Trichlorobenzene	5		
1,1,1-Trichloroethane	350	1910	
1,1,2-Trichloroethane	10	55	carcinogen
Trichloroethylene	50	270	carcinogen
Trichlorofluoromethane	1000	5600	
Trichloromethane	10	49	carcinogen
1,2,3-Trichloropropane	10	60	
1,1,2-Trichlorotrifluoroethane	1000		
Tri-*o*-cresol phosphate (also *m*-, *p*-)		0.1	
Triethanolamine	0.5		
Triethylamine	1		
Trifluorobromomethane (Freon 13B1)	1000	6100	
1,1,2-Trifluorotrichloroethane	1000	7600	
Triiodomethane	0.6		
Trimethylamine	5	12	highly toxic
1,2,3-Trimethylbenzene	25	123	
1,2,4-Trimethylbenzene (pseudocumene)	25	123	
1,3,5-Trimethylbenzene (mesitylene)	25	123	
Trinitrotoluene (TNT)		1.5	
Triphenyl phosphate		3	
Turpentine	100	560	
Vinyl acetate	10	35	carcinogen
Vinyl methyl ether			probably anesthetic
Warfarin		0.1	
o-Xylene (also *m*-, *p*-)	100	434	
2,3-Xylidine (also 2,4-, 2,5-, 2,6-, 3,4-, 3,5-)	0.5	2.5	

TABLE 11.50 Some Common Reactive and Incompatible Chemicals

Chemical	Keep out of contact with
Acetic acid	Chromium(VI) oxide, chlorosulfonic acid, ethylene glycol, ethyleneimine, hydroxyl compounds, nitric acid, oleum, perchloric acid, peroxides, permanganates, potasssium *tert*-butoxide, PCl_3
Acetylene	Bromine, chlorine, brass, copper and copper salts, fluorine, mercury and mercury salts, nitric acid, silver and silver salts, alkali hydrides, potassium metal
Alkali metals	Moisture, acetylene, metal halides, ammonium salts, oxygen and oxidizing agents, halogens, carbon tetrachloride, carbon, carbon dioxide, carbon disulfide, chloroform, chlorinated hydrocarbons, ethylene oxide, boric acid, sulfur, tellurium
Aluminum	Chlorinated hydrocarbons, halogens, steam
Ammonia, anhydrous	Mercury, halogens, hypochlorites, chlorites, chlorine(I) oxide, hydrofluoric acid (anhydrous), hydrogen peroxide, chromium(VI) oxide, nitrogen dioxide, chromyl(VI) chloride, sulfinyl chloride, magnesium perchlorate, peroxodisulfates, phosphorus pentoxide, acetaldehyde, ethylene oxide, acrolein, gold(III) chloride
Ammonium nitrate	Acids, metal powders, flammable liquids, chlorates, nitrites, sulfur, finely divided organic or combustible materials, perchlorates, urea
Ammonium perchlorate	Hot copper tubing, sugar, finely divided organic or combustible materials, potassium periodate and permanganate, powdered metals, carbon, sulfur
Aniline	Nitric acid, peroxides, oxidizing materials, acetic anhydride, chlorosulfonic acid, oleum, ozone
Benzoyl peroxide	Direct sunlight, sparks and open flames, shock and friction, acids, alcohols, amines, ethers, reducing agents, polymerization catalysts, metallic naphthenates
Bromine	Ammonia, carbides, dimethylformamide, fluorine, ozone, olefins, reducing materials including many metals, phosphine, silver azide
Calcium carbide	Moisture, selenium, silver nitrate, sodium peroxide, tin(II) chloride, potassium hydroxide plus chlorine, HCl gas, magnesium
Carbon, activated	Calcium hypochlorite, all oxidizing agents, unsaturated oils
Chlorates	Ammonium salts, acids, metal powders, sulfur, finely divided organic or combustible materials, cyanides, metal sulfides, manganese dioxide, sulfur dioxide, organic acids
Chlorine	Ammonia, acetylene, alcohols, alkanes, benzene, butadiene, carbon disulfide, dibutyl phthalate, ethers, fluorine, glycerol, hydrocarbons, hydrogen, sodium carbide, finely divided metals, metal acetylides and carbides, nitrogen compounds, nonmetals, nonmetal hydrides, phosphorus compounds, polychlorobiphenyl, silicones, steel, sulfides, synthetic rubber, turpentine
Chlorine dioxide	Ammonia, carbon monoxide, hydrogen, hydrogen sulfide, methane, mercury, nonmetals, phosphine, phosphorus pentachloride
Chlorites	Ammonia, organic matter, metals
Chloroform	Aluminum, magnesium, potassium, sodium, aluminum chloride, ethylene, powerful oxidants
Chlorosulfonic acid	Saturated and unsaturated acids, acid anhydrides, nitriles, acrolein, alcohols, ammonia, esters, HCl, HF, ketones, hydrogen peroxide, metal powders, nitric acid, organic materials, water
Chromic(VI) acid	Acetic acid, acetic anhydride, acetone, alcohols, alkali metals, ammonia, dimethylformamide, camphor, glycerol, hydrogen sulfide, phosphorus, pyridine, selenium, sulfur, turpentine, flammable liquids in general
Cobalt	Acetylene, hydrazinium nitrate, oxidants
Copper	Acetylene and alkynes, ammonium nitrate, azides, bromates, chlorates, iodates, chlorine, ethylene oxide, fluorine, peroxides, hydrogen sulfide, hydrazinium nitrate

TABLE 11.50 Some Common Reactive and Incompatible Chemicals (*Continued*)

