II. *On the Refraction-Equivalents of the Elements.*

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In our paper "On the Refraction, Dispersion, and Sensitiveness of Liquids," Mr. Dale and I pointed out a property of bodies which we termed their "specific refractive energy." It is the refractive index minus unity, divided by the density, or in symbolical language $\frac{\mu-1}{d}$. We found that this is a constant unaffected by temperature, and that the specific refractive energy of a mixture is the mean of the specific refractive energies of its constituents. At the same time, however, we admitted that in both cases our numbers were not in perfect accordance with theory, there being some unknown cause which affected them to a slight extent. These conclusions, both in regard to the general law and its qualification, have been since confirmed by continental physicists, and especially by the late rigorous experiments of Wüllner*.

In the same paper we ventured also on the generalization that "every liquid has a specific refractive energy composed of the specific refractive energies of its component elements, modified by the manner of combination." Later research has confirmed this also, extending it to conditions of matter other than liquid, and showing more clearly when such modifications occur, and what is their nature. Professor Landolt, of Bonn, has greatly advanced our knowledge of the subject, and has simplified the calculations by adopting what he terms the refraction-equivalent, that is, the specific refractive energy multiplied by the atomic weight, or $P\frac{\mu-1}{d}$. Recent investigations in fact tend to the general conclusion that the refraction-equivalent, not only of mixtures, but of every compound body, is the sum of the refraction-equivalents of the elements that compose it.

Were this perfectly true, like the statement "the atomic weight of a compound is the sum of the atomic weights of its constituents," it would be a simple matter to determine the refraction-equivalents of all the elements; and then we should be in a position to calculate the effect of every transparent body of known composition on the rays of light transmitted by it. But it is not absolutely true: even in Landolt's first paper it is evident that there are exceptions; the unknown cause which modifies the refraction of mixtures probably acts in cases of more perfect chemical combination; and the conviction has grown that some elements have two or more refraction-equivalents.

I have continued from time to time to make observations on this subject, and the

* Pogg. Annalen, vol. cxxxiii. p. 1.

period seems now to have come at which it is wise to put on permanent record the results at which I have hitherto arrived. I shall give therefore first the data, and then the deductions in reference to each element examined.

The Data.

These consist of the observations of DULONG* on the refraction of gases, of MALUS, BREWSTER, and others† on solids, and of DELFFS‡, JAMIN, SAUBER §, LANDOLT ||, HAAGEN ¶, and KETTELER ** on liquids, in addition to such determinations as I have myself made, whether previously published †† or not.

Most of my fresh experiments have been made with a new instrument constructed by Mr. BROWNING, with a horizontal instead of a vertical circle, and several other improvements.

I have continued to measure the solar lines A, D, and H, whilst LANDOLT has preferred the three bright lines of the hydrogen spectrum. I have calculated the refraction for the line A, as being the most free from whatever influence there may be connected with dispersion, and the German professor has reckoned for hydrogen α, which is identical with the solar C. These rays are so near together that the difference can scarcely affect the first place of decimals in a refraction-equivalent. When the determinations are made with greater precision, it will be for physicists to decide which shall be finally adopted.

In the subjoined Tables the actual refractive indices are given, and the refraction-equivalents as calculated from them. For the complete data, I must refer to the papers of the several observers, and to Appendices I., II., and III., where my own new experiments are tabulated.

TABLE I.—Simple Elements.

Elementary substance.	Condition.	Part of spectrum.	Refractive index.	Authority for index.	Refraction-equivalent.
Carbon	Diamond	Bright	2·470	Brewster, &c.	5·18
"	"	Red	2·4606	Schrauf.	4·85
Sulphur	Solid	Bright	2·03	Various.	16·0
"	Liquid	A	1·9024	Gladstone and Dale.	15·98
"	"	D	1·9295	"	16·47
Phosphorus	Solid	D	2·1168	"	18·98
"	Liquid	A	2·0389	"	18·27
"	"	D	2·0746	"	18·89
Bromine	"	A	1·6260	Gladstone.	16·23
Chlorine	Gaseous	Bright	1·000779	Dulong.	8·87
Hydrogen	"	"	1·000138	"	1·53
Oxygen	"	"	1·000272	"	3·04
Nitrogen	"	"	1·000300	"	3·30

* Annales de Chimie, xxxi. p. 154.

† Ency. Brit., Article "Optics."

‡ POGG. Annalen, lxxxi. p. 470.

§ Ibid. cxvii. 577.

|| Ibid. cxvii. 353, cxxii. 545, cxxiii. 595.

¶ Ibid. cxxiii. 125.

** Ibid. cxxiv. 390.

†† The papers of Mr. DALE and myself in the Philosophical Transactions, 1858, p. 887, and 1863, p. 317; Phil. Mag. July 1859; also Brit. Assoc. Report, 1863, Trans. Sec. p. 12; my paper in Journal Chem. Soc. 1865, p. 108.

TABLE II.—Binary Compounds.

Substance.	Formula.	Part of Spectrum.	Refractive index.	Authority for index.	Refraction-equivalent.
Bisulphide of Carbon	CS_2	A	1·6121	Gladstone and Dale	36·67
„ „	„	C	1·61846	Wüllner	37·20
„ „	„	D	1·6299	Gladstone and Dale	37·73
„ „ Gaseous	„	Bright	1·001500	Dulong	33·21
Carbonic Oxide	CO	„	1·000340	„	7·53
„ Acid Gas	CO_2	„	1·000449	„	10·03
Cyanogen	CN	„	1·000834	„	9·18
Tetrachloride of Carbon	CCl_4	A	1·4560	Gladstone	44·2
„ „	„	C	1·45789	Haagen	44·21
Olefiant Gas	C_2H_4	Bright	1·000678	Dulong	15·09
Amylene	C_5H_{10}	A	1·3844	Gladstone and Dale	37·63
Oil of Turpentine	$C_{10}H_{16}$	A	1·4614	„ „	72·9
Hydride of Œnanthyle	C_7H_{16}	A	1·3899	„ „	55·0
„ Capryl	C_8H_{18}	A	1·3973	„ „	62·95
Sulphurous Acid Gas	SO_2	Bright	1·000665	Dulong	14·91
„ „ Liquid	„	D	1·33835	Ketteler	14·59
Hydrosulphuric Acid	H_2S	Bright	1·000644	Dulong	14·28
Chloride of Sulphur	S_2Cl_2	C	1·64368	Haagen	51·64
Water, Solid	H_2O	D	1·3089	Gladstone and Dale	6·05
„ Liquid	„	A	1·32924	Gladstone	5·926*
„ „	„	D	1·33328	„	5·999*
„ „	„	H	1·34393	„	6·191*
„ „	„	C	1·33111	Landolt	5·96
„ „	„	D	1·33250	Kühlmann	6·006
„ Gaseous	„	Bright	1·000260	Dulong	5·778
Hydrochloric Acid	HCl	„	1·000449	„	10·71
Ammonia	NH_3	„	1·000385	„	8·60
Nitrous Oxide	N_2O	„	1·000503	„	11·22
Nitric „	NO	„	1·000303	„	6·74
Terchloride of Phosphorus	PCl_3	A	1·5062	Gladstone and Dale	48·3
Terbromide „	PBr_3	A	1·6730	„ „	63·36
Arsenious Anhydride	As_2O_3	...	1·748	Descloizeau	40·03
Terchloride of Arsenic	$AsCl_3$	C	1·5920	Haagen	49·59
Pentachloride of Antimony	$SbCl_5$	C	1·5845	„	74·61
„ „	„	A	1·5739	Gladstone	74·03
Tetrachloride of Silicon	$SiCl_4$	C	1·4119	Haagen	47·06
„ Tin	$SnCl_4$	C	1·5070	„	59·05
„ „	„	A	1·5035	Gladstone	58·76
„ Titanium	$TiCl_4$	A	1·5856	„	65·08
Chloride of Sodium	$NaCl$	A	1·5369	„	15·02
Calomel	Hg_2Cl_2	Bright	1·970	Brewster	65·46
Fluor-spar	CaF_2	„	1·436	„	10·76
Quartz, ordinary ray	SiO_2	„	1·5484	Malus	12·41
„ extraordinary ray	„	„	1·5582	„	12·63

* These are the numbers adopted throughout the series of aqueous solutions, with the new instrument, recorded in Appendix II. The water was purposely not deprived of air.

TABLE III.—Ternary and other Compounds.

Substance.	Formula.	Part of spectrum.	Refractive index.	Authority for index.	Refraction-equivalent.
Alcohol	C_2H_6O	A	1·3615	Gladstone	20·857*
„	„	D	1·3655	„	21·084*
„	„	H	1·3769	„	21·745*
Methylated Acetone	C_4H_8O	A	1·3817	„	33·89
Butyrone	$C_7H_{14}O$	A	1·4073	„	56·29
Laurostearate of Ethyl	$C_{12}H_{23}(C_2H_5)O_2$	Red	1·4240	Delffs	111·5
Cyanide „	C_2H_5CN	B	1·362552	Sauber	25·57
Nitrate „	$C_2H_5NO_3$	B	1·3768	„	30·94
„ „	„	Red	1·381	Jamin	31·17
„ Amyl	$C_5H_{11}NO_3$	A	1·4065	Gladstone and Dale	54·01
Carbonic Ether	$(C_2H_5)_2CO_3$	A	1·3779	„	45·86
Silicic „	$(C_2H_5)_4SiO_4$	A	1·3781	„	84·38
Boracic „	$(C_2H_5)_3B_2O_3$	A	1·3676	„	65·95
Triethylarsine	$As(C_2H_5)_3$	A	1·4597	„	64·69
Mercuric Methyl	$Hg(CH_3)_2$	A	1·5229	Gladstone	40·54
„ Ethyl	$Hg(C_2H_5)_2$	A	1·5162	Gladstone and Dale	54·48
Cane-sugar	$C_{12}H_{22}O_{11}$	Bright	1·541	Brewster	119·3
Phosgene	$COCl_2$	„	1·001159	Dulong	25·64
Chloroform	$CHCl_3$	A	1·4400	Gladstone and Dale	35·25
Chlorobenzole	C_6H_5Cl	A	1·5135	„	52·13
Trichlorobenzole	$C_6H_3Cl_3$	A	1·5563	„	69·62
Bichloride of Ethylene	$C_2H_4Cl_2$	C	1·44201	Haagen	34·84
„ Chlorethylene	$C_2H_3Cl_3$	A	1·4619	Gladstone and Dale	43·51
Bibromide „	$C_2H_3ClBr_2$	A	1·5430	„	53·73
„ Bromethylene	$C_2H_3Br_3$	A	1·5809	„	59·28
Bromoform	$CHBr_3$	A	1·5554	„	53·31
Bromide of Ethyl	C_2H_5Br	C	1·42132	Haagen	31·46
„ „	„	B	1·4138	Sauber	32·15
„ Amyl	$C_5H_{11}Br$	C	1·43856	Haagen	54·98
Bibromide of Ethylene	$C_2H_4Br_2$	C	1·53389	„	45·98
„ „	„	Red	1·532	Jamin	45·82
Iodide of Methyl	CH_3I	A	1·5171	Gladstone and Dale	33·50
„ „	„	C	1·52434	Haagen	32·89
„ Ethyl	C_2H_5I	C	1·50812	„	40·96
„ „	„	Red	1·503	Jamin	40·81
„ „	„	A	1·5026	Gladstone and Dale	40·78
„ Propyl	C_3H_7I	A	1·4934	„	48·99
„ Amyl	$C_5H_{11}I$	A	1·4804	„	63·62
„ „	„	C	1·48714	Haagen	65·46
Chloral	C_2HCl_3O	Red	1·461	Jamin	45·3
Phosphite of Ethyl	$3(C_2H_5)PO_3$	A	1·3996	Gladstone	61·76
Sulphuric Acid	H_2SO_4	A	1·4205	„	21·90
Nitric Acid	HNO_3	A	1·4047	„	16·46
Chloride of Ammonium	NH_4Cl	Bright	1·625	Brewster	22·08
Oxychloride of Phosphorus	$POCl_3$	A	1·4810	Gladstone and Dale	43·79
„ Vanadium	$VOCl_3$	A	1·6143	Gladstone	57·96
„ Chromium	CrO_2Cl_2	A	1·5177	„	42·08
Nitrate of Lead	$Pb2(NO_3)$	Bright	1·758	Brewster	57·0
Sulphate of Barium (ord. ray)	$BaSO_4$	„	1·6352	Malus	33·29
„ „ (ext. ray)	„	„	1·6468	„	33·90
Kryolite	Na_3AlF_6	„	1·346	Brewster	24·63
Alum	$KAl, 2SO_4, 12H_2O$	„	1·458	Wollaston	126·78
Zircon, least	$ZrSiO_4$	„	1·961	Brewster	39·22
„ greatest	„	„	2·015	„	41·42
Borax	$Na_2B_4O_7, 10H_2O$	„	1·475	„	45·8+60
Ferrocyanide of Potassium	$K_4Fe(CN)_6, 3H_2O$	„	1·586	„	117·28+18

