XI. *On the Specific Gravity of Alloys.* *By* A. Matthiessen, *Ph.D.* *Communicated by Professor* Wheatstone.

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Before commencing a research on the law of the conducting power for electricity of alloys, it was considered necessary to determine their specific gravities; to ascertain whether they expand or contract, so as to be able to account for differences which might be obtained in their conducting powers.

The metals used for the alloys were those which were easily obtained in a pure state in large quantities, and were purified as follows:—

1. *Antimony.*—By Liebig's process.

2. *Tin.*—Commercial metal dissolved in nitric acid, and the binoxide reduced by charcoal.

3. *Cadmium.*—Commercial metal dissolved in hydrochloric acid and precipitated by sulphuretted hydrogen; the sulphide dissolved in hydrochloric acid and precipitated by carbonate of soda; the carbonate heated, a part of the oxide reduced by hydrogen, and the rest distilled with charcoal.

4. *Bismuth.*—Commercial metal dissolved in nitric acid, precipitated by water and reduced by charcoal.

5. *Silver.*—Reduced from the pure chloride by fusion with carbonate of soda. The greater part of the silver used for making the alloys was procured in a state of purity from Messrs. Johnson and Matthey.

6. *Lead.*—Commercial acetate recrystallized three times and heated.

7. *Mercury.*—Commercial metal treated with nitric acid, and allowed to stand with it about a month, being at intervals well-shaken.

8. *Gold.*—Prepared by precipitating chloride of gold by algaroth powder, &c., and also by precipitation of the chloride of gold by protosulphate of iron*, &c. Some of the gold employed was procured pure from Messrs. Johnson and Matthey.

The quantity of each alloy made was about 20 grms.; the two metals were weighed out accurately in proper proportions, and fused together in a porcelain crucible; a jet of gas being allowed to play in the same from above to prevent the oxidation of the metals. The alloys were cast in a wooden mould, a porcelain slab (previously blackened by holding it over a gas flame to prevent the adhering of the metal) forming the bottom. They were always re-fused and re-cast, at least three times, before the first determination was made, then re-fused before they were determined a second time, and again before

* See Appendix at the end of my paper "On the Electric Conducting Power of Alloys," in this volume, p. 175.

the third determination; often being re-cast several times, as the castings did not always succeed. To prevent as much as possible the formation of internal cavities from crystallization, the alloys were cast very thin, the thickness of the casting being in most cases about 3 to 4 millims.

The method employed for taking the specific gravities, was that of hanging the alloys by a very fine platinum wire in distilled water, which had been boiled to free it from air, and allowed to cool *in vacuo*. This method gave better results than that of weighing the metal or alloy in a bottle filled with water, on account of the difficulty of perfectly drying the bottle when full, and obtaining the same weight twice following.

The amalgams which were liquid, and those not sufficiently hard to hang by the platinum wire, were weighed in a glass tube to which a platinum wire was soldered.

The weight of the tube alone in air and water was determined at the temperature at which the experiments were made, and therefore, in calculating the specific gravities, these values had only to be subtracted from those found.

The balance used was one of LIEBIECH's, which turns to the 0·1 mgr. when loaded with 100 grms. in each pan; and when the alloy was weighed in water, it turned to the 0·2 mgr. The air adhering to the alloy, when weighed in water, was removed by a soft brush, the alloy being brushed until its weight became constant.

In calculating the specific gravities, the weight of the water displaced was corrected for the temperature, so that the unit is in all cases distilled water at 0° C. A similar correction could not be made for the temperature of the alloys, as their coefficients of expansion are not known. All the weighings were reduced to a vacuum, and a correction was made for that part of the platinum wire which dipped in the water. The length of wire dipping in was about 60 millims., which weighed 8 mgrs.; these would lose in water about 0·35 mgr. Supposing, as is really the case, that sometimes 10 millims. more or less dipped in, the error made would be about 0·06 mgr.; but as the 0·3 mgr. only make an error, if not brought into calculation, in most cases of about 0·001 per cent. of the specific gravity found, the error made in this way may be overlooked.

The equivalents used for calculating the quantities of metal required for the alloys were—

Antimony*	122·3	Silver	108
Tin	58	Lead	103·7
Cadmium	56	Mercury	100
Bismuth	208	Gold	197

Table I. gives the specific gravities of the pure metals employed, and the temperature (T.) in the Centigrade scale: the values given are the results of three consecutive determinations. On account of the number of alloys experimented with, it was considered as well, in order to save space, only to give the mean of the three determinations; and

* DEXTER, POGGENDORFF's 'Annalen,' vol. c. p. 563. This is the latest determination, and the one adopted by BUNSEN in his recent paper. LIEBIG's 'Annalen,' vol. cvi. p. 1.

where they did not agree amongst themselves to 0·1 per cent. of the value, a + will be placed by the alloy, and the value there given is the mean of a number of experiments (generally six or more)*.