Chemical	Keep out of contact with
Copper(II) sulfate	Hydroxylamine, magnesium
Cumene hydroperoxide	Acids (inorganic or organic)
Cyanides	Acids, water or steam, fluorine, magnesium, nitric acid and nitrates, nitrites
Cyclohexanol	Oxidants
Cyclohexanone	Hydrogen peroxide, nitric acid
Decaborane-14	Dimethyl sulfoxide, ethers, halocarbons
Diazomethane	Alkali metals, calcium sulfate
1,1-Dichloroethylene	Air, chlorotrifluoroethylene, ozone, perchloryl fluoride
Dimethylformamide	Halocarbons, inorganic and organic nitrates, bromine, chromium(VI) oxide, aluminum trimethyl, phosphorus trioxide
1,1-Dimethylhydrazine	Air, hydrogen peroxide, nitric acid, nitrous oxide
Dimethylsulfoxide	Acyl and aryl halides, boron compounds, bromomethane, nitrogen dioxide, magnesium perchlorate, periodic acid, silver difluoride, sodium hydride, sulfur trioxide
Dinitrobenzenes	Nitric acid
Dinitrotoluenes	Nitric acid
1,4-Dioxane	Silver perchlorate
Esters	Nitrates
Ethylamine	Cellulose, oxidizers
Ethers	Oxidizing materials, boron triiodide
Ethylene	Aluminum trichloride, carbon tetrachloride, chlorine, nitrogen oxides, tetrafluoroethylene
Ethylene oxide	Acids and bases, alcohols, air, 1,3-nitroaniline, aluminum chloride, aluminum oxide, ammonia, copper, iron chlorides and oxides, magnesium perchlorate, mercaptans, potassium, tin chlorides, alkane thiols
Ethyl ether	Liquid air, chlorine, chromium(VI) oxide, lithium aluminum hydride, ozone, perchloric acid, peroxides
Ethyl sulfate	Oxidizing materials, water
Flammable liquids	Ammonium nitrate, chromic acid, the halogens, hydrogen peroxide, nitric acid
Fluorine	Isolate from everything; only lead and nickel resist prolonged attack
Formamide	Iodine, pyridine, sulfur trioxide
Freon 113	Aluminum, barium, lithium, samarium, NaK alloy, titanium
Glycerol	Acetic anhydride, hypochlorites, chromium(VI) oxide, perchlorates, alkali peroxides, sodium hydride
Hydrazine	Alkali metals, ammonia, chlorine, chromates and dichromates, copper salts, fluorine, hydrogen peroxide, metallic oxides, nickel, nitric acid, liquid oxygen, zinc diethyl
Hydrides	Powerful oxidizing agents, moisture
Hydrocarbons	Halogens, chromium(VI) oxide, peroxides
Hydrogen	Halogens, lithium, oxidants, lead trifluoride
Hydrogen bromide	Fluorine, iron(III) oxide, ammonia, ozone
Hydrogen chloride	Acetic anhydride, aluminum, 2-aminoethanol, ammonia, chlorosulfonic acid, ethylenediamine, fluorine, metal acetylides and carbides, oleum, perchloric acid, potassium permanganate, sodium, sulfuric acid
Hydrogen fluoride	Acetic anhydride, 2-aminoethanol, ammonia, arsenic trioxide, chlorosulfonic acid, ethylenediamine, ethyleneimine, fluorine, HgO, oleum, phosphorus trioxide, propylene oxide, sodium, sulfuric acid, vinyl acetate
Hydrogen iodide	Fluorine, nitric acid, ozone, metals
Hydrogen peroxide	Copper, chromium, iron, most metals or their salts, alcohols, acetone, organic materials, flammable liquids, combustible materials
Hydrogen selenide	Hydrogen peroxide, nitric acid
Hydrogen sulfide	Fuming nitric acid, oxidizing gases, peroxides

TABLE 11.50 Some Common Reactive and Incompatible Chemicals (*Continued*)

Chemical	Keep out of contact with
Hydroquinone	Sodium hydroxide
Hydroxylamine	Barium oxide and peroxide, carbonyls, chlorine, copper(II) sulfate, dichromates, lead dioxide, phosphorus trichloride and pentachloride, permanganates, pyridine, sodium, zinc
Hypochlorites, salts of	Urea, amines, anthracene, carbon, carbon tetrachloride, ethanol, glycerol, mercaptans, organic sulfides, sulfur, thiols
Indium	Acetonitrile, nitrogen dioxide, mercury(II) bromide, sulfur
Iodine	Acetaldehyde, acetylene, aluminum, ammonia (aqueous or anhydrous), antimony, bromine pentafluoride, carbides, cesium oxide, chlorine, ethanol, fluorine, formamide, lithium, magnesium, phosphorus, pyridine, silver azide, sulfur trioxide
Iodine monochloride	Aluminum foil, organic matter, metal sulfides, phosphorus, potassium, rubber, sodium
Iodoform	Acetone, lithium, mercury(II) oxide, mercury(I) chloride, silver nitrate
Iodomethane	Silver chlorite, sodium
Iron disulfide	Water, powdered pyrites
Isothiourea	Acrylaldehyde, hydrogen peroxide, nitric acid
Ketones	Aldehydes, nitric acid, perchloric acid
Lactonitrile	Oxidizing materials
Lead	Ammonium nitrate, chlorine trifluoride, hydrogen peroxide, sodium azide and carbide, zirconium, oxidants
Lead(II) azide	Calcium stearate, copper, zinc, brass, carbon disulfide
Lead chromate	Iron hexacyanoferrate(4−)
Lead dioxide	Aluminum carbide, hydrogen peroxide, hydrogen sulfide, hydroxylamine, nitroalkanes, nitrogen compounds, nonmetal halides, peroxoformic acid, phosphorus, phosphorus trichloride, potassium, sulfur, sulfur dioxide, sulfides, tungsten, zirconium
Lead(II) oxide	Chlorinated rubber, chlorine, ethylene, fluorine, glycerol, metal acetylides, perchloric acid
Lead(II,IV) oxide	Same as for lead dioxide
Lithium hydride	Nitrous oxide, oxygen
Magnesium	Air, beryllium fluoride, ethylene oxide, halogens, halocarbons, HI, metal cyanides, metal oxides, metal oxosalts, methanol, oxidants, peroxides, sulfur, tellurium
Maleic anhydride	Alkali metals, amines, KOH, NaOH, pyridine
Manganese dioxide	Aluminum, hydrogen sulfide, oxidants, potassium azide, hydrogen peroxide, peroxosulfuric acid, sodium peroxide
Mercaptans	Powerful oxidizers
Mercury	Acetylenic compounds, chlorine, fulminic acid, ammonia, ethylene oxide, metals, methyl azide, oxidants, tetracarbonylnickel
Mercury(II) cyanide	Fluorine, hydrogen cyanide, magnesium, sodium nitrite
Mercury(I) nitrate	Phosphorus
Mercury(II) nitrate	Acetylene, aromatics, ethanol, hypophosphoric acid, phosphine, unsaturated organic compounds
Mercury(II) oxide	Chlorine, hydrazine hydrate, hydrogen peroxide, hypophosphorous acid, magnesium, phosphorus, sulfur, butadiene, hydrocarbons, methanethiol
Mesityl oxide	2-Aminoethanol, chlorosulfonic acid, nitric acid, ethylenediamine, sulfuric acid
Methanol	Beryllium dihydride, chloroform, oxidants, potassium *tert*-butoxide
Methylamine	Nitromethane
N-Methylformamide	Benzenesulfonyl chloride
Methyl isobutyl ketone	Potassium *tert*-butoxide

TABLE 11.50 Some Common Reactive and Incompatible Chemicals (*Continued*)

