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Sixth Report of the Committee on Atomic Weights of the International Union of Chemistry

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The following report of the Committee covers the twelve-month period, September 30, 1934 to September 30, 1935.[1]

Three changes have been made in the table of atomic weights. Those of tantalum and radium have been changed from 181.4 and 225.97 to 180.88 and 226.05, respectively. Protactinium, with atomic weight 231, has been added to the table.

Carbon.—For some time it has seemed probable that the International value for the atomic weight of carbon, 12.00, is too low (Reports of this Committee for 1933 and 1934). Many recent determinations of densities and compressibilities of gaseous hydrocarbons and oxides of carbon have yielded values higher than this. Furthermore, the isotopic weight of C^{12} from mass spectrographic results appears to be slightly higher than 12.00 on the chemical scale[2] and allowance[3] for $^1/_{106}$ or[2] $^1/_{140}$ of C^{13} raises the average value for the mixture of isotopes by about 0.01 unit.

Pending the completion of chemical determinations of the atomic weight of carbon now under way no change has been made in the value in the International Table, although the value 12.01 appears nearer the true value than 12.00.

Potassium.—Johnson[4] has determined the ratio KCl:Ag. Five samples of potassium chloride were prepared from the sources and by the operations indicated below: (1) Norwegian potassium oxalate: Six crystallizations as oxalate, one as chloride and fusion. (2) German potassium nitrate: Ten crystallizations as nitrate, three precipitations as chloride with hydrogen chloride with intermediate fusion and crystallization from water. (3) German potassium chlorate: Ten crystallizations as chlorate, and decomposition to chloride. (4) German potassium chloride: One crystallization from water, two precipitations with hydrogen chloride with intermediate fusion and crystallization from water, one crystallization from constant boiling hydrochloric acid, one from water and fusion. (5) Searles Lake, California, U. S. A., potassium chloride: One crystallization from dilute ammonia, two crystallizations from water, one from normal hydrochloric acid (made from the same sample), eight crystallizations from water and fusion. All five samples were further crystallized three times from water, filtered through platinum sponge and again crystallized.

The salt was prepared for weighing by fusion in nitrogen (in a Pt–Rh boat), and after being dissolved to make a 0.2 *N* solution was added dropwise to a 0.2 *N* solution of an equivalent amount of pure silver. In Analyses 3, 12, 13, 14 and 15 both solutions were added dropwise to 200 ml. of water. After standing thirteen to fifty days at

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(1) Authors of papers bearing on the subject are requested to send copies to each of the three members of the Committee at the earliest possible moment: Prof. G. P. Baxter, Coolidge Laboratory, Harvard University, Cambridge, Mass., U. S. A.; Prof. O. Hönigschmid, Sofienstrasse 9/2, Munich, Germany; Prof. P. LeBeau, Faculté de Pharmacie, 4 Avenue de l'Observatoire, Paris VI^e, France.

(2) Aston, *Proc. Roy. Soc.* (London), **A149**, 400 (1935); *Nature*, **135**, 541 (1935).

(3) Jenkins and Ornstein, *Proc. Acad. Sci. Amsterdam*, **35**, 1212 (1933).

(4) Johnson, *J. Phys. Chem.*, **39**, 781 (1935).

room temperature the end-point of the titration was found, after cooling to 0°, by the "standard solution" method (Johnson) and potentiometrically.

THE ATOMIC WEIGHT OF POTASSIUM

Sample of KCl	KCl, g.	Ag, g.	Ratio KCl : Ag	At. wt. K
1	7.174405	10.38101	0.691109	39.100
2	7.159125	10.35886	.691111	39.100
3	7.139503	10.33051	.691108	39.100
4	7.110874	10.28910	.691107	39.100
5	7.119655	10.30174	.691112	39.100
1	7.113533	10.29294	.691108	39.100
2	7.124221	10.30839	.691109	39.100
3	7.241729	10.47841	.691110	39.100
4	7.128585	10.31474	.691107	39.100
5	7.163709	10.36550	.691111	39.100
1	7.132066	10.31981	.691104	39.099
2	7.151197	10.34747	.691106	39.100
3	7.230660	10.46250	.691103	39.099
4	7.212326	10.43594	.691105	39.099
5	7.102363	10.27681	.691106	39.100
		Average	.691108	39.100

The atomic weight of potassium thus found is slightly higher than recent values found by others from the same ratio, and that employed in the International Table.