Solutions.

If the refraction-equivalent of a mixture or of a chemical compound be the sum of the refraction-equivalents of its constituents, the same may be expected to hold good in the case of a solution. This consideration led me to examine a large number of aqueous

* These are the numbers employed in calculating the alcoholic solutions given in Appendix III.

solutions of salts, bodies which in their solid state are generally doubly refracting, and necessarily present difficulties that are not met with in the examination of liquids.

The method usually adopted was as follows:—An amount of salt representing the atomic weight was dissolved in n atoms of water, and the refractive index and density of the solution were taken. From these was reckoned the refraction-equivalent, and subtracting from this n times the refraction-equivalent of water for the solar line A, there remained the refraction-equivalent of the dissolved salt for that part of the spectrum. Thus to take an actual instance: 1 atom or 58·5 parts of chloride of sodium were dissolved in 12 atoms or 216 parts of water. The refractive index of the solution for A was 1·3683, and the specific gravity at the same temperature was 1·168; $\frac{\mu A-1}{d}$ therefore was 0·3154, and $P\frac{\mu A-1}{d}$ was $0·3154\times(58·5+216)$, that is, 86·57. From this, the refraction-equivalent of the whole compound system, 12 times 5·926 (*i. e.* 71·12) the refraction-equivalent of water was subtracted, leaving 86·57—71·12, or 15·45, as the refraction-equivalent of chloride of sodium. That a number so arrived at fairly represents the action exerted by the chemical compound on light, is evident from the following considerations.

1st. The refraction-equivalent 15·45 closely approximates to that previously determined for chloride of sodium from the examination of solid rock-salt, namely 15·02. Similarly, cane-sugar dissolved in water gave 119·0, while from BREWSTER's observation of the crystallized solid it should be 119·3 (see Table III.). Again, crystallized borax, after making allowance for the refraction due to the water of crystallization, gave 45·8, while from its aqueous solution its equivalent was determined at 45·9. Chloride of ammonium, solid and in solution, gave respectively 22·08 and 22·33.

2nd. The refraction-equivalents of several solid organic bodies, as determined from their aqueous solutions, agree closely with what might be calculated from LANDOLT's values for C, H, and O. Thus,

	Experiment.	Calculation.
Citric Acid	60·89	61·4
Racemic Acid	45·54	45·8
Tartaric Acid	45·29	45·8

3rd. The refraction-equivalent as reckoned from a solution is not affected by varying the amount of water. This has been proved in the case of the chlorides of sodium, potassium, strontium, and copper, iodide of sodium, sulphate of ammonium, and other salts, and even in the case of the combinations of water with strong acids, such as sulphuric and nitric acids. The following experiment on chloride of sodium will serve as an illustration.

Composition of solution.	Refraction-equivalent of Na Cl.	Variation from mean.
1 atom Chloride of Sodium + 10·74 atoms Water	15·33	−0·07
" + 12 "	15·45	+0·05
" + 12 "	15·51	+0·11
" + 12 "	15·51	+0·11
" + 14 "	15·26	−0·14
" + 16 "	15·32	−0·08
" + 18 "	15·47	+0·07
" + 20 "	15·43	+0·03
" + 22 "	15·55	+0·15
" + 24 "	15·51	+0·11
" + 26 "	15·37	−0·03
" + 34 "	15·30	−0·10

This shows also that under favourable circumstances a refraction-equivalent may be depended on to the first place of decimals, but not to the second.

4th. The calculated refraction-equivalent is the same whether water or alcohol be the solvent employed. This was tested in the following cases, the actual observations for which are given in Appendix III.

TABLE IV.

Substance.	Aqueous solution.	Alcoholic solution.
Cobalt Chloride	32·02	32·38
Copper Chloride (line D)...............	34·00	34·72
Mercuric Chloride	41·23	35·59
Potassium Iodide	35·72	35·1
Potassium Sulphocyanide	33·47	33·7
Ammonia	9·49	8·97

The mercuric salt appears to be exceptional, but this metal will be seen later on to be anomalous.

But whatever may be the worth of these considerations, an examination of some corresponding series of salts in solution, viz. the chlorides, bromides, and iodides, convinced me at once that we thus obtain numbers made up of two component parts, the one due to the base, the other to the radical with which it is combined; and the multiplication of these experiments on a large variety of salts has only served to deepen this conviction.

The actual observations will be found in the Appendix, but the refraction-equivalents thus arrived at are given in the following Table.

As the determination of the refraction-equivalent of a salt in solution depends on the difference between it and the refraction-equivalent of water, it is evident that experimental errors will be multiplied undesirably if the water be large in quantity as compared with the salt. Hence the most soluble salts give the most trustworthy results. In some instances the solubility of the salts depended on the addition of some other salt or acid to the solution; in such cases the refraction due to the salt or acid, as well as that due to the water, has been deducted, and in the following Tables the number so arrived at has been marked with an asterisk (*).

TABLE V.—Refraction-equivalents of Compounds in Solution.

Substance.	Atomic weight.	Monobasic.							Bibasic.		
		Chloride.	Bromide.	Iodide.	Nitrate.	Formiate.	Acetate.	Cyanide.	Sulphate.	Hyposulphite.	Lactate.
UNIVALENT.											
Potassium	39·1	18·83	25·09	35·72	22·11	20·24	27·78	17·23	33·11	47·88	76·25
Sodium	23	15·40	21·89	32·52	18·89	......	24·34	......	26·92	41·80	69·45
Lithium	7	14·86	20·56	31·49	......	......	23·25	......	24·26	......	......
Cæsium	133	24·4	......	......	......	......	......	......	......	......	......
Rubidium	85·4	24·28	......	......	......	......	......	......	45·95*	......	......
Silver	108	......	......	......	27·44	......	......	25·52*	......	66·3*	......
Thallium	204	......	......	......	37·2	32·88	40·45	......	......	......	......
Ammonium	18	22·33	28·53	38·90	25·44	......	31·57	......	39·22	......	......
Hydrogen	1	14·22	20·65	31·17	16·50	13·81	21·29	......	22·45	......	......
BIVALENT.											
Barium	137	37·32	50·72	69·72	43·26	39·82	56·44	......	......	......	78·98
Strontium	87·5	35·04	47·52	......	41·68	39·04	......	......	......	......	78·2
Calcium	40	32·28	44·32	64·66	38·66	33·94	49·80	......	......	42·52	......
Magnesium	24	28·88	......	......	35·92	30·80	46·02	......	24·18	38·52	......
Cerium	92	35·08	......	......	......	......	......	......	......	......	......
Didymium	96	34·18	......	......	......	......	......	......	......	......	......
Zinc	65·2	30·76	43·96	65·67	38·52	34·95	48·80	26·2*	27·61	......	......
Cadmium	112	35·32	47·88	......	41·38	......	......	......	30·34	......	......
Copper	63·4	33·40	......	......	40·04	......	......	......	27·80	......	......
Iron	56	32·86	46·26	......	......	......	......	......	29·09	......	......
Nickel	58·8	31·39*	......	......	38·30	......	......	......	28·16	......	......
Cobalt	58·8	32·02	......	......	38·48	......	50·06	......	29·01	......	......
Manganese	55	33·58	47·24	65·14	40·22	......	51·34	......	27·83	......	73·8
Lead	207	......	......	......	52·56	......	64·52	......	......	......	......
Mercury	200	41·23	......	......	48·80*	......	......	34·16	......	......	......
Palladium	106·5	43·90*	......	......	......	......	......	......	......	......	......
TRIVALENT.											
Aluminium	27·4	40·5*	......	......	......	......	......	......	67·7	......	......
Iron	56	51·27	......	......	62·20*	......	......	......	90·9*	......	......
Chromium	52·2	48·2*	......	......	......	......	......	......	82·46*	......	......
Gold	196·7	56·11*	......	......	......	......	......	......	......	......	......
Rhodium	104·4	65·08*	......	......	......	......	......	......	......	......	......
QUADRIVALENT.											
Platinum	197·4	71·06*	......	......	......	......	......	......	......	......	......

TABLE V.—Supplementary.

Substance.	Atomic weight.	Monobasic.					Bibasic.				
		Alcoholate.	Hydrate.	Silicate.	Hypophosphite.	Nitrite.	Tartrate.	Chromate.	Bichromate.	Oxalate.	Carbonate.
UNIVALENT.											
Potassium	39·1	28·10	12·61	31·03*	27·28	19·31	57·87	51·50	82·55	37·71	28·77
Sodium	23	24·61	9·20	27·28	......	15·50	50·85	46·08	74·87	......	22·35
Lithium	7	......	......	......	......	......	......	43·62	72·60	......	......
Ammonium	18	......	15·42	......	......	......	......	58·12	87·06	42·22	......
Hydrogen	1	20·857	5·92632	......	......	......	45·29	......	......	23·44	......
BIVALENT.											
Calcium	40	......	......	......	46·88	......	......	......	......	......	......
Manganese	24	......	......	......	48·10	......	......	......	......	......	......

Substance.	Atomic weight.	Monobasic.			Bibasic.			Tribasic.	Quadribasic.
		Fluoride.	Arsenite.	Sulphocyanide.	Sulphite.	Biborate.	Permanganate.	Ferricyanide.	Ferrocyanide.
Potassium	39·1	9·55	......	33·47	35·10*	......	91·8	102·05	114·72
Sodium	23	......	26·14*	......	......	45·9	......	......	......