Chemical	Keep out of contact with
Methyl methacrylate	Air, benzoyl peroxide
4-Methylnitrobenzene	Sulfuric acid, tetranitromethane
2-Methylpyridine	Hydrogen peroxide, iron(II) sulfate, sulfuric acid
Methylsodium	4-Chloronitrobenzene
Molybdenum trioxide	Chlorine trifluoride, interhalogens, metals
Naphthalene	Chromium trioxide, dinitrogen pentaoxide
2-Naphthol	Antipyrine, camphor, phenol, iron(III) salts, menthol, oxidizing materials, permanganates, urethane
Neodymium	Phosphorus
Nickel	Aluminum, aluminum(III) chloride, ethylene, 1,4-dioxan, hydrogen, methanol, nonmetals, oxidants, sulfur compounds
Nickel carbonyl	Air, bromine, oxidizing materials
Niobium	Bromine trifluoride, chlorine, fluorine
Nitrates	Aluminum, BP, cyanides, esters, phosphorus, tin(II) chloride, sodium hypophosphite, thiocyanates
Nitric acid, fuming	Organic matter, nonmetals, most metals, ammonia, chlorosulfonic acid, chromium trioxide, cyanides, dichromates, hydrazines, hydrides, HCN, HI, hydrogen sulfide, sulfur dioxide, sulfur halides, sulfuric acid, flammable liquids and gases
Nitric oxide	Aluminum, BaO, boron, carbon disulfide, chromium, many chlorinated hydrocarbons, fluorine, hydrocarbons, ozone, phosphine, phosphorus, hydrazine, acetic anhydride, ammonia, chloroform, Fe, K, Mg, Mn, Na, sulfur
Nitrites	Organic nitrites in contact with ammonium salts, cyanides
Nitrobenzene	Nitric acid, nitrous oxide, silver perchlorate
Nitroethane	Hydroxides, hydrocarbons, metal oxides
Nitrogen trichloride	Ammonia, As, hydrogen sulfide, nitrogen dioxide, organic matter, ozone, phosphine, phosphorus, KCN, KOH, Se, dibutyl ether
Nitrogen dioxide	Cyclohexane, fluorine, formaldehyde, alcohols, nitrobenzene, petroleum, toluene
Nitrogen triiodide	Acids, bromine, chlorine, hydrogen sulfide, ozone
α-Nitroguanidine	Complex salts of mercury and silver
Nitromethane	Acids, alkylmetal halides, hydroxides, hydrocarbons, organic amines, formaldehyde, nitric acid, perchlorates
1-Nitropropane	*See* under Nitromethane; chlorosulfonic acid, oleum
Nitrosyl fluoride	Haloalkenes, metals, nonmetals
Nitrosyl perchlorate	Acetones, amines, diethyl ether, metal salts, organic materials
Nitrourea	Mercury(II) and silver salts
Nitrous acid	Phosphine, phosphorus trichloride, silver nitrate, semicarbazone
Nitryl chloride	Ammonia, sulfur trioxide, tin(IV) bromide and iodide
Oxalic acid	Furfuryl alcohol, silver, mercury, sodium chlorate, sodium chlorite, sodium hypochlorite
Oxygen	Acetaldehyde, acetone, alcohols, alkali metals, alkaline earth metals, Al-Ti alloys, ether, carbon disulfide, halocarbons, hydrocarbons, metal hydrides, 1,3,5-trioxane
Ozone	Alkenes, aromatic compounds, bromine, diethyl ether, ethylene, HBr, HI, nitric oxide, nitrogen dioxide, rubber, stibine
Palladium	Arsenic, carbon, ozonides, sulfur, sodium tetrahydridoborate
Paraformaldehyde	Liquid oxygen
Paraldehyde	Alkalies, HCN, iodides, nitric acid, oxidizers
Pentaborane-9	Dimethylsulfoxide
Pentacarbonyliron	Acetic acid, nitric oxide, transition metal halides, water, zinc

TABLE 11.50 Some Common Reactive and Incompatible Chemicals (*Continued*)

Chemical	Keep out of contact with
2-Pentanone	Bromine trifluoride
3-Pentanone	Hydrogen peroxide, nitric acid
Perchlorates	Carbonaceous materials, finely divided metals particularly magnesium and aluminum, sulfur, benzene, olefins, ethanol, sulfur, sulfuric acid
Perchloric acid	Acetic acid, acetic anhydride, alcohols, antimony compounds, azo pigments, bismuth and its alloys, methanol, carbonaceous materials, carbon tetrachloride, cellulose, dehydrating agents, diethyl ether, glycols and glycolethers, HCl, HI, hypophosphites, ketones, nitric acid, pyridine, steel, sulfoxides, sulfuric acid
Permanganates	All reducing agents, organic materials
Peroxides	Reducing agents, organic materials, thiocyanates
Peroxoacetic acid	Acetic anhydride, olefins, organic matter
Peroxobenzoic acid	Olefins, reducing materials
Peroxoformic acid	Metals and nonmetals, organic materials
Peroxosulfuric acid	Acetone, alcohols, aromatic compounds, catalysts
Phenol	Butadiene, peroxodisulfuric acid, peroxosulfuric acid, aluminum chloride plus nitrobenzene
Phenylhydrazine	Lead dioxide, oxidizers
Phosgene	Aluminum, alkali metals, 2-propanol
Phosphine	Air, boron trichloride, bromine, chlorine, nitric acid, nitrogen oxides, nitrous acid, oxygen, silver nitrate
Phosphorus pentachloride	Aluminum, chlorine, chlorine dioxide, chlorine trioxide, fluorine, magnesium oxide, nitrobenzene, diphosphorus trioxide, potassium, sodium, urea, water
Phosphorus pentafluoride	Water or steam
Phosphorus pentasulfide	Air, alcohols, water
Phosphorus pentoxide	Formic acid, HF, inorganic bases, metals, oxidants, water
Phosphorus, red	Organic materials
Phosphorus tribromide	Potassium, ruthenium tetroxide, sodium, water
Phosphorus trichloride	Acetic acid, aluminum, chromyl dichloride, dimethylsulfoxide, hydroxylamine, lead dioxide, nitric acid, nitrous acid, organic matter, potassium, sodium water
Phosphorus, white	Air, oxidants of all types, halogens, metals
Phosphoryl chloride	Carbon disulfide, *N,N*-dimethylformamide, 2,5-dimethylpyrrole, 2,6-dimethylpyridine 1-oxide, dimethylsulfoxide, water, zinc
Phthalic acid	Nitric acid, sodium nitrite
Piperazine	Oxidizers
Platinum	Acetone, arsenic, hydrazine, lithium, proxosulfuric acid, phosphorus, selenium, tellurium
Potassium	*See* under Alkali metals
Potassium *tert*-butoxide	Organic compounds, sulfuric acid
Potassium hydride	Air, chlorine, acetic acid, acrolein, acrylonitrile, maleic anhydride, nitroparaffins, *N*-nitrosomethylurea, tetrahydrofuran, water
Potassium perchlorate	Aluminum plus magnesium, carbon, nickel plus titanium, reducing agents, sulfur, sulfuric acid
Potassium permanganate	Organic or readily oxidizable materials
Potassium sodium alloy	Air, carbon dioxide, carbon disulfide, halocarbons, metal oxides
2-Propyn-1-ol	Alkali metals, mercury(II) sulfate, oxidizing materials, phosphorus pentoxide, sulfuric acid
Pyridine	Chlorosulfonic acid, chromium trioxide, formamide, maleic anhydride, nitric acid, oleum, perchromates, silver perchlorate, sulfuric acid
Pyrrolidine	Oxidizing materials