TABLE I.

Specific gravity found.

Metal.	1st Determination.	T.	2nd Determination re-fused.	T.	3rd Determination re-fused.	T.	Mean of Spec. grav.	Mean of T.	Determined by
Antimony ...	6·715	13°·6	6·713	14°·4	6·710	15°·0	6·713	14°·3	A. Matthiessen.
Tin	7·293	11·5	7·295	12·8	7·294	14·0	7·294	12·8	A. Matthiessen.
Cadmium......	8·655	10·0	8·657	10·2	8·654	11·2	8·655	10·5	A. Matthiessen.
Bismuth	9·823	12·0	9·824	12·4	9·823	12·4	9·823	12·3	Dr. M. Holzmann.
Silver †.........	......	...	......	...	......	...	10·468	13·2	Dr. M. Holzmann.
Lead	11·374	13·0	11·380	16·5	11·376	11·0	11·376	13·5	Dr. M. Holzmann.
Mercury	13·575	14·0	13·569	14·7	13·574	14·8	13·573	14·5	Dr. M. Holzmann.
Gold	19·261	10·0	19·269	15·5	19·264	12·8	19·265	12·8	A. Matthiessen.

Table II. gives the mean of the three determinations made with the alloys, the mean of the temperatures (T.), and the specific gravity calculated from the first of the following formulæ:—

$$S=\frac{A+A_1}{V+V_1}=\left(\frac{Vs+V_1s_1}{V+V_1}\right) \quad . \quad . \quad . \quad (1.)$$

$$S=\frac{ns+n_1s_1}{n+n_1}, \quad . \quad . \quad . \quad (2.)$$

$$S=\frac{As+A_1s_1}{A+A_1}, \quad . \quad . \quad . \quad (3.)$$

where S=the specific gravity of the alloy,
V and V_1=the volumes of the metals, taking
n and n_1=the numbers of the equivalents of the metals, and
A and A_1=their respective weights.
s and s_1=their specific gravities.

* Those alloys which are underlined have been made twice, as it was supposed these must have an error in the weighing out of the metals, as they do not agree with the calculated values. The values, however, were found to be correct.

† No concordant results could be obtained with this metal. Experiments were made with it after having been fused under borax, chloride of sodium, charcoal, in hydrogen. The above value is the mean of a number of determinations which varied between 10·424 and 10·511.

Some specimens of not quite pure silver were lent me by Mr. PH. WORSLEY, who prepared them as follows:—

The silver was made as hot as possible, and well-stirred with a stick of charcoal before pouring. The mould was a steel one, forming a bar of about 25 millims. square and about 300 millims. high. The bar weighed about 2½ kilogrammes. The top of it, when cold, showed a funnel-shaped depression, and the soundest part of it was about two-thirds down, and from this different pieces were cut, which gave very good results. The values obtained were 10·504, 16°·7; 10·505, 17°·2; 10·502, 19°·2. A second bar gave similar numbers; they were 10·500, 24°·5; 10·496, 24°·8; 10·492, 25°·0.

The specific gravity of an alloy is calculated from the above formulæ, under the supposition that the specific gravity of the metals employed take part of that of the alloy in the ratio of their relative volumes (1.), equivalents (2.), or weights (3.). Of these formulæ only the first is for all cases correct, supposing the alloy neither contracts nor expands; the second only when the volumes and equivalents of the metals employed are in the same ratio with each other, as in the case of gold, silver, &c.; and the third only when the specific gravities of the two metals are equal. The two last methods of calculation are here mentioned, as several chemists have calculated their results from these formulæ.

Table II.

Antimony-Tin Series (determined by Mr. C. Long).

Alloy.	Mean of		Calculated specific gravity, from volume.	Ratio of volumes, $\frac{V+V_1}{v}$*.
	Specific gravity found.	T.		
Sb_6Sn	6·739	16°·2	6·752	1·0019
Sb_4Sn	6·747	13·4	6·770	1·0034
Sb_2Sn	6·781	13·5	6·817	1·0053
$SbSn$	6·844	13·8	6·889	1·0066
$SbSn_2$	6·929	15·8	6·984	1·0079
$SbSn_4$	7·023	15·8	7·082	1·0084
$SbSn_6$	7·100	10·6	7·133	1·0046
$SbSn_{10}$+	7·140	19·0	7·186	1·0065
$SbSn_{20}$	7·208	18·5	7·234	1·0036
$SbSn_{40}$	7·276	19·4	7·262	0·9981
$SbSn_{100}$	7·279	20·0	7·281	1·0003
$SbSn_{200}$	7·284	20·2	7·287	1·0004

Antimony-Bismuth Series (determined by Dr. M. Holzmann).