A glance at this Table will be enough to show that the numbers are not independent of one another, but that there is a remarkable relation between them. Thus the bromides are between six and seven higher than the chlorides corresponding to them in the case of the univalent metals, and double that number in the case of the bivalent; again, the line of sodium salts consists of numbers from three to four lower than the corresponding potassium salts in the monobasic series, and double that number in the bibasic. This kind of relation is precisely what was to be expected if the refraction-equivalent of a salt is really made up of the refraction-equivalents of its constituents. These differences are drawn out in the following Tables. Table VI. exhibits the differences between the refraction-equivalent of potassium indicated by the letter A, and those of the other metals, together with ammonium and hydrogen, the radicals with which they are combined being indicated by Greek letters. Table VII. shows the differences between the refraction-equivalent of chlorine, represented by α, and those of the other radicals, the refraction-equivalent of each metal being represented by a different Roman letter.

TABLE VI.

Substance.	Chloride.	Bromide.	Iodide.	Nitrate.	Formiate.
UNIVALENT.					
Potassium	$A+\alpha$	$A+\beta$	$A+\gamma$	$A+\delta$	$A+\epsilon$
Sodium	$A-3{\cdot}43+\alpha$	$A-3{\cdot}20+\beta$	$A-3{\cdot}20+\gamma$	$A-3{\cdot}22+\delta$	....
Lithium	$A-3{\cdot}97+\alpha$	$A-4{\cdot}53+\beta$	$A-4{\cdot}23+\gamma$	....	....
Cæsium	$A+5{\cdot}6+\alpha$	....	....	....	....
Rubidium	$A+5{\cdot}45+\alpha$	....	....	....	....
Silver	....	....	....	$A+5{\cdot}33+\delta$	....
Thallium	....	....	....	$A+15{\cdot}1+\delta$	$A+12{\cdot}64+\epsilon$
Ammonium	$A+3{\cdot}50+\alpha$	$A+3{\cdot}44+\beta$	$A+3{\cdot}18+\gamma$	$A+3{\cdot}33+\delta$	....
Hydrogen	$A-4{\cdot}61+\alpha$	$A-4{\cdot}44+\beta$	$A-4{\cdot}55+\gamma$	$A-5{\cdot}61+\delta$	$A-6{\cdot}43+\epsilon$
BIVALENT.					
Barium	$2(A-0{\cdot}17+\alpha)$	$2(A+0{\cdot}27+\beta)$	$2(A-0{\cdot}86+\gamma)$	$2(A-0{\cdot}48+\delta)$	$2(A-0{\cdot}33+\epsilon)$
Strontium	$2(A-1{\cdot}31+\alpha)$	$2(A-1{\cdot}33+\beta)$	....	$2(A-1{\cdot}27+\delta)$	$2(A-0{\cdot}72+\epsilon)$
Calcium	$2(A-2{\cdot}69+\alpha)$	$2(A-2{\cdot}93+\beta)$	$2(A-3{\cdot}39+\gamma)$	$2(A-2{\cdot}78+\delta)$	$2(A-3{\cdot}27+\epsilon)$
Magnesium	$2(A-4{\cdot}39+\alpha)$	....	....	$2(A-4{\cdot}15+\delta)$	$2(A-4{\cdot}84+\epsilon)$
Cerium	$2(A-1{\cdot}29+\alpha)$	....	....	....	....
Didymium	$2(A-1{\cdot}74+\alpha)$	....	....	....	....
Zinc	$2(A-3{\cdot}45+\alpha)$	$2(A-3{\cdot}11+\beta)$	$2(A-2{\cdot}89+\gamma)$	$2(A-2{\cdot}85+\delta)$	$2(A-2{\cdot}77+\epsilon)$
Cadmium	$2(A-1{\cdot}17+\alpha)$	$2(A-1{\cdot}15+\beta)$	....	$2(A-1{\cdot}42+\delta)$	....
Copper	$2(A-2{\cdot}13+\alpha)$	....	....	$2(A-2{\cdot}09+\delta)$	....
Iron	$2(A-2{\cdot}40+\alpha)$	$2(A-1{\cdot}96+\beta)$	....	....	....
Nickel	$2(A-3{\cdot}13+\alpha)$	....	....	$2(A-2{\cdot}96+\delta)$	....
Cobalt	$2(A-2{\cdot}82+\alpha)$	....	....	$2(A-2{\cdot}87+\delta)$	....
Manganese	$2(A-2{\cdot}04+\alpha)$	$2(A-1{\cdot}47+\beta)$	$2(A-3{\cdot}15+\gamma)$	$2(A-2{\cdot}00+\delta)$	....
Lead	....	....	....	$2(A+4{\cdot}17+\delta)$	....
Mercury	$2(A+1{\cdot}78+\alpha)$	....	....	$2(A+2{\cdot}29+\delta)$	....
Palladium	$2(A+3{\cdot}12+\alpha)$	....	....	....	....
TRIVALENT.					
Aluminium	$3(A-5{\cdot}3+\alpha)$	....	....	$3(A-1{\cdot}38+\delta)$	....
Iron	$3(A-1{\cdot}59+\alpha)$	....	....	....	....
Chromium	$3(A-2{\cdot}8+\alpha)$	....	....	....	....
Gold	$3(A-0{\cdot}13+\alpha)$	....	....	....	....
Rhodium	$3(A+2{\cdot}86+\alpha)$	....	....	....	....
QUADRIVALENT.					
Platinum	$4(A-1{\cdot}65+\alpha)$	....	....	....	....

Table VI.—(continued.)

Substance.	Acetate.	Cyanide.	Sulphate.	Hyposulphite.	Lactate.
Univalent.					
Potassium	A+ζ	A+η	2A+θ	2A+ι	2A+κ
Sodium	A− 3·44+ζ	....	2(A−3·10)+θ	2(A−3·04)+ι	2(A−3·40)+κ
Lithium	A− 4·53+ζ	....	2(A−4·42)+θ	....	....
Cæsium	....	....	....	....	....
Rubidium	....	....	2(A+6·42)+θ	....	....
Silver	....	A+8·29+η	....	2(A+9·2)+ι	....
Thallium	A+12·67+ζ	....	....	....	....
Ammonium	A+ 3·79+ζ	....	2(A+3·05)+θ	....	....
Hydrogen	A− 6·49+ζ	....	2(A−5·33)+θ	....	....
Bivalent.					
Barium	2(A+ 0·44+ζ)	....	....	....	2(A+1·30)+κ
Strontium	....	....	....	....	2(A+0·9)+κ
Calcium	2(A− 2·88+ζ)	....	....	2(A−2·68)+ι	....
Magnesium	2(A− 4·77+ζ)	....	2(A−4·46)+θ	2(A−4·68)+ι	....
Cerium	....	....	....	....	....
Didymium	....	....	....	....	....
Zinc	2(A− 3·35+ζ)	2(A−4·13+η)	2(A−2·75)+θ	....	....
Cadmium	....	....	2(A−1·38)+θ	....	....
Copper	....	....	2(A−2·65)+θ	....	....
Iron	....	....	2(A−2·01)+θ	....	....
Nickel	....	....	2(A−2·47)+θ	....	....
Cobalt	2(A− 2·75+ζ)	....	2(A−2·05)+θ	....	....
Manganese	2(A− 2·11+ζ)	....	2(A−2·64)+θ	....	2(A−1·3)+κ
Lead	2(A+ 4·48+ζ)	....	....	....	....
Mercury	....	2(A−0·15+η)	....	....	....
Palladium	....	....	....	....	....
Trivalent.					
Aluminium	....	....	3(2(A−5·3)+θ)	....	....
Iron	....	....	3(2(A−1·4)+θ)	....	....
Chromium	....	....	3(2(A−2·81)+θ)	....	....
Gold	....	....	....	....	....
Rhodium	....	....	....	....	....
Quadrivalent.					
Platinum	....	....	....	....	....

Table VI.—Supplementary.

Substance.	Alcoholate.	Hydrate.	Silicate.	Hypophosphite.	Nitrite.
Univalent.					
Potassium	A+λ	A+μ	A+ν	A+ξ	A+ο
Sodium	A−3·52+λ	A−3·41+μ	A−3·75+ν	....	A−3·81+ο
Lithium	....	....	....	....	....
Ammonium	....	A+2·81+μ	....	....	....
Hydrogen	A−7·24+λ	A−6·68+μ	....	....	....
Bivalent.					
Calcium	....	....	....	2(A−3·84+ξ)	....
Manganese	....	....	....	2(A−3·23+ξ)	....

Substance.	Tartrate.	Chromate.	Bichromate.	Oxalate.	Carbonate.
Univalent.					
Potassium	2A+π	2A+ρ	2A+σ	2A+τ	2A+υ
Sodium	2(A−3·51)+π	2(A−2·71)+ρ	2(A−3·84)+σ	....	2(A−3·21)+υ
Lithium	....	2(A−3·94)+ρ	2(A−4·97)+σ	....	....
Ammonium	....	2(A+3·31)+ρ	2(A+2·25)+σ	2(A+2·25)+τ	....
Hydrogen	2(A−6·29)+π	....	....	2(A−7·13)+τ	....
Bivalent.					
Calcium	....	....	....	....	....
Manganese	....	....	....	....	....

TABLE VII.

Substance.	Chloride.	Bromide.	Iodide.	Nitrate.	Formiate.
UNIVALENT.					
Potassium	A+α	A+α+6·26	A+α+16·89	A+α+3·28	A+α+1·41
Sodium	B+α	B+α+6·49	B+α+17·12	B+α+3·49	...
Lithium	C+α	C+α+5·70	C+α+16·63	...	...
Rubidium	D+α	...	...	...	...
Silver	...	...	...	E+β	...
Thallium	...	...	...	F+β	F+β−4·3
Ammonium	G+α	G+α+6·20	G+α+16·57	G+α+3·11	...
Hydrogen	H+α	H+α+6·43	H+α+16·95	H+α+2·28	H+α−0·41
BIVALENT.					
Barium	I+2α	I+2(α+6·70)	I+2(α+16·20)	I+2(α+2·97)	I+2(α+1·25)
Strontium	K+2α	K+2(α+6·24)	...	K+2(α+3·32)	K+2(α+2·00)
Calcium	L+2α	L+2(α+6·02)	L+2(α+16·19)	L+2(α+3·19)	L+2(α+0·83)
Magnesium	M+2α	...	...	M+2(α+3·52)	M+2(α+0·96)
Zinc	N+2α	N+2(α+6·60)	N+2(α+17·45)	N+2(α+3·88)	N+2(α+2·09)
Cadmium	O+2α	O+2(α+6·28)	...	O+2(α+3·03)	...
Copper	P+2α	...	...	P+2(α+3·32)	...
Iron	Q+2α	Q+2(α+6·70)	...	...	...
Nickel	R+2α	...	...	R+2(α+3·45)	...
Cobalt	S+2α	...	...	S+2(α+3·23)	...
Manganese	T+2α	T+2(α+6·83)	T+2(α+15·78)	T+2(α+3·32)	...
Lead	...	...	...	V+2β	...
Mercury	W+2α	...	...	W+2(α+3·78)	...
TRIVALENT.					
Aluminium	X+3α	...	...	...	...
Iron	Y+3α	...	...	Y+3(α+3·64)	...
Chromium	Z+3α	...	...	...	...