TABLE 11.50 Some Common Reactive and Incompatible Chemicals (*Continued*)

Chemical	Keep out of contact with
Quinoline	Dinitrogen tetroxide, linseed oil, maleic anhydride, thionyl chloride
Salicylic acid	Iodine, iron salts, lead acetate
Silicon	Alkali carbonates, calcium, chlorine, cobalt(II) fluoride, manganese trifluoride, oxidants, silver fluoride, sodium-potassium alloy
Silver	Acetylene, ammonium compounds, ethyleneimine, hydrogen peroxide, oxalic acid, sulfuric acid, tartaric acid
Sodium	*See* under Alkali metals
Sodium peroxide	Glacial acetic acid, acetic anhydride, aniline, benzene, benzaldehyde, carbon disulfide, diethyl ether, ethanol or methanol, ethylene glycol, ethyl acetate, furfural, glycerol, metals, methyl acetate, organic matter
Sulfides	Acids, powerful oxidizers, moisture
Sulfur	Oxidizing materials, halogens
Sulfur dioxide	Halogens, metal oxides, polymeric tubing, potassium chlorate, sodium hydride
Sulfuric acid	Chlorates, metals, HCl, organic materials, perchlorates, permanganates, water
Sulfuryl dichloride	Alkalis, diethyl ether, dimethylsulfoxide, dinitrogen tetroxide, lead dioxide, phosphorus
Tellurium	Halogens, metals
Tetrahydrofuran	Tetrahydridoaluminates, KOH, NaOH
Tetranitroaniline	Reducing materials
Tetranitromethane	Aluminum, cotton, aromatic nitro compounds, hydrocarbons, cotton, toluene
Thiocyanates	Chlorates, nitric acid, peroxides
Thionyl chloride	Ammonia, dimethylsulfoxide, linseed oil, quinoline, sodium
Thiophene	Nitric acid
Thymol	Acetanilide, antipyrine, camphor, chlorohydrate, menthol, quinine sulfate, urethene
Tin(II) chloride	Boron trifluoride, ethylene oxide, hydrazine hydrate, nitrates, Na, K, hydrogen peroxide
Tin(IV) chloride	Alkyl nitrates, ethylene oxide, K, Na turpentine
Titanium	Aluminum, boron trifluoride, carbon dioxide, CuO, halocarbons, halogens, PbO, nitric acid, potassium chlorate, potassium nitrate, potassium permanganate, steam at high temperatures, water
Toluene	Sulfuric plus nitric acids, nitrogen dioxide, silver perchlorate, uranium hexafluoride
Toluidines	Nitric acid
2,4,6-Trinitrotoluene	Sodium dichromate, sulfuric acid
1,3,5-Trioxane	Oxidizing materials, acids
Urea	Sodium nitrite, phosphorus pentachloride
Vinylidene chloride	Chlorosulfonic acid, nitric acid, oleum

TABLE 11.51 Chemicals Recommended for Refrigerated Storage

A. Due to chemical decomposition or polymerization

Acetaldehyde	Isoprene
Acrolein	Lecithin
Adenosinetriphosphoric acid	Mercaptoacetic acid
Bromacetaldehyde, diethyl acetal	Methyl acrylate
Bromosuccinimide	2-Methyl-1-butene
3-Buten-2-one	Methylenedi-1,4-phenylene diisocyanate
tert-Butyl hydroperoxide	4-Methyl-1-pentene
2-Chlorocyclohexanone	α-Methylstyrene
Cupferron	1-Naphthyl isocyanate
1,3-Cyclohexadiene	1-Pentene
1,3-Dihydroxy-2-propanone	Isopentyl acetate
Divinylbenzene	Pyruvic acid
Ethyl methacrylate, monomer	Styrene, stabilized
Glutathione	Tetramethylsilane
Glycidol	Thioacetamide
Histamine, base	Veratraldehyde
Hydrocinnamaldehyde	Vitamin E (and the acetate)

B. Due to flammability and high volatility

Acetaldehyde	Iodomethane
Bromoethane	Isoprene
tert-Butylamine	Isopropylamine
Carbon disulfide	Methylal
1-Chloropropane	2-Methylbutane
3-Chloropropane	2-Methyl-2-butene
Cyclopentane	Methyl formate
Diethyl ether	Pentane
2,2-Dimethylbutane	Propylamine
Dimethyl sulfide	Propylene oxide
Furan	Trichlorosilane

TABLE 11.52 Chemicals Which Polymerize or Decompose on Extended Refrigeration

Formaldehyde	Sodium methoxide
Hydrogen peroxide	Sodium nitrate
Sodium chlorite [sodium chlorate (IV)]	Sodium peroxide
Sodium chromate(VI)	Strontium nitrate
Sodium dithionite	Urea
Sodium ethoxide	

11.8 SIEVES AND SCREENS

TABLE 11.53 U.S. Standard Sieve Series

	Sieve opening			Sieve opening	
Sieve no.	mm	inch	Sieve no.	mm	inch
	125	5.00	10	2.00	0.0787
	106	4.24	12	1.70	0.0661
	90	3.50	14	1.40	0.0555
	75	3.00	16	1.18	0.0469
	63	2.50	18	1.00	0.0394
	53	2.12	20	0.850	0.0331
	45	1.75	25	0.710	0.0278
	37.5	1.50	30	0.600	0.0234
	31.5	1.25	35	0.500	0.0197
	26.5	1.06	40	0.425	0.0165
	22.4	0.875	45	0.355	0.0139
	19.0	0.75	50	0.300	0.0117
	16.0	0.625	60	0.250	0.0098
	13.2	0.530	70	0.212	0.0083
	11.2	0.438	80	0.180	0.0070
	9.5	0.375	100	0.150	0.0059
	8.0	0.312	120	0.125	0.0049
	6.7	0.265	140	0.106	0.0041
3.5	5.60	0.223	170	0.090	0.0035
4	4.75	0.187	200	0.075	0.0029
5	4.00	0.157	230	0.063	0.0025
6	3.35	0.132	270	0.053	0.0021
7	2.80	0.111	325	0.045	0.0017
8	2.36	0.0937	400	0.038	0.0015

Specifications are from ASTM E.11-81/ISO 565. The sieve numbers are the approximate number of openings per linear inch.