Chromium.—Nuñez[5] has redetermined the atomic weight of chromium through the ratios of chromyl chloride to silver and silver chloride. Dry potassium dichromate, which had been six times recrystallized from slightly acid solution, was mixed with dry sodium chloride, which had been six times precipitated with hydrogen chloride. Upon the mixture, contained in an exhausted glass system, was dropped concentrated sulfuric acid, and the resulting chromyl chloride was collected over metallic silver. The product was then subjected to several fractional distillations in exhausted glass systems, in the first two of which the chromyl chloride stood over silver for twenty-four hour periods. The final product was collected in sealed glass bulbs.

A preliminary preparation (Series I) was made in a glass system containing greased joints. In preparing material for Series II and III only fused connections were employed. Series II and III represent more and less volatile portions of the same sample.

During the handling of the chromyl chloride care was taken so far as possible to avoid exposure to light, in order to avoid decomposition, since the substance is photochemically sensitive especially to light of short wave length.

After being weighed the bulbs containing the chromyl chloride were broken under water and the chloride precipitated with solutions of nearly equivalent quantities of pure silver. The end-point was determined nephelometrically and finally the silver chloride was washed, collected, dried and weighed. Dissolved silver chloride was estimated nephelometrically. Weights are corrected to vacuum.

The result, 52.013, confirms the current value in the International Table.

THE ATOMIC WEIGHT OF CHROMIUM

Series	Sample	CrO_2Cl_2, g.	Ag, g.	Ratio $CrO_2Cl_2 : 2Ag$	At. wt. Cr	AgCl, g.	Ratio $CrO_2Cl_2 : 2AgCl$	At. wt. Cr
I	1	2.23946	3.11873	0.718068	52.016	4.14375	0.540443	52.017
	2	3.40565	4.74299	.718039	52.010	6.30183	.540422	52.011
			Average	.718054	52.013		.540432	52.014
II	1	3.95716	5.51087	.718064	52.015	7.32206	.540443	52.017
	2	5.20776	7.25239	.718075	52.018	9.63597	.540450	52.019
	3	3.81350	5.31090	.718052	52.013	7.05634	.540436	52.015
	4	4.00910	5.58329	.718053	52.013	7.41855	.540416	52.009
	5	2.99479	4.17077	.718042	52.011	5.54165	.540415	52.009
			Average	.718057	52.014		.540432	52.014
III	6	3.78022	5.26473	.718027	52.008	6.99504	.540414	52.009
	7	2.94949	4.10753	.718069	52.017	5.45773	.540424	52.012
	8	1.41900	1.97620	.718045	52.011	2.62570	.540427	52.012
			Average	.718047	52.012		.540422	52.011
			Average of all	.718053	52.013		.540429	52.013

Arsenic.—Baxter and Frizzell[6] have determined the ratio of arsenic trichloride to iodine, by hydrolyzing weighed quantities of arsenic trichloride with di-sodium phosphate and allowing the arsenious acid to react with weighed very nearly equivalent quantities of iodine in nearly neutral solution. A slight deficiency of one or the other was then made up with dilute solutions of arsenious acid or iodine.

Arsenic trichloride was purified by extensive

[5] Nuñez, *Anales soc. españ. fís. quím.*, **33**, 533 (1935).

[6] Baxter and Frizzell, THIS JOURNAL, **57**, 851 (1935).

fractionation in exhausted systems and collected in weighed glass capsules. Iodine was purified by three distillations from potassium iodide made from iodine of the same degree of purity as that to be distilled (Samples I and II). Sample III resulted from thermal decomposition of very pure iodine pentoxide in an earlier investigation of Baxter and Butler on the atomic weight of iodine. All three samples were sublimed over hot platinum in a current of air. In Series 1 the iodine was weighed in stoppered weighing tubes. In Series 2 and 3 it was weighed in exhausted sealed glass bulbs. The hydrolysis of the arsenic trichloride and the reaction of the arsenious acid with iodine were carried out without contact with oxygen by working in exhausted vessels up to the final determination of the end-point. Fractions of arsenic trichloride are numbered in the order of decreasing volatility. Weights are corrected to vacuum. The value 126.917 is used for the atomic weight of iodine. In the paper the erroneous value 126.916 is employed.