Substance.	Acetate.	Cyanide.	Sulphate.	Hyposulphite.	Lactate.
UNIVALENT.					
Potassium	A+α+8·95	A+α−1·60	2(A+α)−4·55	2(A+α)+10·22	2(A+α)+38·59
Sodium	B+α+8·94	...	2(B+α)−3·88	2(B+α)+11·00	2(B+α)+38·65
Lithium	C+α+8·39	...	2(C+α)−5·46	...	...
Rubidium	...	...	2(D+α)−2·61	...	...
Silver	...	E+β−1·92	...	2(E+β)+11·4	...
Thallium	F+β+3·25	...	...	...	...
Ammonium	G+α+9·24	...	2(G+α)−5·44	...	...
Hydrogen	H+α+7·07	...	2(H+α)−5·99	...	...
BIVALENT.					
Barium	I+2(α+9·56)	...	...	...	I+2α+41·66
Strontium	...	...	...	...	K+2α+43·2
Calcium	L+2(α+8·76)	...	...	L+2α+10·24	...
Magnesium	M+2(α+8·57)	...	M+2α−4·70	M+2α+9·64	...
Zinc	N+2(α+9·02)	N+2(α−2·28)	N+2α−3·15	...	...
Cadmium	...	...	O+2α−4·98	...	...
Copper	...	...	P+2α−5·60	...	...
Iron	...	...	Q+2α−3·77	...	...
Nickel	...	...	R+2α−3·23	...	...
Cobalt	S+2(α+9·02)	...	S+2α−3·01	...	...
Manganese	T+2(α+8·88)	...	T+2α−5·75	...	T+2α+40·2
Lead	V+2(β+5·98)	...	...	...	...
Mercury	...	W+2(α−3·53)	...	...	...
TRIVALENT.					
Aluminium	...	...	2(X+3α)−3(4·5)	...	...
Iron	...	...	2(Y+3α)−3(3·9)	...	...
Chromium	...	...	2(Z+3α)−3(5·41)	...	...

TABLE VII.—Supplementary.

Substance.	Alcoholate.	Hydrate.	Silicate.	Hypophosphite.	Nitrite.
UNIVALENT.					
Potassium	$A+\alpha+9·27$	$A+\alpha-6·22$	$A+\alpha+12·20$	$A+\alpha+8·45$	$A+\alpha+0·48$
Sodium	$B+\alpha+9·21$	$B+\alpha-6·20$	$B+\alpha+11·88$	....	$B+\alpha+0·10$
Lithium	....	....	....	....	....
Ammonium	....	$G+\alpha-6·91$	....	....	....
Hydrogen	$H+\alpha+6·637$	$H+\alpha-8·294$	....	....	....
BIVALENT.					
Calcium	....	....	....	$L+2(\alpha+7·30)$	....
Manganese	....	....	....	$T+2(\alpha+7·26)$	....

Substance.	Tartrate.	Chromate.	Bichromate.	Oxalate.	Carbonate.
UNIVALENT.					
Potassium	$2(A+\alpha)+20·21$	$2(A+\alpha)+13·84$	$2(A+\alpha)+44·89$	$2(A+\alpha)+0·05$	$2(A+\alpha)-8·89$
Sodium	$2(B+\alpha)+20·05$	$2(B+\alpha)+15·28$	$2(B+\alpha)+44·07$	....	$2(B+\alpha)-8·45$
Lithium	....	$2(C+\alpha)+13·90$	$2(C+\alpha)+42·88$	....	....
Ammonium	....	$2(G+\alpha)+13·46$	$2(G+\alpha)+42·40$	$2(G+\alpha)-2·44$	....
Hydrogen	$2(H+\alpha)+16·85$	....	....	$2(H+\alpha)-5·00$	....
BIVALENT.					
Calcium	....	....	....	....	....
Manganese	....	....	....	....	....

TABLE VII.—Supplementary.

Substance.	Fluoride.	Arsenite.	Sulphocyanide.	Sulphite.
Potassium	$A+\alpha-9·28$	....	$A+\alpha+14·64$	$2(A+\alpha)-2·56$
Sodium	....	$B+\alpha+10·70$	....	....

Substance.	Biborate.	Permanganate.	Ferricyanide.	Ferrocyanide.
Potassium	....	$2(A+\alpha)+54·1$	$3(A+\alpha)+46·56$	$4(A+\alpha)+39·40$
Sodium	$2(B+\alpha)+15·1$	....	....	....

The differential numbers along a line in Table VI., or down a column in Table VII., are sufficiently near to show that we are dealing with a reality; but they are sufficiently wide apart to show that we must rely upon the average of the numbers and not on any single experiment, if we wish to get a refraction-equivalent true to the first place of decimals. Unfortunately all experimental errors fall upon this residuary number.

The only exception to this regularity which is worth notice, is in the case of hydrogen, which is A—4·5 or thereabouts in the hydracids, but drops to somewhere about A—6·7 in the organic acids. This seems to indicate that in the first group hydrogen has a refraction-equivalent somewhere about 2·2 higher than in the other.

Though these Tables alone do not afford us the means of determining a single refraction-equivalent of a metal or of any other element, it is evident that the refraction-equivalents of the whole would be a simple matter of calculation if we could determine with certainty the value of any letter, Roman or Greek, that is, the refraction-equivalent of any one of the constituents. The means of arriving at this will be explained in the second part of this paper under the head of Potassium.

Deductions.

Carbon.—Crystallized carbon (that is diamond) has a refraction-equivalent of about 5·0; the same number was arrived at by LANDOLT from a consideration of a multitude of organic substances. If we compare together the two gaseous oxides, CO, 7·53, and CO_2, 10·03, it is clear that the second atom of oxygen is represented by 2·5, and taking the first atom at the same it leaves 5·03 for carbon.

If, indeed, anything is certain in this whole subject, it is that carbon, whether pure or in combination with other elements, and thus forming solid liquid or gaseous bodies, exerts the same influence on the rays of light transmitted by it, and that this influence may be expressed by the number 5·0; but the cumulative evidence on which this conviction rests is derived from the whole range of organic bodies, and from many other compounds of carbon that will be considered under other headings. The apparent exceptions, such as the aromatic series of organic compounds, may be accounted for by a part of the hydrogen having a higher refraction-equivalent than it usually exhibits*.

Hydrogen.—According to DULONG'S observations hydrogen gas has a refraction-equivalent of 1·53, and it seems to have the same in water; LANDOLT, however, has shown that in the large majority of the organic compounds examined by him, it does not exceed 1·3. This is confirmed by such observations as those on the new ketones, or on laurostearate of ethyl, given in Table III. LANDOLT examined no hydrocarbons, but assuming C=5·0, the series in Table II. give the following values for H:—

Olefiant Gas	gives	1·27
Amylene	„	1·26
Oil of Turpentine . . .	„	1·43
Hydride of Œnanthyl .	„	1·25
Hydride of Capryl . .	„	1·27

This is the value of H in acetic, formic, tartaric, and oxalic acids; but from Table VI. it would appear that the hydrogen in hydrochloric, hydrobromic, and hydriodic acids has a value about 2·2 higher than in these organic acids; it must therefore be about 3·5. The same element in nitric and sulphuric acids seems to have a value intermediate between these.

Oxygen.—Gaseous oxygen, according to DULONG, is 3·04; and LANDOLT found that 3·0 suited well for calculating the refraction-equivalent of the great group of organic compounds. There is, however, more uncertainty about this number; most of the substances examined by the German professor contained comparatively little of the element, and his best comparisons give a somewhat lower figure.

Assuming C=5·0, and H=1·3,

Sugar	gives	O=2·8
Carbonic Acid . . .	„	O=2·5
Carbonic Oxide . .	„	O=2·5
Oxalic Acid	„	O=2·7

* See Postscript.

Formic Acid . . .	gives	O=3·1
Tartaric Acid . . .	,,	O=2·9
Citric Acid	,,	O=2·9

On comparing nitrate of potassium, KNO_3, 22·11, with nitrite of potassium, KNO_2, 19·31, we deduce for O the value 2·8.

From this diversified evidence, 2·9 may be fairly taken as the probable value of oxygen.

Sulphur.—The pure element, whether solid or liquid, has a refraction-equivalent of 16·0 or 16·3; as deduced from CS_2, 36·7, it will be 15·85. Again, the difference between KCNS, 33·47, and KCN, 17·23, gives S=16·24; it will be seen that it has a similar value in chloride of sulphur. It is evident, however, that in the two gases, H_2S, 14·28, and SO_2, 14·91, or in liquified SO_2, 14·59, it cannot be 16; nor yet in its other oxygen compound, H_2SO_4, 21·9.

Phosphorus.—The refraction-equivalent for this very dispersive elementary body is 18·3 for the line A. In its compounds with the halogens it seems to exert the same influence on light, but in phosphoric acid its refractive energy must be greatly diminished.

Chlorine.—The gas itself has the refraction-equivalent of 8·87, as reckoned from DULONG'S experiments, and the same figure represents it in gaseous phosgene; but a somwehat higher number is arrived at when liquid compounds are examined. Thus, taking the numbers previously given for carbon, hydrogen, sulphur, and phosphorus, we find—

From	Tetrachloride of Carbon . . .	Chlorine	= 9·8
,,	Chloroform	,,	= 9·6
,,	,, (HAAGEN) . . .	,,	= 9·7
,,	Bichloride of Chlorethylene .	,,	= 9·9
,,	Chloride of Sulphur	,,	= 9·8
,,	Terchloride of Phosphorus . .	,,	=10·0
,,	Bichloride of Ethylene . . .	,,	= 9·8
,,	Chloral	,,	=10·4

Moreover the substitution of chlorine for hydrogen in benzole gives for each Cl—H 8·7, that is Cl=10·0. The mean of these numbers is 9·9.

Bromine.—The liquid element has a refraction-equivalent of 16·23. The determinations of compounds of carbon, hydrogen, and phosphorus give:—

From	Bromoform	Bromine	=15·7
,,	Bibromide of Bromethylene .	,,	=15·1
,,	Bibromide of Chlorethylene .	,,	=15·0
,,	Terbromide of Phosphorus .	,,	=15·0
,,	Bromide of Ethyl	,,	=15·0
,,	Bromide of Amyl	,,	=15·7
,,	Bibromide of Ethylene . .	,,	=15·4

The average of these numbers is 15·3.

Iodine.—Solutions of iodine have hitherto given results which are not comparable among themselves.

From Iodide of Methyl	Iodine	=24·6
,, ,, ,, Ethyl	,,	=24·3
,, ,, ,, Propyl	,,	=24·9
,, ,, ,, Amyl	,,	=24·3

The average of these is 24·5; HAAGEN gives 24·87 for the line C, as deduced from the same series of compounds.

It would appear that the differences between the three halogens are as follows: Br=Cl+5·4, and I=Cl+14·6. This does not exactly agree with the differences between the three series of dissolved haloid salts, where Br=Cl+6·36, and I=Cl+16·46.

Potassium.—The number of potassium salts in solution whose refraction-equivalents have been determined is 26. There are two ways of arriving at the equivalent of the metal itself from these data. 1st. If we know the value of any of the radicals conjoined with potassium (expressed in Table VI. by Greek letters), it is a simple question of subtraction. 2nd. If we know the value of any other capital letter in Table VII., we have merely to add to it, or subtract from it, the mean number representing the difference between it and A, and we arrive at A itself, that is the refraction-equivalent of potassium.