Sb_2Bi	7·864	9·4	7·856	0·9989
$SbBi$	8·392	11·0	8·385	0·9991
$SbBi_2$	8·886	14·0	8·888	1·0002
$SbBi_4$	9·277	12·1	9·272	0·9995
$SbBi_6$	9·435	9·4	9·433	0·9998

Antimony-Lead Series (determined by A. Matthiessen).

$SbPb$	8·201	13·7	8·268	1·0082
$SbPb_2$	8·989	11·7	9·945	1·0062
$SbPb_4$	9·811	14·3	9·822	1·0011
$SbPb_6$	10·144	15·4	10·211	1·0066
$SbPb_{10}$	10·586	19·3	10·599	1·0012
$SbPb_{20}$+	10·930	19·9	10·952	1·0020
$SbPb_{50}$	11·194	20·5	11·196	1·0002

* Where v= volume of the alloy found, and $V+V_1$= volumes of the metals composing it.

TABLE II. (continued.)

Tin-Cadmium Series (determined by A. MATTHIESSEN).

Alloy.	Mean of		Calculated specific gravity, from volume.	Ratio of volumes, $\frac{V+V_1}{v}$.
	Specific gravity found.	T.		
Sn_6Cd	7·434	12·7°	7·456	1·0029
Sn_4Cd	7·489	15·0	7·524	1·0047
Sn_2Cd	7·690	12·9	7·687	0·9996
$SnCd$	7·904	13·2	7·905	0·9999
$SnCd_2$	8·139	11·1	8·137	0·9998
$SnCd_4$	8·336	14·5	8·335	0·9999
$SnCd_6$	8·432	15·0	8·424	0·9990

Tin-Bismuth Series (determined by Mr. M. CARTY).

$Sn_{44}Bi$	7·438	19·9	7·438	1·0000
Sn_8Bi	7·943	20·0	7·925	0·9977
Sn_6Bi	8·112	14·2	8·071	0·9949
Sn_4Bi	8·339	13·9	8·305	0·9959
Sn_2Bi	8·772	12·6	8·738	0·9961
$SnBi$	9·178	15·9	9·132	0·9950
$SnBi_2$	9·435	15·0	9·423	0·9987
$SnBi_4$	9·614	12·7	9·606	0·9991
$SnBi_6$	9·675	15·2	9·674	0·9999
$SnBi_{10}$	9·737	19·8	9·731	0·9994
$SnBi_{30}$	9·774	23·0	9·792	1·0019
$SnBi_{44}$	9·803	22·8	9·801	0·9998
$SnBi_{60}$	9·811	19·0	9·807	0·9996
$SnBi_{90}$	9·814	19·5	9·812	0·9998
$SnBi_{200}$	9·815	18·1	9·818	1·0003

Tin-Silver Series (determined by Dr. M. HOLZMANN).

$Sn_{36}Ag+$	7·421	18·6	7·404	0·9977
$Sn_{10}Ag$	7·551	18·8	7·507	0·9941
$Sn_{12}Ag+$	7·666	18·4	7·603	0·9918
Sn_6Ag+	7·963	19·3	7·858	0·9868
Sn_4Ag+	8·223	16·3	8·071	0·9815
Sn_2Ag	8·828	13·8	8·543	0·9677
$SnAg$	9·507	12·9	9·086	0·9558
$SnAg_2$	9·953	14·8	9·585	0·9630

Tin-Lead Series (determined by Mr. C. LONG).

Sn_6Pb	7·927	15·2	7·948	1·0027
Sn_4Pb	8·188	16·0	8·203	1·0018
Sn_2Pb	8·779	17·2	8·781	1·0002
$SnPb$	9·460	15·5	9·474	1·0015
$SnPb_2$	10·080	14·8	10·136	1·0055
$SnPb_4$	10·590	14·3	10·645	1·0052
$SnPb_6$	10·815	15·6	10·857	1·0039

Tin-Mercury Series (determined by Dr. M. HOLZMANN).

Sn_2Hg	9·362	9·9	9·282	0·9914
$SnHg$	10·369	14·2	10·313	0·9946
$SnHg_2$	11·456	11·3	11·373	0·9927

TABLE II. (continued.)