THE ATOMIC WEIGHT OF ARSENIC

Fraction of $AsCl_3$	Sample of I_2	$AsCl_3$, g.	I_2, g.	Ratio $AsCl_3 : I_2$	At. wt. As
		Series 1			
3	I	10.33337	14.46807	0.714219	74.922
10	III	12.03069	16.84522	.714190	74.915
32	III	11.90242	16.66431	.714246	74.929
31	III	11.76237	16.46851	.714234	74.926
11	III	11.50761	16.11185	.714233	74.926
12	III	10.86983	15.21915	.714221	74.923
13	III	10.43957	14.61741	.714187	74.914
14	III	10.52815	14.74051	.714232	74.925
16	II	9.23191	12.92578	.714225	74.924
15	II	9.75285	13.65529	.714218	74.922
			Average	.714221	74.923
		Series 2			
4	I	11.07602	15.50784	0.714221	74.923
5	II	11.02523	15.43720	.714199	74.917
6	II	10.81172	15.13922	.714153	74.905
9	III	11.03085	15.44504	.714200	74.917
7	III	11.41153	15.97940	.714140	74.902
			Average	.714183	74.913
		Series 3			
33	III	14.50315	20.30806	0.714157	74.906
34	III	16.22008	22.71162	.714175	74.911
30	III	9.63062	13.48470	.714189	74.914
17	III	10.11654	14.16485	.714200	74.917
29	III	10.05286	14.07583	.714193	74.915
28	III	10.60621	14.85068	.714190	74.915
19	III	11.13389	15.58919	.714206	74.919
27	III	10.93869	15.31583	.714208	74.919
20	III	9.78401	13.69959	.714183	74.913
26	III	9.85690	13.80122	.714205	74.919
25	III	9.62562	13.47741	.714204	74.918
21	II	10.24867	14.34997	.714195	74.916
22	III	9.97953	13.97324	.714189	74.914
			Average	.714192	74.915
			Average of all	.714200	74.917

The result supports the present International value.

Tellurium.—Hönigschmid and Baudrexler[7] have compared tellurium tetrachloride with silver. Tellurium was dissolved in nitric acid and the basic nitrate was four times recrystallized from nitric acid. Ignition to dioxide followed. After solution in hydrochloric acid the metal was precipitated with hydrazine and after being dried was distilled in a current of hydrogen (I). A second sample which was used in an earlier investigation on the tetrabromide was similarly purified except that the final distillation was in vacuum (II). In a spectrographic examination Gerlach found both samples to be free from impurities.

To prepare the tetrachloride tellurium metal was heated in oxygen-free chlorine in a quartz apparatus until the mixture of di- and tetrachloride formed at first had been completely converted to tetrachloride. It was then twice sublimed in a current of chlorine and hydrogen chloride and collected in a weighed quartz tube. After fusion in chlorine the product was allowed to solidify and cool in nitrogen, and was transferred to a weighing bottle in dry air. This material was used in the first series of analyses.

Other samples of the tetrachloride, prepared in an identical fashion, were sublimed in exhausted glass apparatus and sealed in glass bulbs for weighing. Here slight dissociation of the tetrachloride into the darker dichloride was sometimes observed. The analyses in the second series were made only with fractions which showed no trace of darkening.

For analysis the tellurium tetrachloride was dissolved in tartaric acid and then compared with weighed equivalent amounts of pure silver in the usual way, and the silver chloride was collected and weighed. Weights are corrected to vacuum.

The average value 127.63 is only slightly higher than that recently found by Hönigschmid, Sachtleben and Wintersberger from analyses of tellurium tetrabromide and the synthesis of silver telluride, 127.61.

Terbium.—Marsh[8] purified terbium material, containing chiefly gadolinium, dysprosium and terbium, by fractionation of the dimethylphos-

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(7) Hönigschmid and Baudrexler, *Z. anorg. allgem. Chem.*, **223**, 91 (1935).