For calculation by the first method, the numbers already arrived at may be employed, namely, C=5, H=1·3, O=2·9, S=16; and from the ethyl compounds in Table III. the following values may also be accepted, NO_3=14·4, SiO_4=18·4, CO_3=12·9, and CN=9·1, the two latter numbers corresponding with those of carbonic anhydride and cyanogen gas in Table II. We obtain

From the Formiate	Potassium	=8·14
,, Acetate	,,	=8·08
,, Oxalate	,,	=8·05
,, Alcoholate	,,	=8·72
,, Lactate	,,	=7·92
,, Tartrate	,,	=7·63
,, Nitrate	,,	=7·71
,, Silicate	,,	=8·30
,, Carbonate	,,	=7·93
,, Cyanide	,,	=8·13
,, Sulphocyanide . . .	,,	=8·37
	Mean . . .	8·09

Deductions from the chloride, bromide, and iodide are omitted from this list, because, as has been shown already, the differences between the refraction-equivalents of these halogens in dissolved salts must be somewhat greater than we find them to be in organic compounds. It is true this *à priori* objection does not lie against the chloride itself, but the close analogy between its properties and those of the two other halogens renders

it open to suspicion. If, indeed, we assume Cl=9·9, we obtain K=8·9, a higher number than any of the above. Considering the whole scope of the evidence, I would rather determine chlorine from potassium, than potassium from chlorine.

By the second method, assuming H in water=1·5, and in the hydracids 3·5, we obtain from a comparison of hydrate of potassium with water K=8·18, and from a comparison of the potassium salts with the hydracids K=8·03.

The numbers thus arrived at range from 7·6 to 8·7; but the determinations most to be relied on are a little above 8·0, and the whole concurrent testimony points to 8·1 as the most probable number.

Having determined 8·1 as the refraction-equivalent of potassium (the A of Table VI.), it is perfectly simple to calculate the refraction-equivalent of every other metal in that Table. It is only necessary to add to, or subtract from, 8·1 the mean of the figures in each line; but, inasmuch as some observations deserve more confidence than others, the exact mean was not always followed, but rather what was thought to be the most trustworthy number.

From this it results that

Sodium	=A− 3·3,	that is	4·8
Lithium	=A− 4·3	,,	3·8
Cæsium	=A+ 5·6	,,	13·7
Rubidium	=A+ 5·9	,,	14·0
Silver	=A+ 7·6	,,	15·7
Thallium	=A+13·5	,,	21·6
Barium	=2(A−0·2)	,,	15·8
Strontium	=2(A−1·3)	,,	13·6
Calcium	=2(A−2·9)	,,	10·4
Magnesium . . .	=2(A−4·6)	,,	7·0
Cerium	=2(A−1·3)	,,	13·6
Didymium	=2(A−1·7)	,,	12·8
Zinc	=2(A−3·0)	,,	10·2
Cadmium	=2(A−1·3)	,,	13·6
Copper	=2(A−2·3)	,,	11·6
Iron	=2(A−2·1)	,,	12·0
Nickel	=2(A−2·9)	,,	10·4
Cobalt	=2(A−2·7)	,,	10·8
Manganese	=2(A−2·0)	,,	12·2
Lead	=2(A+4·3)	,,	24·8
Mercury	=2(A+2·0)	,,	20·2
Palladium	=2(A+3·1)	,,	22·4
Aluminium . . .	=3(A−5·3)	,,	8·4
Iron	=3(A−1·4)	,,	20·1
Chromium	=3(A−2·8)	,,	15·9

Gold	$=3(A-0{\cdot}1)$	that is	24·0
Rhodium	$=3(A+5{\cdot}2)$	„	39·9
Platinum	$=4(A-1{\cdot}6)$	„	26·0

Assuming these to be the correct numbers, we are in a position to assign values to all the inorganic radicals of the salts comprised in Table VII. We have:—

TABLE VIII.

Radical.	From the potassium salt.	From the sodium salt.	From the mean of all salts.
Cl	10·7	10·6	10·7
Br	17·0	17·1	17·0
I	27·6	27·7	27·2
NO_3	14·0	14·1	14·0
CN	9·1	......	......
SO_4	16·85	17·3	17·0
S_2O_3	31·6	32·2	31·7
H_3SiO_4	22·9	22·5	......
PH_2O_2	19·2	......	18·4
NO_2	11·2	10·7	......
CrO_4	35·3	36·5	35·5
Cr_2O_7	66·35	65·3	65·0
CO_3	12·6	12·75	......
F	1·45	......	......
AsO_2	......	21·3	......
SCN	25·4	......	......
SO_2	18·9	......	......
B_4O_7	......	36·3	......
Mn_2O_8	75·6	......	......
FeC_6N_6 (Ferricy.)	77·75	......	......
„ (Ferrocy.)	82·3	......	......

This Table shows that the three halogens, chlorine, bromine, and iodine, have higher refraction-equivalents in these mineral salts than they have in their organic compounds, and that the divergence increases as we advance in the series*.

	In organic compounds.	In mineral salts.
Chlorine	9·9	10·7
Bromine	15·3	17·0
Iodine	24·5	27·2

It also gives us additional information respecting the refraction-equivalents of some of the metals.

Iron.—This metal in combination with cyanogen in the ferrocyanide and ferricyanide of potassium has apparently a higher equivalent than in the compounds where it plays the part of a base.

Manganese.—This element exists in a highly oxidized condition in permanganate of potassium. If O be taken at 2·9, the refraction-equivalent of manganese will be 26·2.

Chromium.—This also exists in combination with oxygen in the chromates and bichromates. There it has a refraction-equivalent of about 23.

* In estimating metals from their chlorides, the equivalent 9·9 has been taken where the chloride is decomposed by water, 10·7 where it is soluble without decomposition. This arbitrary distinction seems to have a foundation in fact.

In the oxychloride (Table III.) it seems to have about the same power as in the chromium salts, viz. 16·5.

Mercury.—This metal presents greater difficulties in the estimation of its refraction-equivalent than any other in the list, and a comparison of its value, as deduced from all its compounds, only increases the difficulty.

From the Chloride in Water	. . . .	Mercury=19·8
„ „ Alcohol	. . .	„ =14·2
„ Nitrate	. . . .	„ =20·8
„ Cyanide	. . . .	„ =16·0
„ Crystallized Calomel	. . . .	„ =22·0
„ Mercuric Methide	. . . . .	„ =22·7

These differences are beyond what may be due to errors of experiment.

There are some other elementary bodies the refraction-equivalents of which may be deduced from the observations recorded.

Tin.—From the Tetrachloride	. . . .	Sn=19·2
Titanium.—From the Tetrachloride	. . . .	Ti=25·5
Arsenic.—From the Tetrachloride	. . . .	As=19·9 (line C)
„ Arsenious Anhydride	. . . . . .	„ =15·7
„ Sodium Arsenite	. . . .	„ =15·5
„ Cacodylic Acid	. . . .	„ =15·2
„ Triethylarsine	. . . .	„ =15·2

Arsenic acid and some arseniates have been examined, but the results are discordant, showing, however, always a lower equivalent than 15.

Antimony.—From the Terchloride	. . .	Sb=31·8
„ Pentachloride	. . .	„ =24·5
Vanadium.—From the Oxychloride	. . .	V=25·3

Nitrogen.—From DULONG's numbers for gaseous nitrogen the refraction-equivalent is 3·30, but no other means of calculation give so low a figure. The gaseous compounds afford the following results:—

From Cyanogen	. . . .	N=4·18
„ Nitrous Oxide	. . .	N=4·16
„ Nitric Oxide	. . .	N=3·84
„ Ammonia	. . . .	N=4·10

These point clearly to 4·0 or 4·1. The hydrogen in ammonia has been taken as gaseous hydrogen, viz. 1·5. It is to be remarked that ammonium in the series of salts is 11·5; but it is impossible to calculate N from this, as the refraction-equivalent of hydrogen is uncertain. Cyanogen in its compounds is 9·1; hence the nitrogen is also 4·1 in this combination. In the nitrates and nitrites, however, it seems to have a greater influence on light.

From NO_3 . . . . $N=5{\cdot}3$
,, NO_2 . . . . . . $N=5{\cdot}3$

Silicon.—From the tetrachloride, Si=7·5. Silicic acid, $Si\,O_2$, in the form of quartz has the refraction-equivalent 12·4 and 12·6 for the ordinary and extraordinary rays respectively; as deduced from silicic ether it is 12·6, and from the soluble silicates 12·6. Therefore Si=6·8.

Boron.—$B_2\,O_3$, as deduced from boracic ether, is 16·45, from crystallized borax 16·85, and from borax in solution 16·7. Taking the mean of these values, B=4·0.

Zirconium.—From zircon, Zr=20·8 or 22·6, according as we reckon from the ordinary or extraordinary ray.

Fluorine.—From potassium fluoride F=1·45. The numbers given for fluor-spar and kryolite confirm this very small value, or rather indicate that this body has scarcely any influence on the rays of light.

Summary.

The general results of the foregoing deductions give the following numbers as the refraction-equivalents of the elements, already determined more or less accurately.

Element.	Atomic weight.	Refraction-equivalent.	Specific refractive energy.
Aluminium	27·4	8·4	0·307
Antimony	122	24·5 ?	0·201 ?
Arsenic	75	15·4 (other values?)	0·205
Barium	137	15·8	0·115
Boron	11	4·0	0·364
Bromine	80	15·3, in dissolved salts 16·9	0·191 or 0·211
Cadmium	112	13·6	0·121
Cæsium	133	13·7 ?	0·103 ?
Calcium	40	10·4	0·260
Carbon	12	5·0	0·417
Cerium	92	13·6 ?	0·148 ?
Chlorine	35·5	9·9, in dissolved salts 10·7	0·279 or 0·301
Chromium	52·2	15·9 (in chromates 23 ?)	0·305 or 0·441 ?
Cobalt	58·8	10·8	0·184
Copper	63·4	11·6	0·183
Didymium	96	12·8 ?	0·133 ?
Fluorine	19	1·4 ?	0·073 ?
Gold	197	24·0 ?	0·122 ?
Hydrogen	1	1·3, in hydracids 3·5	1·3 or 3·5
Iodine	127	24·5, in dissolved salts 27·2	0·193 or 0·214
Iron	56	12·0 in ferrous, 20·1 in ferric salts	0·214 or 0·359
Lead	207	24·8	0·120
Lithium	7	3·8	0·543
Magnesium	24	7·0	0·292
Manganese	55	12·2 (26·2 ? in permanganate)	0·222 or 0·476 ?
Mercury	200	20·2 ?	0·101 ?
Nickel	58·8	10·4	0·177
Nitrogen	14	4·1, or 5·3 in higher oxides	0·293 or 0·379
Oxygen	16	2·9	0·181
Palladium	106·5	22·4 ?	0·210 ?
Phosphorus	31	18·3 (other values?)	0·590
Platinum	197·4	26·0	0·132
Potassium	39·1	8·1	0·207
Rhodium	104·4	24·2 ?	0·232 ?
Rubidium	85·4	14·0	0·164
Silicon	28	7·5 ? (6·8 in oxygen compounds)	0·268 ? or 0·243
Silver	108	15·7 ?	0·145 ?
Sodium	23	4·8	0·209
Strontium	87·5	13·6	0·155
Sulphur	32	16·0 (other values?)	0·500
Thallium	204	21·6 ?	0·106 ?
Tin	118	19·2 ?	0·163 ?
Titanium	50	25·5 ?	0·510 ?
Vanadium	51·2	25·3 ?	0·494 ?
Zinc	65·2	10·2	0·156
Zirconium	89·6	21·0 ?	0·234 ?