Tin-Gold Series (determined by Dr. M. HOLZMANN).

Alloy.	Mean of: Specific gravity found.	Mean of: T.	Calculated specific gravity, from volume.	Ratio of volumes, $\frac{V+V_1}{v}$.
Sn_{100} Au	7·441	22°·9	7·446	1·0007
Sn_{30} Au	7·801	22·8	7·786	0·981
Sn_{18} Au	8·118	22·4	8·092	0·9968
Sn_{12} Au	8·470	23·1	8·452	0·9979
Sn_8 Au	8·931	25·6	8·951	1·0023
Sn_6 Au	9·405	23·7	9·407	1·0002
Sn_5 Au	9·715	22·4	9·743	1·0029
Sn_4 Au	10·168	23·7	10·206	1·0037
Sn_3 Au	10·794	23·6	10·885	1·0084
Sn_2 Au	11·833	14·6	11·978	1·0022
Sn Au	14·244	14·2	14·028	0·9848
Sn Au_2	16·367	15·4	15·913	0·9722

Cadmium-Bismuth Series (determined by A. MATTHIESSEN).

Cd_6 Bi	9·079	13·1	9·067	0·9987
Cd_4 Bi	9·195	15·5	9·181	0·9985
Cd_2 Bi	9·388	15·0	9·380	0·9991
Cd Bi	9·554	13·4	9·550	0·9996
Cd Bi_2	9·669	14·8	9·668	0·9999
Cd Bi_4	9·737	14·7	9·740	1·0003
Cd Bi_6	9·766	15·4	9·766	1·0000

Cadmium-Lead Series (determined by Dr. M. HOLZMANN).

Cd_6 Pb	9·160	13·7	9·173	1·0014
Cd_4 Pb	9·353	12·0	9·364	1·0012
Cd_2 Pb	9·755	14·7	9·780	1·0026
Cd Pb	10·246	11·7	10·246	1·0000
Cd Pb_2	10·656	13·4	10·663	1·0006
Cd Pb_4	10·950	9·2	10·966	1·0015
Cd Pb_6	11·044	14·8	11·088	1·0039

Bismuth-Silver Series (determined by Dr. M. HOLZMANN).

Bi_{200} Ag	9·802	23·5	9·825	1·0023
Bi_{50} Ag	9·813	23·6	9·829	1·0016
Bi_{24} Ag	9·820	23·3	9·836	1·0016
Bi_{12} Ag	9·836	21·8	9·848	1·0012
Bi_6 Ag	9·859	21·0	9·871	1·0012
Bi_4 Ag	9·899	15·2	9·893	0·9994
Bi_2 Ag	9·966	14·9	9·949	0·9983
Bi Ag	10·068	15·6	10·034	0·9966
Bi Ag_2	10·197	13·2	10·141	0·9945
Bi Ag_4	10·323	15·1	10·249	0·9928

Table II. (continued.)

Bismuth-Lead Series (determined by Mr. M. Carty).

Alloy.	Mean of		Calculated specific gravity, from volume.	Ratio of volumes, $\frac{V+V_1}{v}$.
	Specific gravity found.	T.		
Bi_{30} Pb	9·844	21°·7	9·845	1·0001
Bi_{24} Pb	9·845	21·6	9·850	1·0005
Bi_{20} Pb	9·850	21·3	9·856	1·0006
Bi_{12} Pb	9·887	20·6	9·877	0·9990
Bi_{10} Pb	9·893	19·5	9·887	0·9994
Bi_8 Pb	9·934	21·1	9·902	0·9968
Bi_6 Pb	9·973	15·0	9·927	0·9953
Bi_4 Pb	10·048	10·7	9·974	0·9927
Bi_2 Pb	10·235	12·5	10·098	0·9866
Bi Pb	10·538	14·0	10·290	0·9765
Bi Pb_2	10·956	14·9	10·541	0·9621
Bi Pb_4	11·141	12·7	10·805	0·9698
Bi Pb_6	11·161	14·8	10·942	0·9803
Bi Pb_8	11·188	20·8	11·026	0·9855
Bi Pb_{10}	11·196	20·2	11·083	0·9899
Bi Pb_{24}	11·280	22·5	11·238	0·9963
Bi Pb_{100}	11·331	23·0	11·340	1·0008

Bismuth-Gold Series (determined by Dr. M. Holzmann).