(8) Marsh, *J. Chem. Soc.*, 1972 (1934); 772 (1935).

THE ATOMIC WEIGHT OF TELLURIUM

Sample	$TeCl_4$, g.	Ag, g.	Ratio $TeCl_4 : 4Ag$	At. wt. Te	AgCl, g.	Ratio $TeCl_4 : 4AgCl$	At. wt. Te
			$TeCl_4$ sublimed in chlorine and hydrogen chloride				
II	3.10877	4.97861	0.624425	127.62			
II	3.10067	4.96557	.624434	127.63			
II	2.76664	4.43026	.624487	127.65	5.88640	0.470006	127.65
II	3.22268	5.16097	.624433	127.63	6.85689	.469929	127.64
II	2.83816	4.54547	.624393	127.61	6.03937	.469943	127.61
II	2.48858	3.98535	.624432	127.63	5.29502	.469985	127.64
II	2.90220	4.64760	.624451	127.64	6.17487	.470002	127.65
II	2.46428	3.94633	.624449	127.63	5.24358	.469961	127.62
II	2.28970	3.66727	.624361	127.60	4.87216	.469956	127.62
II	2.87152	4.59861	.624432	127.63	6.11069	.469918	127.60
II	2.41697	3.87036	.624482	127.65	5.14279	.469973	127.63
II	2.07278	3.31955	.624416	127.62	4.41041	.469975	127.63
		Average	.624433	127.63		.469965	127.63
			$TeCl_4$ sublimed in vacuum				
I	3.28709	5.26438	0.624402	127.61	6.99440	0.469960	127.62
I	2.55532	4.09223	.624432	127.63			
I	4.47487	7.16715	.624358	127.60	9.52250	.469926	127.60
I	6.26285	10.02985	.624421	127.62	13.32623	.469964	127.64
I	3.10159	4.96705	.624433	127.63	6.59955	.469970	127.63
II	2.31719	3.71078	.624448	127.63			
		Average	.624416	127.62		.469955	127.62

phates until the arc lines of gadolinium in the tail fractions and the absorption bands of dysprosium in the head fractions could not be detected. Terbium oxalate was precipitated with oxalic acid, washed and air dried at 30°. Weighed portions of oxalate were ignited in silica crucibles first in air at 1000°, then in hydrogen at 700–800° and after rapid cooling by quenching with water were weighed. Other weighed portions of oxalate were dissolved in dilute sulfuric acid containing manganous sulfate and then were titrated with standard permanganate. Weights are corrected to vacuum.

THE ATOMIC WEIGHT OF TERBIUM

$Tb_2(C_2O_4)_3$, g.	Tb_2O_3, g.	% of Tb_2O_3	$Tb_2(C_2O_4)_3$, g.	C_2O_3, g.	% of C_2O_3
0.8046	0.38337	47.655	0.34336	0.09662	28.139
1.16364	.55446	47.649	.32038	.09010	28.119
1.33993	.63838	47.643	.32307	.09091	28.139
1.27706	.60848	47.647	.56839	.15977	28.110
1.14461	.54333	47.644	.57361	.16147	28.149
	Average	47.648	.58153	.16365	28.141
			.62028	.17465	28.157
				Average	28.136

The average atomic weight of terbium calculated from the two percentages is 158.89, which is lower than that found by Urbain from the ratio of octohydrated sulfate to sulfate, 159.2, but agrees with Aston's finding that terbium is a simple element of atomic weight 158.91.

Europium.—Meyers and Hopkins[9] have compared europium chloride with silver. Starting with material consisting chiefly of samarium, europium and gadolinium, fractional crystallization as double magnesium nitrates was first carried out with the addition of bismuth to split samarium and europium. Fractional crystallization of the europium and gadolinium fractions as simple nitrates followed with bismuth as separating element. After removing most of the samarium in this way, further fractionation as double magnesium nitrates, as simple nitrates and again as double magnesium nitrates was carried out. Of the final twelve fractions, Nos. 8, 9 and 10 gave no spectroscopic evidence of impurity.

After removal of bismuth each of these fractions was purified by alternate precipitation of oxalate and hydroxide, and the final oxalate was ignited to oxide.