In the above Table those equivalents are marked ? where they have been deduced from only one compound, or where the different determinations are not fairly accordant.

At some future time I hope to reexamine each of the doubtful points, and to extend the observations to the whole range of the chemical elements. The question of dispersion-equivalents is also of interest: the data for an investigation of the matter are given in the Appendix, since the refractive index has been calculated for the lines D and H, as well as the line A; but I have avoided encumbering the present paper with any remarks on this subject.

The specific refractive energy of a body is in some respects worthy of more consideration than the refraction-equivalent, for it is a physical property independent of chemical theories. If these energies in the preceding Table are compared with one another several suggestive facts may be observed.

1st. Hydrogen has more than double the energy of any other element, even in the lowest number that can be assigned to it.

2nd. Phosphorus, vanadium, titanium, and sulphur have singularly high energies, and they are substances that present certain chemical analogies.

3rd. There are several pairs of analogous elements having the same, or nearly the same, energy; thus, bromine and iodine, arsenic and antimony, potassium and sodium, manganese and iron, nickel and cobalt.

4th. An element in altering its quantivalence alters its energy.

5th. If those metals that form the soluble salts of Table V. be arranged in the order of their energies, it will be seen that, with a few exceptions, they are in the inverse order of their combining proportions. This is shown in the annexed Table, where the third column gives the actual weight of the metal that combines with 35·5 of chlorine.

Element.	Specific refractive energy.	Combining proportion.	Element.	Specific refractive energy.	Combining proportion.
Hydrogen	1·300	1	Nickel	·177	29·4
Lithium	·540	7	Rubidium	·164	85·4
Aluminium	·307	9·1	Zinc	·156	32 6
Chromium	·305	17·4	Strontium	·155	43·8
Magnesium	·292	12	Cerium	·148 ?	46
Calcium	·260	20	Silver	·145 ?	108
Zirconium	·234 ?	22·4	Didymium	·133 ?	47·5
Rhodium	·232 ?	34·8	Platinum	·132 ?	49·3
Manganese	·222	27·5	Gold	·122 ?	65·7
Iron	·214	28	Cadmium	·121	56
Palladium	·210 ?	53·2	Lead	·120	103·5
Sodium	·209	23	Barium	·115	68·5
Potassium	·207	39 1	Thallium	·106 ?	204
Cobalt	·184	29·4	Cæsium	·103 ?	133
Copper	·183	31·7	Mercury	·101 ?	100

This has not the regularity of a physical law, but it clearly points to some connexion between the power of a metallic body to saturate the affinities of other elements, and its power to retard the rays of light.

Appendix.

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I. Refractive Indices.

Substance.	Formula.	Specific gravity.	Temperature Centigrade.	μA.	μD.	μH.	Refraction-equivalent.
Bromine	Br	3·085	12	1·6260	....	....	16·23
Water	H_2O	1·0	15	1·32924	1·33328	1·34393	5·92632
Rock-salt	Na Cl	2·086	......	1·5369	1·5443	1·5685	15·02
Carbon Tetrachloride	CCl_4	1·5888	......	1·4560	....	....	44·2
Tin "	$SnCl_4$	2·231	20	1·5035	1·5124	1·5429	58·76
Titanium "	$TiCl_4$	1·727	......	1·5856	1·6039	....	65·08
Antimony Pentachloride	$SbCl_5$	2·322	17·5	1·5739	1·5871	....	74·03
Vanadium Oxychloride	$VOCl_3$	1·841	12	1·6143	1·6416	....	57·96
Chromium "	CrO_2Cl_2	1·908	23	1·5177	1·5242	....	42·08
Sulphuric Acid	H_2SO_4	1·882	11·5	1·4205	1·4251	1·4366	21·90
Nitric Acid	HNO_3	1·549	13	1·4047	1·4115	....	16·46
Alcohol	C_2H_6O	0·797	12	1·3615	1·3655	1·3769	20·857
Methylated Acetone	C_4H_8O	0·811	13	1·3817	1·3860	1·3991	33·89
Butyrone	$C_7H_{14}O$	0·825	13	1·4073	1·4116	1·4262	56·29
Ethylic Phosphite	$(C_2H_5)_3PO_3$	1·074	20	1·3996	1·4032	1·4160	61·76
Mercuric Methyl	$Hg(CH_3)_2$	2·966	30	1·5229	1·5336	1·5683	40·54

II. Aqueous Solutions.

Substance.	Formula.	Equivalents of water.	Specific gravity.	Temperature Centigrade.	μA.	μD.	μH.	Refraction-equivalent.
Potassium Chloride	K Cl	20	1·119	15·5	1·3535	1·3581	1·3704	18·80
" "	"	22	1·108	15·5	1·3511	1·3560	1·3682	18·74
" "	"	24	1·100	15·5	1·3493	1·3542	1·3662	18·63
" "	"	26	1·093	15·5	1·3482	1·3527	1·3646	18·80
" "	"	28	1·087	16·5	1·3478	1·3521	1·3638	19·12
" "	"	13	1·167	13	1·3625	1·3670	1·3800	18·84
" "	"	30	1·082	15	1·3462	1·3506	1·3625	18·89
" "	"	15	1·148	13	1·3591	1·3637	1·3768	18·84
" Bromide	K Br	13	1·292	12·5	1·3747	1·3801	1·3953	25·09
" Iodide	K I	13	1·421	13·5	1·4006	1·4073	1·4287	35·72
" Nitrate	KNO_3	25	1·125	13·5	1·3476	1·3519	1·3647	22·11
" "	"	24·77	1·125	14·5	1·3476	1·3522	1·3647	22·10
" Nitrite	KNO_2	17	1·136	24·5	1·3487	1·3528	......	19·31
" Formiate	$KCHO_2$	9·37	1·220	17	1·3647	1·3692	1·3818	20·03
" "	"	11·71	1·179	9	1·3591	1·3636	1·3758	20·46
" Acetate	$KC_2H_3O_2$	10	1·189	14	1·3721	1·3765	1·3891	27·78
" Lactate	$K_2C_6H_{10}O_6$	11·04	1·316	8·5	1·4103	1·4145	1·4297	76·37
" "	"	36·55	1·162	10·5	1·3725	1·3771	1·3897	76·14
" Cyanide	K C N	6·13	1·195	13·5	1·3648	1·3694	1·3822	17·23
" Sulphocyanide	K C N S	9	1·208	14·5	1·4047	1·4105	1·4297	33·47
" Chromate	K_2CrO_4	16	1·231	14·5	1·3853	1·3924	......	51·50
" Hydrate	K H O	5·47	1·368	11·5	1·3987	1·4040	1·4187	12·61
" Fluoride	K F	20	1·111	18	1·3403	1·3448	1·3555	9·55
" Sulphate	K_2SO_4	107·5	1·069	11·5	1·3397	1·3441	1·3551	33·11
" Bisulphate	$KHSO_4$	38·5	1·128	13	1·3472	1·3514	1·3623	27·00
" Tartrate	$K_2C_4H_4O_6$	19	1·300	17·5	1·3900	1·3947	1·4074	57·87
" Oxalate	$K_2C_2O_4$	54·28	1·112	10·5	1·3497	1·3541	1·3658	37·71
" Ferrocyanide	$K_4C_6N_6Fe$	45·86	1·125	13	1·3667	1·3719	1·3866?	114·24
" "	"	53·68	1·113	14·5	1·3635	1·3682	1·3819	115·20
" Ferricyanide	$K_3C_6N_6Fe$	77	1·109	25·5	1·3606	1·3657	......	101·44
" "	"	68·47	1·110	13	1·3616	1·3669	......	102·73
" "	"	53·99	1·149	......	1·3728	1·3783	......	101·99
" Permanganate	$KMnO_4$	162	1·027	11	1·3360	......	......	45·9
" Hyposulphite	$K_2S_2O_3$	13·07	1·397	......	1·4118	1·4174	1·4335	47·88
" Silicate	$KH_3SiO_4-0{\cdot}07K_2O$	8·18	1·334	17	1·3795	1·3842	1·3962	29·68
" Carbonate	K_2CO_3	26	1·222	14·5	1·3681	1·3731	1·3855	28·54
" "	"	15·66	1·327	18	1·3847	1·3894	1·4018	28·97
" "	"	28·17	1·203	20	1·3649	1·3695	1·3811	28·79