11.9 THERMOMETRY

11.9.1 Temperature and Its Measurement

The new international temperature scale, known as ITS-90, was adopted in September 1989. However, neither the definition of thermodynamic temperature nor the definition of the kelvin or the Celsius temperature scales has changed; it is the way in which we are to realize these definitions that has changed. The changes concern the recommended thermometers to be used in different regions of the temperature scale and the list of secondary standard fixed points. The changes in temperature determined using ITS-90 from the previous IPTS-68 are always less than 0.4 K, and almost always less than 0.2 K, over the range 0–1300 K.

The ultimate definition of thermodynamic temperature is in terms of pV (pressure $\times$ volume) in a gas thermometer extrapolated to low pressure. The kelvin (K), the unit of thermodynamic temperature, is defined by specifying the temperature of one fixed point on the scale—the triple point

of water which is defined to be 273.16 K. The Celsius temperature scale (°C) is defined by the equation

$$°C = K - 273.15$$

where the freezing point of water at 1 atm is 273.15 K.

The fixed points in the ITS-90 are given in Table 11.39. Platinum resistance thermometers are recommended for use between 14 K and 1235 K (the freezing point of silver), calibrated against the fixed points. Below 14 K either the vapor pressure of helium or a constant-volume gas thermometer is to be used. Above 1235 K radiometry is to be used in conjunction with the Planck radiation law,

$$L_\lambda = c_1\lambda^{-5}\,(e^{c_2/\lambda T} - 1)^{-1}$$

where L_λ is the spectral radiance at wavelength λ. The first radiation constant, c_1, is $3.741\ 83 \times 10^{-16}$ W · m² and the second radiation constant, c_2, has a value of 0.014 388 m · K.

TABLE 11.54 Fixed Points in the ITS-90

Fixed points	*T*, K	*t*, °C
Triple point of hydrogen	13.8033	−259.3467
Boiling point of hydrogen at 33 321.3 Pa	17.035	−256.115
Boiling point of hydrogen at 101 292 Pa	20.27	−252.88
Triple point of neon	24.5561	−248.5939
Triple point of oxygen	54.3584	−218.7916
Triple point of argon	83.8058	−189.3442
Triple point of mercury	234.3156	−38.8344
Triple point of water	273.16	0.01
Melting point of gallium	302.9146	29.7646
Freezing point of indium	429.7458	156.5985
Freezing point of tin	505.078	231.928
Freezing point of zinc	692.677	419.527
Freezing point of aluminum	933.473	660.323
Freezing point of silver	1234.93	961.78
Freezing point of gold	1337.33	1064.18
Freezing point of copper	1357.77	1084.62
Secondary reference points to extend the scale (IPTS-68):		
Freezing point of platinum	2042	1769
Freezing point of rhodium	2236	1963
Freezing point of iridium	2720	2447
Melting point of tungsten	3660	3387

11.10 THERMOCOUPLES

The thermocouple reference data in Tables 11.55 to 11.63 give the thermoelectric voltage in millivolts with the reference junction at 0°C. Note that the temperature for a given entry is obtained by adding the corresponding temperature in the top row to that in the left-hand column, regardless of whether the latter is positive or negative.

The noble metal thermocouples, Types B, R, and S, are all platinum or platinum-rhodium thermocouples and hence share many of the same characteristics. Metallic vapor diffusion at high temperatures can readily change the platinum wire calibration, hence platinum wires should only be used inside a nonmetallic sheath such as high-purity alumina.

Type B thermocouples (Table 11.56) offer distinct advantages of improved stability, increased mechanical strength, and higher possible operating temperatures. They have the unique advantage that the reference junction potential is almost immaterial, as long as it is between 0°C and 40°C. Type B is virtually useless below 50°C because it exhibits a double-value ambiguity from 0°C to 42°C.

Type E thermoelements (Table 11.57) are very useful down to about liquid hydrogen temperatures and may even be used down to liquid helium temperatures. They are the most useful of the commercially standardized thermocouple combinations for subzero temperature measurements because of their high Seebeck coefficient (58 μV/°C), low thermal conductivity, and corrosion resistance. They also have the largest Seebeck coefficient (voltage response per degree Celsius) above 0°C of any of the standardized thermocouples which makes them useful for detecting small temperature changes. They are recommended for use in the temperature range from -250 to 871°C in oxidizing or inert atmospheres. They should not be used in sulfurous, reducing, or alternately reducing and oxidizing atmospheres unless suitably protected with tubes. They should not be used in vacuum at high temperatures for extended periods of time.

Type J thermocouples (Table 11.58) are one of the most common types of industrial thermocouples because of the relatively high Seebeck coefficient and low cost. They are recommended for use in the temperature range from 0 to 760°C (but never above 760°C due to an abrupt magnetic transformation that can cause decalibration even when returned to lower temperatures). Use is permitted in vacuum and in oxidizing, reducing, or inert atmospheres, with the exception of sulfurous atmospheres above 500°C. For extended use above 500°C, heavy-gauge wires are recommended. They are not recommended for subzero temperatures. These thermocouples are subject to poor conformance characteristics because of impurities in the iron.

The Type K thermocouple (Table 11.59) is more resistant to oxidation at elevated temperatures than the Type E, J, or T thermocouple, and consequently finds wide application at temperatures above 500°C. It is recommended for continuous use at temperatures within the range -250 to 1260°C in inert or oxidizing atmospheres. It should not be used in sulfurous or reducing atmospheres, or in vacuum at high temperatures for extended times.

The Type N thermocouple (Table 11.60) is similar to Type K but it has been designed to minimize some of the instabilities in the conventional Chromel-Alumel combination. Changes in the alloy content have improved the order/disorder transformations occurring at 500°C and a higher silicon content of the positive element improves the oxidation resistance at elevated temperatures.

The Type R thermocouple (Table 11.61) was developed primarily to match a previous platinum–10% rhodium British wire which was later found to have 0.34% iron impurity in the rhodium. Comments on Type S also apply to Type R.

The Type S thermocouple (Table 11.62) is so stable that it remains the standard for determining temperatures between the antimony point (630.74°C) and the gold point (1064.43°C). The other fixed point used is that of silver. The Type S thermocouple can be used from -50°C continuously up to about 1400°C, and intermittently at temperatures up to the freezing point of platinum (1769°C). The thermocouple is most reliable when used in a clean oxidizing atmosphere, but may also be used in inert gaseous atmospheres or in a vacuum for short periods of time. It should not be used in reducing atmospheres, nor in those containing metallic vapor (such as lead or zinc), nonmetallic vapors (such as arsenic, phosphorus, or sulfur), or easily reduced oxides, unless suitably protected with nonmetallic protecting tubes.