Chloride was prepared by dissolving the oxide in a weighed quartz flask and, after evaporation,

THE ATOMIC WEIGHT OF EUROPIUM

Fraction	$EuCl_3$, g.	Ag, g.	Ratio $EuCl_3 : 3Ag$	At. wt. Eu
8	1.15506	1.44544	0.79911	152.25
9	0.43279	0.54140	.79939	152.33
10	.60180	.75291	.79930	152.31
8	1.10986	1.38862	.79924	152.29
8	1.00560	1.25820	.79924	152.29
10	0.52157	0.65262	.79919	152.27
8	.90408	1.13104	.79933	152.32
9	.33150	0.41472	.79930	152.31
10	.57944	.72498	.79925	152.29
8	.91942	1.15035	.79925	152.29
		Average	.79926	152.30

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(9) Meyers and Hopkins, THIS JOURNAL, 57, 241 (1935).

dehydrating the chloride slowly in a current of dry hydrogen chloride, at gradually increasing temperatures until fusion took place. The weighed fused salt was compared with pure silver in the conventional way. Weights are corrected to vacuum.

The final result is considerably higher than both the present International value and that recently found by Aston, 151.90.

Tantalum.—Hönigschmid and Schlee[10] have compared tantalum pentabromide with silver. Potassium tantalum fluoride was six times recrystallized from hydrofluoric acid, and then was converted to tantalic acid with hot concentrated sulfuric acid. Potassium sulfate was removed by washing and the dried acid was ignited at 1000°. x-Ray analysis by Prandtl and v. Hevesy failed to reveal niobium and zirconium, but 0.1% of thorium remained. The latter was reduced to 0.01% by fusing with soda and extracting the residue, with rejection of the insoluble portion (I).

Material recovered from the earlier analyses constituted a second sample (II).

The tetrabromide was prepared in two ways. The first consisted in heating a mixture of the tantalic oxide with carbon in a current of nitrogen and bromine. The resulting tetrabromide was then fractionated in an exhausted system and collected in sealed glass bulbs for weighing.

In the second method the oxide was first converted to sulfide by heating it to 1000° in a current of hydrogen sulfide and carbon disulfide, and then the sulfide was changed to bromide in a stream of nitrogen and bromine. Fractional distillation in a current of nitrogen and bromine eventually eliminated all sulfur bromide and the product was distilled into exhausted glass bulbs, which were sealed by fusion.

THE ATOMIC WEIGHT OF TANTALUM

Sample of $TaBr_5$	$TaBr_5$, g.	Ag, g.	Ratio $TaBr_5 : 5Ag$	At. wt. Ta
I	4.01046	3.72677	1.07612	180.879
I	3.36860	3.13031	1.07612	180.879
I	2.31963	2.15539	1.07620	180.922
I	2.98695	2.77560	1.07615	180.895
I	5.97976	5.55678	1.07612	180.879
I	2.69510	2.50447	1.07611	180.876
I	2.58878	2.40553	1.07618	180.911
I	2.15134	1.99927	1.07606	180.847
II	3.91760	3.64051	1.07611	180.876
II	4.92095	4.57277	1.07614	180.890
II	3.43463	3.19157	1.07616	180.899
II	7.95901	7.39614	1.07610	180.870
II	4.48505	4.16776	1.07613	180.884
II	4.54602	4.22440	1.07613	180.887
		Average	1.07613	180.884

The weighed bulbs were broken under cold oxalic acid, and the tantalic acid which separated was dissolved by warming for some hours. After cooling, the clear solution was filtered and the glass collected and weighed. Comparison with silver in the usual way followed. Weights are corrected to vacuum.

The average result agrees closely with Aston's finding that tantalum is a simple element of atomic weight 180.89 and seems to warrant a change in the value for this element in the International Table.

Radiogenic Lead.—Baxter and Alter[11] have determined the atomic weights of several radiogenic leads. Lead chloride from each specimen was purified by precipitation as sulfide, crystallization of the nitrate and chloride, and sublimation of the chloride in hydrogen chloride. The ratio of lead chloride to silver was found in the conventional way by the equal opalescence method. Weights are corrected to vacuum.

The value for Great Bear Lake material agrees with that found by Marble; that for Bedford I Cyrtolite with that found earlier by Baxter and Alter; that for Curite lead with the value found simultaneously by Hönigschmid with a portion of the same material.