Bi_{90} Au	9·872	21·0	9·873	1·0001
Bi_{40} Au	9·942	21·2	9·935	0·9993
Bi_{20} Au	10·076	18·7	10·046	0·9970
Bi_8 Au	10·452	21·4	10·360	0·9912
Bi_4 Au	11·025	23·0	10·840	0·9833
Bi_2 Au	12·067	16·0	11·659	0·9662
Bi Au	13·403	16·5	12·898	0·9631
Bi Au_2	14·844	16·0	14·462	0·9743

Silver-Lead Series (determined by A. Matthiessen).

Ag_2 Pb	10·800	13·5	10·746	0·9950
Ag Pb	10·925	13·8	10·894	0·9971
Ag Pb_2	11·054	12·5	11·048	0·9995
Ag Pb_4	11·144	18·2	11·175	1·0028
Ag Pb_8	11·196	21·0	11·263	1·0060
Ag Pb_{20}	11·285	22·2	11·327	1·0037
Ag Pb_{50}	11·334	20·6	11·355	1·0018

Silver-Gold Series (determined by A. Matthiessen).

Ag_8 Au	11·760	13·1	11·715	0·9961
Ag_4 Au	12·257	14·7	12·215	0·9965
Ag_2 Au	13·432	14·3	13·383	0·9963
Ag Au	14·870	13·0	14·847	0·9984
Ag Au_2	16·354	13·0	16·315	0·9976
Ag Au_4	17·540	12·3	17·493	0·9973
Ag Au_6	18·041	13·1	17·998	0·9976

TABLE II. (continued.)

Lead-Mercury Series (determined by A. MATTHIESSEN).

Alloy.	Mean of		Calculated specific gravity, from volume.	Ratio of volumes, $\frac{V+V_1}{v}$.
	Specific gravity found.	T.		
Pb_2Hg	11·979	15°·9	12·008	1·0024
$Pb\ Hg$	12·484	15·7	12·358	0·9899
$Pb\ Hg_2$	12·815	15·5	12·734	0·9937

Lead-Gold Series (determined by A. MATTHIESSEN).

Alloy.	Specific gravity found.	T.	Calculated specific gravity, from volume.	Ratio of volumes, $\frac{V+V_1}{v}$.
$Pb_{20}Au$	11·841	23·3	11·794	0·9961
$Pb_{10}Au$	12·274	19·4	12·171	0·9916
$Pb_8\ Au$	12·445	21·6	12·346	0·9920
$Pb_6\ Au$	12·737	21·3	12·618	0·9906
$Pb_4\ Au$	13·306	22·1	13·103	0·9840
$Pb_2\ Au$	14·466	14·3	14·210	0·9823
$Pb\ Au$	15·603	14·5	15·546	0·9963
$Pb\ Au_2$	17·013	14·3	16·832	0·9894

From Table II., which gives in the fourth column the ratio of the sum of the volumes of the two metals to the volume of the alloy, it appears that the alloys of antimony are generally greater in volume than the aggregate of the constituent metals (expand), while those of bismuth, silver, gold, and mercury, generally are less (contract); and we find that the maximum expansion or contraction generally takes place about that point when the alloy contains equal volumes of each metal.

The gold-tin and gold-lead alloys are all very brittle, except those very rich in lead or tin:—$Sn\,Au_2$ to $Sn_3\,Au$ are not at all crystalline, and have a glassy fracture; $Sn_4\,Au$ begins to show a crystalline structure, and has a crystalline fracture; $Sn_5\,Au$ to $Sn_{100}\,Au$ are exceedingly crystalline; and $Sn_5\,Au$ to $Sn_{12}\,Au$ all show a fracture like the cleavage plane of a crystal. The gold-lead alloys appear all to be crystalline, that is, their surface is very much so, but their fracture is glassy. The following alloys expand greatly on cooling, so much so, that the liquid metal breaks through the crust, forming large or small globules, viz. all those of bismuth-antimony, bismuth-gold, and bismuth-lead, which were experimented on; those of bismuth-tin, from $Bi_{210}\,Sn$ to $Bi_2\,Sn$, the rest of the series very slightly; and bismuth-lead, viz. $Bi_{30}\,Pb$ to $Bi_4\,Pb$ ($Bi_2\,Pb$ slightly), the rest apparently not at all. Of the bismuth-cadmium series, $Bi\,Cd_6$ and $Bi\,Cd_4$ expand very slightly, the rest not at all. No concordant results could be obtained with any zinc-tin or zinc-cadmium alloys, on account of their very crystalline structure.

In conclusion, my best thanks are due to Dr. M. HOLZMANN, Mr. C. LONG, and Mr. M. CARTY for their assistance in carrying out the foregoing determinations.