The Type T thermocouple (Table 11.63) is popular for the temperature region below 0°C (but see under Type E). It can be used in vacuum, or in oxidizing, reducing, or inert atmospheres.

TABLE 11.55 Thermoelectric Values in Millivolts at Fixed Points for Various Thermocouples

Abbreviations Used in the Table

FP, freezing point BP, boiling point
NBP, normal boiling point TP, triple point

Fixed point	°C	Type B	Type E	Type J	Type K	Type N	Type R	Type S	Type T
Helium NPB	−268.934		−9.8331		−6.4569	−4.345			−6.2563
Hydrogen TP	−259.347*		−9.7927		−6.4393	−4.334			−6.2292
Hydrogen NBP	−252.88*		−9.7447		−6.4167	−4.321			−6.1977
Neon TP	−248.594*		−9.7046		−6.3966	−4.271			−6.1714
Neon NBP	−246.048		−9.6776		−6.3827	−4.300			−6.1536
Oxygen TP	−218.792*		−9.2499		−6.1446	−4.153			−5.8730
Nitrogen TP	−210.001		−9.0629	−8.0957	−6.0346	−4.083			−5.7533
Nitrogen NBP	−195.802		−8.7168	−7.7963	−5.8257	−3.947			−5.5356
Oxygen NBP	−182.962		−8.3608	−7.4807	−5.6051	−3.802			−5.3147
Carbon dioxide SP	−78.474		−4.2275	−3.7187	−2.8696	−1.939			−2.7407
Mercury TP	−38.834*		−2.1930	−1.4849		−0.985	−0.1830	−0.1895	−1.4349
Ice point	0.000	−0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Diphenyl ether TP	26.87	−0.0024	1.6091	1.3739	1.076	0.698	0.1517	0.1537	1.0679
Water BP	100.00	0.0332	6.3171	5.2677	4.0953	2.774	0.6472	0.6453	4.2773

Benzoic acid TP	122.37	0.0561	7.8468	6.4886	5.0160	3.446	0.8186	0.8129	5.3414
Indium FP	156.598*	0.1019	10.260	8.3743	6.0404	4.508	1.0956	1.0818	7.0364
Tin FP	231.928*	0.2474	15.809	12.552	9.4201	6.980	1.7561	1.7146	11.013
Bismuth FP	271.442	0.3477	18.821	14.743	11.029	8.336	2.1250	2.0640	13.219
Cadmium FP	321.108	0.4971	22.684	17.493	13.085	10.092	2.6072	2.5167	16.095
Lead FP	327.502	0.5182	23.186	17.846	13.351	10.322	2.6706	2.5759	16.473
Mercury BP	356.66	0.6197	25.489	19.456	14.571		2.9630	2.8483	18.218
Zinc FP	419.527*	0.8678	30.513	22.926	17.223		3.6113	3.4479	
Cu-Al eutectic FP	548.23	1.4951	40.901	30.109	22.696		5.0009	4.7140	
Antimony FP	630.74	1.9784	47.561	34.911	26.207		5.9331	5.5521	
Aluminum FP	660.37	2.1668	49.941	36.693	27.461		6.2759	5.8591	
Silver FP	961.93*	4.4908	73.495	55.669	39.779		10.003	9.1482	
Gold FP	1064.43*	5.4336		61.716	43.755		11.364	10.334	
Copper FP	1084.5	5.6263		62.880	44.520		11.635	10.570	
Nickel FP	1455	9.5766					16.811	15.034	
Cobalt FP	1494	10.025					17.360	15.504	
Palladium FP	1554	10.721					18.212	16.224	
Platinum FP	1772	13.262					21.103	18.694	

* Defining fixed points of the International Temperature Scale of 1990 (ITS-90). Except for the triple points, the assigned values of temperature are for equilibrium states at a pressure of one standard atmosphere (101 325 Pa).

TABLE 11.56 Type B Thermocouples: Platinum–30% Rhodium Alloy vs. Platinum–6% Rhodium Alloy

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
0	0.00	−0.0019	−0.0026	−0.0021	−0.0005	0.0023	0.0062	0.0112	0.0174	0.0248
100	0.0332	0.0427	0.0534	0.0652	0.0780	0.0920	0.1071	0.1232	0.1405	0.1588
200	0.1782	0.1987	0.2202	0.2428	0.2665	0.2912	0.3170	0.3438	0.3717	0.4006
300	0.4305	0.4615	0.4935	0.5266	0.5607	0.5958	0.6319	0.6690	0.7071	0.7462
400	0.7864	0.8275	0.8696	0.9127	0.9567	1.0018	1.0478	1.0948	1.1427	1.1916
500	1.2415	1.2923	1.3440	1.3967	1.4503	1.5048	1.5603	1.6166	1.6739	1.7321
600	1.7912	1.8512	1.9120	1.9738	2.0365	2.1000	2.1644	2.2296	2.2957	2.3627
700	2.4305	2.4991	2.5686	2.6390	2.7101	2.7821	2.8548	2.9284	3.0028	3.0780
800	3.1540	3.2308	3.3084	3.3867	3.4658	3.5457	3.6264	3.7078	3.7899	3.8729
900	3.9565	4.0409	4.1260	4.2119	4.2984	4.3857	4.4737	4.5624	4.6518	4.7419
1000	4.8326	4.9241	5.0162	5.1090	5.2025	5.2966	5.3914	5.4868	5.5829	5.6796
1100	5.7769	5.8749	5.9734	6.0726	6.1724	6.2728	6.3737	6.4753	6.5774	6.6801
1200	6.7833	6.8871	6.9914	7.0963	7.2017	7.3076	7.4140	7.5210	7.6284	7.7363
1300	7.8446	7.9534	8.0627	8.1724	8.2826	8.3932	8.5041	8.6155	8.7273	8.8394
1400	8.9519	9.0648	9.1780	9.2915	9.4053	9.5194	9.6338	9.7485	9.8634	9.9786
1500	10.0940	10.2097	10.3255	10.4415	10.5577	10.6740	10.7905	10.9071	11.0237	11.1405
1600	11.2574	11.3743	11.4913	11.6082	11.7252	11.8422	11.9591	12.0761	12.1929	12.3100
1700	12.4263	12.5429	12.6594	12.7757	12.8918	13.0078	13.1236	13.2391	13.3545	13.4696
1800	13.5845	13.6991	13.8135							