Radium.—Hönigschmid and Sachtleben[12] have redetermined the atomic weight of radium through the ratio $RaBr_2:RaCl_2$. Five grams of radium bromide, loaned by the Union Minière du Haut Katanga, was available. Initially this contained 98.83 atomic per cent. of radium and 1.17 of barium. After ten recrystallizations of the chloride by precipitation with hydrogen chloride in quartz the atomic percentage of barium had dropped to 0.3. Fifteen additional similar crystallizations yielded material of atomic weight 226.005. A third series of crystallizations from constant boiling hydrochloric acid raised the atomic weight to 226.05. Ten more crystallizations from constant boiling hydrochloric acid followed. The final material was examined spectroscopically by Gerlach, who estimates the residual barium at not more than 0.002–0.003 atomic per cent., which would lower the atomic weight of radium 0.002–0.003 unit.

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(10) Hönigschmid and Schlee, *Z. anorg. allgem. Chem.*, **221**, 129 (1934).

(11) Baxter and Alter, THIS JOURNAL, **57**, 467 (1935).

(12) Hönigschmid and Sachtleben, *Z. anorg. allgem. Chem.*, **221**, 65 (1934).

THE ATOMIC WEIGHT OF LEAD

Source	Fusion atmosphere	$PbCl_2$, g.	Ag, g.	Ratio $PbCl_2 : 2Ag$	At. wt. Pb
Uraninite, Besner Mine, Parry Sound, Ontario, Canada	$N_2 + HCl$	2.82198	2.19830	1.28371	206.059
	N_2 + 10% HCl	1.17902	0.91849	1.28365	206.046
			Average	1.28368	206.052
Pitchblende, Great Bear Lake, N. W. T., Canada	$N_2 + HCl$	2.17006	1.69051	1.28367	206.051
	$N_2 + HCl$	3.44166	2.68097	1.28374	206.065
			Average	1.28370	206.058
Cyrtolite, Hybla, Ontario, Canada	HCl	0.77361	0.60233	1.28436	206.20
	N_2 + 50% HCl	.47163	.36722	1.28433	206.19
			Average	1.28434	206.20
Cyrtolite II, Bedford, New York, U. S. A.	N_2 + 10% HCl	2.99554	2.33341	1.28376	206.070
	N_2 + 10% HCl	3.20665	2.49788	1.28375	206.067
	HCl	1.06532	0.82984	1.28377	206.071
	N_2 + 50% HCl	3.28903	2.56206	1.28374	206.067
	N_2 + 10% HCl	3.31553	2.58255	1.28382	206.083
			Average	1.28377	206.072
Cyrtolite I, Bedford	N_2 + 50% HCl	0.48244	0.37596	1.28322	205.954
Galena, Yancey County, North Carolina, U. S. A.	N_2 + 10% HCl	3.45151	2.67758	1.28904	207.209
	N_2 + 10% HCl	4.29642	3.33305	1.28904	207.208
			Average	1.28904	207.209
Curite, Katanga, Africa	N_2 + 50% HCl	2.99570	2.33388	1.28357	206.029
	N_2 + 50% HCl	2.01485	1.56973	1.28357	206.028
	HCl	3.01913	2.35212	1.28358	206.031
	N_2 + 10% HCl	2.93470	2.28639	1.28355	206.025
	N_2 + 50% HCl	2.00228	1.55997	1.28354	206.022
			Average	1.28356	206.027

Radium bromide was prepared from the chloride by repeated evaporation with a large excess of hydrobromic acid in quartz. After transference to a weighed quartz boat it was dehydrated in a current of nitrogen and hydrogen bromide at gradually increasing temperatures to 750° and the dried salt was transferred to a weighing bottle in air. The weighed salt was then heated in a current of chlorine and hydrogen chloride, at first at 300°, finally at 750°, and when the chlorine and hydrogen chloride had been displaced by nitrogen at 300° the chloride was transferred to the weighing bottle in dry air. Constancy in weight was readily secured.