II. Aqueous Solutions (continued).

Substance.	Formula.	Equivalents of water.	Specific gravity.	Temperature Centigrade.	μA.	μD.	μH.	Refraction-equivalent.
Potassium Hypophosphite	KPH_2O_2	11	1·222	12·5	1·3733	1·3778	1·3908	27·09
" "	"	8·65	1·243	22	1·3768	1·3821	1·3946	27·48
" Sulphite	$K_2SO_3+0{\cdot}488\,SO_2$	21·62	1·280	22	1·3771	1·3824	1·3957	42·28
" "	" $+0{\cdot}29\,SO_2$	24·20	1·296	22	1·3831	1·3878	1·4013	40·18
" Bichromate	$K_2Cr_2O_7$	120·93	1·085	21·5	1·3511	1·3564	......	82·5
" "	"	215	1·051	15·5	1·3424	1·3472	......	82·6
Sodium Chloride	$NaCl$	10·74	1·183	13·5	1·3710	1·3763	1·3901	15·33
" "	"	12	1·168	9·5	1·3683	1·3736	1·3864	15·45
" "	"	12	1·166	14	1·3680	1·3734	1·3868	15·51
" "	"	12	1·162	12·5	1·3667	1·3717	1·3849	15·51
" "	"	14	1·148	9·5	1·3632	1·3681	1·3814	15·26
" "	"	16	1·132	9	1·3598	1·3649	1·3771	15·32
" "	"	18	1·118	15·5	1·3570	1·3621	1·3748	15·47
" "	"	20	1·109	9	1·3549	1·3596	1·3712	15·43
" "	"	22	1·099	15	1·3529	1·3576	1·3701	15·55
" "	"	24	1·091	14·5	1·3509	1·3555	1·3678	15·51
" "	"	26	1·085	14·5	1·3492	1·3540	1·3661	15·37
" "	"	34	1·066	15	1·3446	1·3491	1·3610	15·30
" Bromide	$NaBr$	13	1·294	11·5	1·3801	1·3855	1·4013	21·89
" Iodide	NaI	15·1	1·373	11·5	1·3968	1·4037	1·4241	32·41
" "	"	27	1·221	11·5	1·3699	1·3752	1·3917	32·63
" Nitrate	$NaNO_3$	13	1·202	12	1·3615	1·3664	1·3803	18·89
" Nitrite	$NaNO_2$	6·49	1·284	14·5	1·3731	1·3782	1·3931	15·50
" Acetate	$NaC_2H_3O_2$	13	1·141	14	1·3668	1·3712	1·3837	24·55
" "	"	12	1·151	11·5	1·3678	1·3724	1·3852	24·13
" Hydrate	$NaHO$	10·21	1·206	11·5	1·3759	1·3812	1·3946	9·20
" Chromate	Na_2CrO_4	16	1·218	12	1·3889	1·3956	......	46·08
" Sulphate	Na_2SO_4	45	1·132	23	1·3491	1·3535	1·3645	26·92
" "	"	63	1·100	18·5	1·3451	1·3494	1·3600	26·91
" Arsenite	$NaAsO_2-0{\cdot}2\,Na_2O$	5·9	1·727	15	1·4564	1·4638	1·4858	23·65
" Arseniate	$Na_2HAsO_4-0{\cdot}64\,Na_2O$	32·68	1·195	16	1·3619	1·3662	1·3781	28·77
" Tartrate	$Na_2C_4H_4O_6$	30	1·204	17	1·3750	1·3797	1·3922	50·85
" Carbonate	Na_2CO_3	23·34	1·216	24	1·3709	1·3753	1·3876	22·07
" "	"	26·77	1·192	14·5	1·3676	1·3722	1·3847	22·63
" Biborate	$Na_2B_4O_7$	467	1·020	18	1·3334	1·3377	1·3487	45·9
" Hyposulphite	$Na_2S_2O_3$	25	1·235	14	1·3858	1·3906	1·4051	41·80
" Bichromate	$Na_2Cr_2O_7$	100	1·103	11	1·3570	1·3623	......	74·87
" Silicate	NaH_3SiO_4	7·96	1·384	16·5	1·3943	1·3990	1·4119	27·28
" Lactate	$Na_2C_6H_{10}O_6$	40·11	1·137	20	1·3693	1·3740	1·3860	69·45
Lithium Chloride	$LiCl$	13	1·090	9	1·3623	1·3670	1·3801	14·86
" Bromide	$LiBr$	13	1·242	12·5	1·3776	1·3826	1·3893	20·56
" Iodide	LiI	13	1·365	......	1·4014	1·4085	1·4306	31·49
" Nitrate	$LiNO_3$	6	1·189	14	1·3683	1·3731	1·3874	19·28
" Acetate	$LiC_2H_3O_2$	10	1·110	14·5	1·3723	1·3774	1·3887	23·25
" Chromate	Li_2CrO_4	22	1·225	14·5	1·4051	1·4142	......	43·62
" Bichromate	$Li_2Cr_2O_7$	72	1·097	14·5	1·3589	1·3651	......	72·60
" Sulphate	Li_2SO_4	26	1·173	13	1·3619	1·3662	1·3771	24·26
Cæsium Chloride	$CsCl$	169	1·042	18	1·3330	1·3374	1·3486	24·4
Rubidium "	$RbCl$	23·77	1·168	17	1·3515	1·3560	1·3682	24·28
" Sulphate	$Rb_2SO_4+1{\cdot}04\,H_2SO_4$	68·58	1·177	17·5	1·3495	1·3536	1·3646	69·30
Silver Nitrate	$AgNO_3$	13	1·512	13·5	1·3920	1·3974	1·4138	27·68
" "	"	8·63	1·721	18	1·4150	1·4212	1·4398	27·28
" "	"	8·71	1·718	17	1·4152	1·4212	1·4399	27·35
" Cyanide	$AgCN+KCN$	60·22	1·110	20	1·3455	1·3502	1·3622	42·75
" Hyposulphite	$Ag_2S_2O_3+2\,NaCl$, $2{\cdot}6\,Na_2S_2O_3$	149·36	1·212	19·5	1·3732	1·3784	1·3933	205·8
Thallium Nitrate	$ThNO_3$	252·6	1·049	13	1·3347	1·3390	1·3502	37·7
" "	"	243·14	1·050	18	1·3342	1·3385	1·3493	36·0
" "	"	231·18	1·052	20	1·3348	1·3392	1·3503	37·8
" Formiate	$ThCHO_2$	39·85	1·283	22	1·3572	1·3624	1·3752	32·88
" Acetate	$ThC_2H_3O_2$	73·24	1·154	10	1·3463	1·3508	1·3634	40·45
Ammonium Chloride	NH_4Cl	13	1·054	14·5	1·3647	1·3695	1·3828	22·44
" "	"	13	1·055	12·5	1·3645	1·3694	1·3825	22·23
" Bromide	NH_4Br	13	1·194	9	1·3797	1·3855	1·4010	28·53
" Iodide	NH_4I	13	1·313	21·5	1·4012	1·4081	1·4292	38·90
" Nitrate	NH_4NO_3	13	1·110	12	1·3623	1·3672	1·3807	25·44
" Hydrate	NH_4HO	12·5	0·971	18	1·3324	1·3366	1·3475	15·17
" "	"	6	0·952	14	1·3409	1·3452	1·3570	15·65
" "	"	1·23	0·894	15	1·3475	1·3519	1·3647	15·44

II. Aqueous Solutions (continued).

Substance.	Formula.	Equivalents of water.	Specific gravity.	Temperature Centigrade.	μA.	μD.	μH.	Refraction-equivalent.
Ammonium Acetate	$NH_4C_2H_3O_2$	7	1·079	14·5	1·3883	1·3929	1·4070	31·57
,, Chromate	$(NH_4)_2CrO_4$	60	1·076	14·5	1·3613	1·3672	......	58·12
,, Bichromate	$(NH_4)_2Cr_2O_7$	65·38	1·107	15	1·3676	1·3740	......	87·06
,, Sulphate	$(NH_4)_2SO_4$	26	1·129	11·5	1·3645	1·3687	1·3801	39·63
,, ,,	,,	26·03	1·129	12·5	1·3637	1·3682	1·3795	39·19
,, ,,	,,	30	1·114	13	1·3600	1·3646	1·3761	39·26
,, ,,	,,	46	1·082	12·5	1·3510	1·3555	1·3668	38·81
,, Oxalate	$(NH_4)_2C_2O_4$	75·22	1·019	26·5	1·3364	1·3408	1·3517	42·22
Hydrochloric Acid	HCl	5	1·143	15	1·3991	1·4053	1·4215	14·53
,, ,,	,,	5	1·144	11·5	1·3954	1·4010	1·4168	14·08
,, ,,	,,	6	1·127	14	1·3924	1·3983	1·4136	14·75
,, ,,	,,	4·16	1·163	22	1·4031	1·4096	1·4268	13·96
,, ,,	,,	4·19	1·165	17·5	1·4035	1·4094	1·4270	13·93
,, ,,	,,	4·5	1·156	17	1·4007	1·4072	1·4239	14·07
Hydrobromic ,,	HBr	13	1·217	11·5	1·3774	1·3830	1·3991	20·65
Hydriodic ,,	HI	13	1·340	23	1·3996	1·4067	......	31·17
Nitric ,,	HNO_3	0·28	1·521	13	1·4076	1·4147	......	16·60
,, ,,	,,	0·9	1·460	12	1·4003	1·4067	1·4252	16·33
,, ,,	,,	2·69	1·376	13	1·3975	1·4040	1·4220	16·59
Formic ,,	$HCHO_2$	3·47	1·103	21·5	1·3499	1·3542	1·3662	13·85
,, ,,	,,	26·22	1·022	22	1·3342	1·3385	1·3495	14·00
,, ,,	,,	26·68	1·023	19	1·3338	1·3381	1·3491	13·57
Acetic ,,	$HC_2H_3O_2$	7·44	1·042	19·5	1·3513	1·3557	1·3671	21·29
Sulphuric ,,	H_2SO_4	0·42	1·843	12	1·4291	1·4340	1·4466	22·09
,, ,,	,,	1	1·767	13	1·4332	1·4384	1·4513	22·50
,, ,,	,,	1	1·781	14·5	1·4344	1·4396	1·4521	22·37
,, ,,	,,	2	1·659	9	1·4230	1·4285	1·4410	22·32
,, ,,	,,	3	1·557	14	1·4117	1·4150	1·4301	22·41
,, ,,	,,	5	1·430	9	1·3949	1·4003	1·4127	22·28
,, ,,	,,	11	1·256	9	1·3714	1·3765	1·3881	22·33
,, ,,	,,	25	1·118	9	1·3499	1·3544	1·3657	23·33
,, ,,	,,	25	1·127	13	1·3514	1·3559	1·3672	22·70
Tartaric ,,	$H_2C_4H_4O_6$	12·86	1·210	23	1·3851	1·3899	1·4022	45·17
,, ,,	,,	12·86	1·213	19·5	1·3869	1·3913	1·4039	45·42
Racemic ,,	,,	40	1·077	24·5	1·3498	1·3544	1·3656	45·54
Oxalic ,,	$H_2C_2O_4$	86·94	1·034	18	1·3368	1·3413	1·3520	23·44
Citric ,,	$H_3C_6H_5O_7$	22	1·161	23	1·3777	1·3820	1·3944	60·89
Cacodylic ,,	$AsC_2H_7O_2$	55·39	1·059	14·5	1·3438	1·3482	1·3596	40·09
Barium Chloride	$BaCl_2$	60	1·166	13	1·3557	1·3601	1·3722	37·32
,, Bromide	$BaBr_2$	26	1·503	8·5	1·4024	1·4080	1·4242	50·72
,, Iodide	BaI_2	56	1·321	22	1·3784	1·3842	1·4008	69·72
,, Nitrate	$Ba(NO_3)_2$	200	1·055	22	1·3356	1·3398	1·3508	43·26
,, Formiate	$Ba(CHO_2)_2$	41·34	1·225	24·5	1·3593	1·3637	1·3759	39·82
,, Acetate	$Ba(C_2H_3O_2)_2$	26	1·314	14·5	1·3826	1·3872	1·4006	56·44
,, Lactate	$BaC_6H_{10}O_6$	84·5	1·137	8	1·3592	1·3635	1·3751	78·98
Strontium Chloride	$SrCl_2$	22·90	1·299	16	1·3883	1·3931	1·4074	34·88
,, ,,	,,	28	1·255	16	1·3801	1·3847	1·3987	34·78
,, ,,	,,	32	1·224	10·5	1·3731	1·3782	1·3912	34·28
,, ,,	,,	36	1·199	16	1·3698	1·3742	1·3869	35·42
,, ,,	,,	40	1·180	16	1·3660	1·3703	1·3829	35·46
,, ,,	,,	44	1·167	11·5	1·3628	1·3670	1·3797	34·80
,, ,,	,,	48	1·152	16	1·3606	1·3647	1·3772	35·70
,, Bromide	$SrBr_2$	26	1·399	9	1·3941	1·3997	1·4158	47·52
,, Nitrate	$Sr(NO_3)_2$	60	1·147	12	1·3527	1·3574	1·3698	41·68
,, Formiate	$Sr(CHO_2)_2$	78·96	1·089	21·5	1·3454	1·3497	1·3606	39·04
,, Lactate	$SrC_6H_{10}O_6$	320·66	1·028	8	1·3370	1·3410	1·3524	78·2
Calcium Chloride	$CaCl_2$	26	1·172	13·5	1·3774	1·3824	1·3960	32·28
,, Bromide	$CaBr_2$	26	1·306	25	1·3874	1·3926	1·4087	44·32
,, Iodide	CaI_2	52	1·241	23	1·3747	1·3805	1·3970	64·66
,, Nitrate	$Ca(NO_3)_2$	26	1·226	12	1·3740	1·3788	1·3931	38·66
,, Formiate	$Ca(CHO_2)_2$	52·44	1·090	21·5	1·3499	1·3543	1·3658	33·94
,, Acetate	$Ca(C_2H_3O_2)_2$	32	1·131	12	1·3689	1·3736	1·3860	49·80
,, Hypophosphite	$Ca(PH_2O_2)_2$	64	1·089	12·5	1·3510	1·3549	1·3666	46·88
,, Hyposulphite	CaS_2O_3	31	1·210	12	1·3855	1·3908	1·4047	42·52
Magnesium Chloride	$MgCl_2$	26	1·156	14·5	1·3757	1·3805	1·3943	28·88
,, Nitrate	$Mg(NO_3)_2$	26	1·194	8·5	1·3683	1·3736	1·3872	35·92
,, Formiate	$Mg(CHO_2)_2$	63·10	1·062	24·5	1·3439	1·3482	1·3595	30·80
,, Acetate	$Mg(C_2H_3O_2)_2$	20	1·170	13·5	1·3835	1·3881	1·4010	46·02
,, Sulphate	$MgSO_4$	31·18	1·187	15·5	1·3643	1·3681	1·3805	24·18