TABLE 11.57 Type E Thermocouples: Nickel-Chromium Alloy vs. Copper-Nickel Alloy

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
−200	−8.824	−9.063	−9.274	−9.455	−9.604	−9.719	−9.797	−9.835		
−100	−5.237	−5.680	−6.107	−6.516	−6.907	−7.279	−7.631	−7.963	−8.273	−8.561
−0	0.000	−0.581	−1.151	−1.709	−2.254	−2.787	−3.306	−3.811	−4.301	−4.777
0	0.000	0.591	1.192	1.801	2.419	3.047	3.683	4.394	4.983	5.646
100	6.317	6.996	7.683	8.377	9.078	9.787	10.501	11.222	11.949	12.681
200	13.419	14.161	14.909	15.661	16.417	17.178	17.942	18.710	19.481	20.256
300	21.033	21.814	22.597	23.383	24.171	24.961	25.754	26.549	27.345	28.143
400	28.943	29.744	30.546	31.350	32.155	32.960	33.767	34.574	35.382	36.190
500	36.999	37.808	38.617	39.426	40.236	41.045	41.853	42.662	43.470	44.278
600	45.085	45.891	46.697	47.502	48.306	49.109	49.911	50.713	51.513	52.312
700	53.110	53.907	54.703	55.498	56.291	57.083	57.873	58.663	59.451	60.237
800	61.022	61.806	62.588	63.368	64.147	64.924	65.700	66.473	67.245	68.015
900	68.783	69.549	70.313	71.075	71.835	72.593	73.350	74.104	74.857	75.608
1000	76.358									

TABLE 11.58 Type J Thermocouples: Iron vs. Copper-Nickel Alloy

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
−200	−7.890	−8.096								
−100	−4.632	−5.036	−5.426	−5.801	−6.159	−6.499	−6.821	−7.122	−7.402	−7.659
−0	0.000	−0.501	−0.995	−1.481	−1.960	−2.431	−2.892	−3.344	−3.785	−4.215
0	0.000	0.507	1.019	1.536	2.058	2.585	3.115	3.649	4.186	4.725
100	5.268	5.812	6.359	6.907	7.457	8.008	8.560	9.113	9.667	10.222
200	10.777	11.332	11.887	12.442	12.998	13.553	14.108	14.663	15.217	15.771
300	16.325	16.879	17.432	17.984	18.537	19.089	19.640	20.192	20.743	21.295
400	21.846	22.397	22.949	23.501	24.054	24.607	25.161	25.716	26.272	26.829
500	27.388	27.949	28.511	29.075	29.642	30.210	30.782	31.356	31.933	32.513
600	33.096	33.683	34.273	34.867	35.464	36.066	36.671	37.280	37.893	38.510
700	39.130	39.754	40.482	41.013	41.647	42.283	42.922			

TABLE 11.59 Type K Thermocouples: Nickel-Chromium Alloy vs. Nickel-Aluminum Alloy

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
−200	−5.891	−6.035	−6.158	−6.262	−6.344	−6.404	−6.441	−6.458		
−100	−3.553	−3.852	−4.138	−4.410	−4.669	−4.912	−5.141	−5.354	−5.550	−5.730
−0	0.000	−0.392	−0.777	−1.156	−1.517	−1.889	−2.243	−2.586	−2.920	−3.242
0	0.000	0.397	0.798	1.203	1.611	2.022	2.436	2.850	3.266	3.681
100	4.095	4.508	4.919	5.327	5.733	6.137	6.539	6.939	7.338	7.737
200	8.137	8.537	8.938	9.341	9.745	10.151	10.560	10.969	11.381	11.793
300	12.207	12.623	13.039	13.456	13.874	14.292	14.712	15.132	15.552	15.974
400	16.395	16.818	17.241	17.664	18.088	18.513	18.839	19.363	19.788	20.214
500	20.640	21.066	21.493	21.919	22.346	22.772	23.198	23.624	24.050	24.476
600	24.902	25.327	25.751	26.176	26.599	27.022	27.445	27.867	28.288	28.709
700	29.128	29.547	29.965	30.383	30.799	31.214	31.629	32.042	32.455	32.866
800	33.277	33.686	34.095	34.502	34.909	35.314	35.718	36.121	36.524	36.925
900	37.325	37.724	38.122	38.519	38.915	39.310	39.703	40.096	40.488	40.879
1000	41.269	41.657	42.045	42.432	42.817	43.202	43.585	43.968	44.349	44.729
1100	45.108	45.486	45.863	46.238	46.612	46.985	47.356	47.726	48.095	48.462
1200	48.828	49.129	49.555	49.916	50.276	50.633	50.990	51.344	51.697	52.049
1300	52.398	52.747	53.093	53.439	53.782	54.125	54.466	54.807		

TABLE 11.60 Type N Thermocouples: Nickel–14.2% Chromium–1.4% Silicon Alloy vs. Nickel–4.4% Silicon–0.1% Magnesium Alloy

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
−200	−3.990	−4.083	−4.162	−4.227	−4.277	−4.313	−4.336	−4.345		
−100	−2.407	−2.612	−2.807	−2.994	−3.170	−3.336	−3.491	−3.634	−3.766	−3.884
−0	0.000	−0.260	−0.518	−0.772	−1.023	−1.268	−1.509	−1.744	−1.972	−2.193
0	0.000	0.261	0.525	0.793	1.064	1.339	1.619	1.902	2.188	2.479
100	2.774	3.072	3.374	3.679	3.988	4.301	4.617	4.936	5.258	5.584
200	5.912	6.243	6.577	6.914	7.254	7.596	7.940	8.287	8.636	8.987
300	9.340	9.695	10.053	10.412	10.772	11.135	11.499	11.865	12.233	12.602
400	12.972	13.344	13.717	14.091	14.467	14.844	15.222	15.601	15.981	16.362
500	16.744	17.127	17.511	17.896	18.282	18.668	19.055	19.443	19.831	20.220
600	20.609	20.999	21.390	21.781	22.172	22.564	22.956	23.348	23.740	24.133
700	24.526	24.919	25.312	25.705	26.098	26.491	26.885	27.278	27.671	28.063
800	28.456	28.849	29.241	29.633	30.025	30.417	30.808	31.199	31.590	31.980
900	32.370	32.760	33.149	33.538	33.926	34.315	34.702	35.089	35.476	35.862
1000	36.248	36.633	37.018	37.402	37.786	38.169	38.552	38.934	39.315	39.696
1100	40.076	40.456	40.835	41.213	41.590	41.966	42.342	42.717	43.091	43.464
1200	43.836	44.207	44.577	44.947	45.315	45.682	46.048	46.413	46.777	47.140
1300	47.502									