Although neither the radium bromide nor the radium chloride were fused before being weighed, very similar experiments in which pure barium bromide was converted to chloride yielded a normal atomic weight so that it is evident that errors from moisture retained by the radium bromide, incomplete conversion, adsorbed air and temperature of the radium salts were either negligible or compensatory.

After the first six experiments had been completed it was discovered that radium salts when placed on the balance owing to heat evolution at first slowly lost in weight, coming to constancy after a period of about an hour. The weights given in the last two analyses in the table represent values obtained after constancy had been reached. For the first six analyses the weights given represent the minimum values observed where the weighings were repeated. All weights are corrected to vacuum.

THE ATOMIC WEIGHT OF RADIUM

Crystal Series	$RaBr_2$, g.	$RaCl_2$, g.	Ratio $RaBr_2 : RaCl_2$	At. wt. Ra
III	2.18675	1.68286	1.299424	226.049
III	3.49878	2.69256	1.299425	226.048
IV	3.46519	2.66677	1.299396	226.077
IV	3.41017	2.62432	1.299449	226.025
IV	3.43249	2.64150	1.299447	226.026
IV	3.40754	2.62239	1.299402	226.070
		Average	1.299424	226.049
IV	3.42566	2.63631	1.299415	226.059
IV	2.35813	1.81475	1.299424	226.049
		Average	1.299420	226.054
		Average of all	1.299423	226.050

THE ATOMIC WEIGHT OF BARIUM

$BaBr_2$, g.	$BaCl_2$, g.	Ratio $BaBr_2 : BaCl_2$	At. wt. Ba
4.89362	3.42946	1.426936	137.356
4.71132	3.30176	1.426912	137.368
3.76377	2.63768	1.426924	137.362
5.04872	3.53818	1.426926	137.361
	Average	1.426925	137.361

INTERNATIONAL ATOMIC WEIGHTS

1936

	Symbol	Atomic Number	Atomic Weight
Aluminum	Al	13	26.97
Antimony	Sb	51	121.76
Argon	A	18	39.944
Arsenic	As	33	74.91
Barium	Ba	56	137.36
Beryllium	Be	4	9.02
Bismuth	Bi	83	209.00
Boron	B	5	10.82
Bromine	Br	35	79.916
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Carbon	C	6	12.00
Cerium	Ce	58	140.13
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.457
Chromium	Cr	24	52.01
Cobalt	Co	27	58.94
Columbium	Cb	41	92.91
Copper	Cu	29	63.57
Dysprosium	Dy	66	162.46
Erbium	Er	68	167.64
Europium	Eu	63	152.0
Fluorine	F	9	19.00
Gadolinium	Gd	64	157.3
Gallium	Ga	31	69.72
Germanium	Ge	32	72.60
Gold	Au	79	197.2
Hafnium	Hf	72	178.6
Helium	He	2	4.002
Holmium	Ho	67	163.5
Hydrogen	H	1	1.0078
Indium	In	49	114.76
Iodine	I	53	126.92
Iridium	Ir	77	193.1
Iron	Fe	26	55.84
Krypton	Kr	36	83.7
Lanthanum	La	57	138.92
Lead	Pb	82	207.22
Lithium	Li	3	6.940
Lutecium	Lu	71	175.0
Magnesium	Mg	12	24.32
Manganese	Mn	25	54.93
Mercury	Hg	80	200.61
Molybdenum	Mo	42	96.0
Neodymium	Nd	60	144.27
Neon	Ne	10	20.183
Nickel	Ni	28	58.69
Nitrogen	N	7	14.008
Osmium	Os	76	191.5
Oxygen	O	8	16.0000
Palladium	Pd	46	106.7
Phosphorus	P	15	31.02
Platinum	Pt	78	195.23
Potassium	K	19	39.096
Praseodymium	Pr	59	140.92
Protactinium	Pa	91	231
Radium	Ra	88	226.05
Radon	Rn	86	222
Rhenium	Re	75	186.31
Rhodium	Rh	45	102.91
Rubidium	Rb	37	85.44
Ruthenium	Ru	44	101.7
Samarium	Sm	62	150.43
Scandium	Sc	21	45.10
Selenium	Se	34	78.96
Silicon	Si	14	28.06
Silver	Ag	47	107.880
Sodium	Na	11	22.997
Strontium	Sr	38	87.63
Sulfur	S	16	32.06
Tantalum	Ta	73	180.88
Tellurium	Te	52	127.61
Terbium	Tb	65	159.2
Thallium	Tl	81	204.39
Thorium	Th	90	232.12
Thulium	Tm	69	169.4
Tin	Sn	50	118.70
Titanium	Ti	22	47.90
Tungsten	W	74	184.0
Uranium	U	92	238.14
Vanadium	V	23	50.95
Xenon	Xe	54	131.3
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.92
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