II. Aqueous Solutions (continued).

Substance.	Formula.	Equivalents of water.	Specific gravity.	Temperature Centigrade.	μA.	μD.	μH.	Refraction-equivalent.
Magnesium Hyposulphite	$Mg S_2 O_3$	26	1·225	13	1·3906	1·3958	1·4099	38·52
Cerium Chloride	$Ce Cl_2$	75·68	1·110	12·5	1·3519	1·3566	1·3686	35·08
Didymium „	$Di Cl_2$	126·23	1·061	15	1·3407	1·3450	1·3566	34·18
Zinc Chloride	$Zn Cl_2$	8·84	1·519	12	1·4271	1·4331	1·4502	30·58
„ „	„	10·68	1·447	9	1·4147	1·4204	1·4365	30·81
„ „	„	13·88	1·360	14·5	1·3983	1·4038	1·4191	30·74
„ „	„ $+0{\cdot}054\ Zn O$	7·96	1·563	12	1·4338	1·4402	1·4578	31·51
„ Bromide	$Zn Br_2$	26	1·363	9	1·3895	1·3954	1·4113	43·96
„ Iodide	$Zn I_2$	21·44	1·564	20	1·4276	1·4352	......	65·67
„ Nitrate	$Zn (N O_3)_2$	26	1·297	12·5	1·3803	1·3855	1·4003	38·52
„ Formiate	$Zn (C H O_2)_2$	152·28	1·037	22	1·3357	1·3401	1·3510	34·8
„ „	„	193·32	1·032	22	1·3352	1·3395	1·3506	35·1
„ Acetate	$Zn (C_2 H_3 O_2)_2$	34	1·163	13	1·3662	1·3708	1·3835	48·80
„ Cyanide	$Zn (C N)_2 + 1{\cdot}58\ K C N$	141·72	1·044	23·5	1·3366	1·3408	1·3512	53·4
„ Sulphate	$Zn S O_4$	104	1·082	12·5	1·3426	1·3474	1·3581	27·61
Cadmium Chloride	$Cd Cl_2$	26	1·304	12	1·3796	1·3849	1·3991	35·32
„ Bromide	$Cd Br_2$	26	1·438	24	1·3910	1·3968	1·4133	47·88
„ Nitrate	$Cd (N O_3)_2$	26	1·369	12·5	1·3801	1·3853	1·3999	41·38
„ Sulphate	$Cd S O_4$	28·56	1·346	25·5	1·3721	1·3767	1·3891	30·34
Copper Chloride	$Cu Cl_2$	12·466	1·432	21	......	1·4354	......	D 34·30
„ „	„	20	1·290	23	......	1·4012	......	D 33·78
„ „	„	40	1·155	23	......	1·3698	......	D 33·82
„ „	„	60	1·105	23	......	1·3587	1·3704	D 34·32
„ Nitrate	$Cu (N O_3)_2$	17·96	1·392	17	......	1·4044	1·4211	D 40·64
„ Sulphate	$Cu S O_4$	59·78	1·149	13	1·3554	1 3600	1·3713	27·80
Ferrous Chloride	$Fe Cl_2$	28·58	1·195	24	1·3767	1·3815	1·3949	32·86
„ Bromide	$Fe Br_2$	36·58	1·249	25·5	1·3758	1·3812	1·3959	46·26
„ Sulphate	$Fe SO_4$	37	1·212	21·5	1·3672	1·3712	1·3837	28·79
„ „	„	40·8	1·186	20·5	1·3630	1·3671	1·3792	29·39
Nickel Chloride	$Ni Cl_2 + 0{\cdot}09\ H Cl$	23·22	1·273	24	......	1·3987	......	D 33·26
„ Nitrate	$Ni (N O_3)_2$	26	1·298	15·5	......	1·3890	......	D 39·14
„ Sulphate	$Ni SO_4$	30	1·264	13·5	1·3747	1·3796	......	28·16
Cobalt Chloride	$Co Cl_2$	24	1·254	15	1·3889	1·3945	1·4086	32·02
„ Nitrate	$Co (N O_3)_2$	30	1·259	15·5	1·3767	1·3818	1·3957	38·48
„ Acetate	$Co (C_2 H_3 O_2)_2$	44	1·124	15	1·3607	1·3659	1·3772	50·18
„ „	„	38·42	1·133	20	1·3623	1·3666	1·3790	49·94
„ Sulphate	$Co SO_4$	32	1·238	15·5	1·3704	1·3748	1·3867	29·01
Manganese Chloride	$Mn Cl_2$	26	1·194	13	1·3774	1·3824	1·3964	33·58
„ Bromide	$Mn Br_2$	26	1·323	12·5	1·3899	1·3954	1·4117	47·24
„ Iodide	$Mn I_2$	159·14	1·090	20	1·3463	1·3510	1·3642	65·14
„ Nitrate	$Mn (N O_3)_2$	26	1·251	12·5	1·3757	1·3807	1·3952	40·22
„ Acetate	$Mn (C_2 H_3 O_2)_2$	32	1·153	13	1·3710	1·3763	1·3893	51·34
„ Hypophosphite	$Mn (P H_2 O_2)_2$	54	1·104	13	1·3512	1·3568	1·3674	48·10
„ Sulphate	$Mn S O_4$	23·68	1·297	21·5	1·3784	1·3828	1·3949	28·07
„ „	„	26	1·277	15·5	1·3748	1·3794	1·3915	27·60
„ Lactate	$Mn C_6 H_{10} O_6$	124·2	1·054	8	1·3459	1·3502	1·3618	73·8
Lead Nitrate	$Pb (N O_3)_2$	50	1·297	11	1·3676	1·3731	1·3876	53·56
„ Acetate	$Pb (C_2 H_3 O_2)_2$	64	1·192	15	1·3576	1·3625	1·3755	64·52
Mercuric Chloride	$Hg Cl_2$	241·4	1·049	23	1·3342	1·3385	1·3492	39·8
„ „	„	274·52	1·044	14·5	1·3347	1·3389	1·3499	42·6
„ „	„	279·04	1·043	18	1·3341	1·3383	1·3492	40·54
„ „	„ $+0{\cdot}96\ Na Cl$	25·88	1·491	11·5	1·3924	1·3987	1·4170	55·34
„ „	„ $+2{\cdot}15\ Na Cl,\ 0{\cdot}16\ Na_2 S O_4$	57·64	1·285	13	1·3704	1·3765	1·3912	80·14
„ Nitrate	$Hg (N O_3)_2 + 1{\cdot}14\ H N O_3$	25·06	1·556	12	1·3972	1·4033	1·4207	67·60
„ Cyanide	$Hg (C N)_2$	146	1·071	25·5	1·3342	1·3385	1·3495	33·60
„ „	„	158·88	1·067	18	1·3349	1·3390	1·3703	34·74
Palladium Chloride	$Pd Cl_2 + 1{\cdot}18\ H Cl$	28·10	1·267	11·5	1·3962	......	......	60·66
Aluminium Chloride	$Al Cl_3 + 0{\cdot}182\ Al_2 O_3$	41·82	1·165	9	1·3771	1·3820	1·3958	45·23
„ Sulphate	$Al_2 (S O_4)_3$	104	1·165	25	1·3584	1·3627	1·3739	67·7
Ferric Chloride	$Fe Cl_3$	13	1·177	22	1·3827	1·3888	......	52·16
„ „	„	22·44	1·273	24·5	1·4141	1·4221	......	51·27
„ Nitrate	$Fe (N O_3)_3 + 2{\cdot}5\ H N O_3$	59·5	1·212	24·5	1·3760	1·3814	......	103·45
„ Sulphate	$Fe_2 (S O_4)_3 + 1{\cdot}9\ H_2 S O_4$	141·6	1·168	24	1·3624	1·3673	1·3814?	133·5
Chromium Chloride	$Cr Cl_3 + 0{\cdot}56\ Cr_2 O_3$	67·64	1·165	13	1·3769	1·3826?	......	71·90
„ Sulphate	$Cr_2 (S O_4)_3 - 1{\cdot}41\ H_2 S O_4$	70·58	1·231	18	1·3790	......	......	50·81
Gold Chloride	$Au Cl_3 + 0{\cdot}868\ H Cl$	24·33	1·483	11·5	1·4079	1·4160	......	68·45
Rhodium „	$Rh Cl_3 + 3 Na Cl$	91·97	1·172	11·5	1·3717	1·3771	......	102·48
Platinum „	$Pt Cl_4 + 0{\cdot}94\ H Cl$	20·30	1·665	11	1·4610	1·4709	......	84·34

III. Alcoholic Solutions.

Substance.	Formula.	Equivalents of alcohol.	Specific gravity.	Temperature Centigrade.	μA.	μD.	μH.	Refraction-equivalent.
Potassium Alcoholate	$K C_2 H_5 O$	5·28	0·915	12·5	1·3871	1·3916	1·4046	28·22
" "	"	5·355	0·911	20·5	1·3852	1·3896	1·4026	28·03
" Iodide	K I	217·8	0·799	19·5	1·3591	1·3632	1·3743	35·1
" Sulphocyanide	K S C N	46·9	0·813	19	1·3649	1·3693	1·3812	33·7
Sodium Alcoholate	$Na C_2 H_5 O$	5·88	0·875	24	1·3807	1·3856	1·3985	24·61
Copper Chloride	$Cu Cl_2$	11·90	0·961	12	......	1·4026	......	D 34·72
Cobalt "	$Co Cl_2$	24·34	0·873	17	1·3769	1·3814	1·3937	31·72
" "	"	35·04	0·851	12	1·3733	......	1·3893	33·06
Mercury "	$Hg Cl_2$	16·2	1·043	19·5	1·3828	1·3872	1·4006	35·10
" "	"	20·24	0·995	12	1·3795	1·3839	1·3970	36·08
Ammonia	$N H_3$	5·0	0·780	20	1·3576	1·3618	1·3726	8·97

I am indebted to friends for the use of some of the above compounds. Professor FRANKLAND kindly lent me the mercuric methide and the ketones; Professor WILLIAMSON the titanium tetrachloride, chromium oxychloride, and ethylic phosphite; Professor ROSCOE the vanadium oxychloride; and Mr. PERKIN the cacodylic acid.

POSTSCRIPT, 21st March, 1870.

Since writing the statement about the aromatic compounds under the head of carbon, I have satisfied myself that their exceptionally high refractive power cannot be explained by the higher equivalent of hydrogen.

More recent experiments have confirmed the numbers provisionally assigned to antimony and gold, and led to some augmentation in those for didymium and zirconium.