TABLE 11.61 Type R Thermocouples: Platinum–13% Rhodium Alloy vs. Platinum

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
(Below zero)		−0.0515	−0.100	−0.1455	−0.1877	−0.2264				
0	0.0000	0.0543	0.1112	0.1706	0.2324	0.2965	0.3627	0.4310	0.5012	0.5733
100	0.6472	0.7228	0.8000	0.8788	0.9591	1.0407	1.1237	1.2080	1.2936	1.3803
200	1.4681	1.5571	1.6471	1.7381	1.8300	1.9229	2.0167	2.1113	2.2068	2.3030
300	2.4000	2.4978	2.5963	2.6954	2.7953	2.8957	2.9968	3.0985	3.2009	3.3037
400	3.4072	3.5112	3.6157	3.7208	3.8264	3.9325	4.0391	4.1463	4.2539	4.3620
500	4.4706	4.5796	4.6892	4.7992	4.9097	5.0206	5.1320	5.2439	5.3562	5.4690
600	5.5823	5.6960	5.8101	5.9246	6.0398	6.1554	6.2716	6.3883	6.5054	6.6230
700	6.7412	6.8598	6.9789	7.0984	7.2185	7.3390	7.4600	7.5815	7.7035	7.8259
800	7.9488	8.0722	8.1960	8.3203	8.4451	8.5703	8.6960	8.8222	8.9488	9.0758
900	9.2034	9.3313	9.4597	9.5886	9.7179	9.8477	9.9779	10.1086	10.2397	10.3712
1000	10.5032	10.6356	10.7684	10.9017	11.0354	11.1695	11.3041	11.4391	11.5745	11.7102
1100	11.8463	11.9827	12.1194	12.2565	12.3939	12.5315	12.6695	12.8077	12.9462	13.0849
1200	13.2239	13.3631	13.5025	13.6421	13.7818	13.9218	14.0619	14.2022	14.3426	14.4832
1300	14.6239	14.7647	14.9056	15.0465	15.1876	15.3287	15.4699	15.6110	15.7522	15.8935
1400	16.0347	16.1759	16.3172	16.4583	16.5995	16.7405	16.8816	17.0225	17.1634	17.3041
1500	17.4447	17.5852	17.7256	17.8659	18.0059	18.1458	18.2855	18.4251	18.5644	18.7035
1600	18.8424	18.9810	19.1194	19.2575	19.3953	19.5329	19.6702	19.8071	19.9437	20.0797
1700	20.2151	20.3497	20.4834	20.6161	20.7475	20.8777	21.0064			

TABLE 11.62 Type S Thermocouples: Platinum–10% Rhodium Alloy vs. Platinum

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
(Below zero)		−0.0527	−0.1028	−0.1501	−0.1944	−0.2357				
0	0.0000	0.0552	0.1128	0.1727	0.2347	0.2986	0.3646	0.4323	0.5017	0.5728
100	0.6453	0.7194	0.7948	0.8714	0.9495	1.0287	1.1089	1.1902	1.2726	1.3558
200	1.4400	1.5250	1.6109	1.6975	1.7849	1.8729	1.9617	2.0510	2.1410	2.2316
300	2.3227	2.4143	2.5065	2.5991	2.6922	2.7858	2.8798	2.9742	3.0690	3.1642
400	3.2597	3.3557	3.4519	3.5485	3.6455	3.7427	3.8403	3.9382	4.0364	4.1348
500	4.2336	4.3327	4.4320	4.5316	4.6316	4.7318	4.8323	4.9331	5.0342	5.1356
600	5.2373	5.3394	5.4417	5.5445	5.6477	5.7513	5.8553	5.9595	6.0641	6.1690
700	6.2743	6.3799	6.4858	6.5920	6.6986	6.8055	6.9127	7.0202	7.1281	7.2363
800	7.3449	7.4537	7.5629	7.6724	7.7823	7.8925	8.0030	8.1138	8.2250	8.3365
900	8.4483	8.5605	8.6730	8.7858	8.8989	9.0124	9.1262	9.2403	9.3548	9.4696
1000	9.5847	9.7002	9.8159	9.9320	10.0485	10.1652	10.2823	10.3997	10.5174	10.6354
1100	10.7536	10.8720	10.9907	11.1095	11.2286	11.3479	11.4674	11.5871	11.7069	11.8269
1200	11.9471	12.0674	12.1878	12.3084	12.4290	12.5498	12.6707	12.7917	12.9127	13.0338
1300	13.1550	13.2762	13.3975	13.5188	13.6401	13.7614	13.8828	14.0041	14.1254	14.2467
1400	14.3680	14.4892	14.6103	14.7314	14.8524	14.9734	15.9042	15.2150	15.3356	15.4561
1500	15.5765	15.6967	15.8168	15.9368	16.0566	16.1762	16.2956	16.4148	16.5338	16.6526
1600	16.7712	16.8895	17.0076	17.1255	17.2431	17.3604	17.4474	17.5942	17.7105	17.8264
1700	17.9417	18.0562	18.1698	18.2823	18.3937	18.5038	18.6124			

TABLE 11.63 Type T Thermocouples: Copper vs. Copper-Nickel Alloy

Thermoelectric voltage in millivolts; reference junction at 0°C.

°C	0	10	20	30	40	50	60	70	80	90
−200	−5.603	−5.753	−5.889	−6.007	−6.105	−6.181	−6.232	−6.258		
−100	−3.378	−3.656	−3.923	−4.177	−4.419	−4.648	−4.865	−5.069	−5.261	−5.439
−0	0.000	−0.383	−0.757	−1.121	−1.475	−1.819	−2.152	−2.475	−2.788	−3.089
0	0.000	0.391	0.789	1.196	1.611	2.035	2.467	2.908	3.357	3.813
100	4.277	4.749	5.227	5.712	6.204	6.702	7.207	7.718	8.235	8.757
200	9.286	9.820	10.360	10.905	11.456	12.011	12.572	13.137	13.707	14.281
300	14.860	15.443	16.030	16.621	17.217	17.816	18.420	19.027	19.638	20.252
400	20.869									

11.11 CORRECTION FOR EMERGENT STEM OF THERMOMETERS

When a thermometer which has been standardized for total immersion is used with a part of the liquid column at a temperature below that of the bulb, the reading is low and a correction must be applied. The stem correction, in degrees Celsius, is given by

$$KL(t_o - t_m) = \text{degrees Celsius}$$

where K = constant, characteristic of the particular kind of glass and temperature (see Table 11.49)
L = length of exposed thermometer, °C (that is, the length not in contact with vapor or liquid being measured)
t_o = observed temperature on thermometer
t_m = mean temperature of exposed column (obtained by placing an auxiliary thermometer alongside with its bulb midpoint)

For thermometers containing organic liquids, it is sufficient to use the approximate value, $K = 0.001$. In such thermometers the value of K is practically independent of the kind of glass.

TABLE 11.64 Values of K for Stem Correction of Thermometers

Temperature, °C	Soft glass	Heat-resistant glass
0–150	0.000 158	0.000 165
200	0.000 159	0.000 167
250	0.000 161	0.000 170
300	0.000 164	0.000 174
350		0.000 178
400		0.000 183
450		0.000 188