The atomic weight of radium thus found is 0.08 higher than the value found by Hönigschmid some years ago with much smaller quantities of material. The new value, 226.05, has been adopted for the International Table.

Protactinium.—A. v. Grosse[13] working with material isolated by v. Grosse and Agruss, has determined the ratio $2K_2PaF_7:Pa_2O_3$. After two precipitations with hydrogen peroxide from dilute sulfuric acid solution the preparation showed no evidence of impurity when examined in an x-ray spectrograph. The double fluoride was prepared by dissolving protactinium oxide in hydrofluoric acid and adding the necessary quantity of potassium fluoride. The resulting crystals were twice recrystallized from hydrofluoric acid.

After being dried at 20° in vacuum over phosphorus pentoxide, the double fluoride was converted to sulfates by evaporation with an excess of sulfuric acid and then the protactinium was precipitated as hydroxide with ammonia, col-

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(13) A. v. Grosse, *Proc. Roy. Soc.* (London), **A150**, 363 (1935).

lected, ignited eventually to 800°, and weighed. Weights are corrected to vacuum.

THE ATOMIC WEIGHT OF PROTACTINIUM

K_2PaF_7, g.	Pa_2O_5, g.	Ratio $2K_2PaF_7 : Pa_2O_5$	At. wt. Pa
0.091907	0.056274	1.6332	230.4
.070047	.042913	1.6323	230.8
		Average 1.6328	230.6

The result seems to be in accord with the expectation that protactinium has the atomic weight 231.

Aston[14] by determination of packing fractions and abundance ratios with the mass spectrograph has obtained the following atomic weights.

Carbon	12.0080	Gallium	69.71
Calcium	40.076	Zirconium	91.24
Titanium	47.91	Silver	107.87
Iron	55.84	Cadmium	112.2
Nickel	58.68	Indium	114.80
		Hafnium	178.4

The only serious discrepancy between these values and the International values is with cadmium.

Thorium and rhodium were found to be probably simple.

By comparison of doublets Aston[15] has obtained new values for several light atoms, although these are still regarded as provisional.

O^{16} =	16.0000	O = 16.0000
H =	1.0081	1.0079
D =	2.0148	2.0143
He =	4.0041	4.0031
C^{12} =	12.0048	12.0018

If the abundance ratio of D is 1/5000 and that of C^{13} is 1/100, the atomic weights of hydrogen and carbon become 1.0081 and 12.012.

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[14] Aston, *Proc. Roy. Soc.* (London) **A149**, 396 (1935).

[15] Aston, *Nature*, **135**, 541 (1935).

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[CONTRIBUTION FROM THE BUREAU OF CHEMISTRY AND SOILS, U. S. DEPARTMENT OF AGRICULTURE]

The Hydrogen Bond between Oxygen Atoms in Some Organic Compounds

BY G. E. HILBERT, O. R. WULF, S. B. HENDRICKS AND U. LIDDEL

Bonding of hydrogen to two atoms has been recognized and described under such various terms as partial valence, secondary forces, hydrogen bond, chelate ring, coördination, Dimroth ring, association, intramolecular association and the "ortho effect." This very multiplicity of naming reflects the amorphous character of the concept and its partially uncorrelated appearance in the literature during the last twenty-five years.

Such a role of hydrogen in molecule formation seems to have been first postulated by Moore and Winmill[1] (secondary forces) to account for the differences in the basicity of the tertiary and quaternary ammonium bases. The concept was developed (hydrogen bond) within the scope of the Lewis valence theory by Huggins[2] and by Latimer and Rodebush[3] to account for the association of water and for the formation of such ions as HF_2^-.[4] It was extended to organic compounds (chelation) by Sidgwick[5] as a particular case of Werner's coördination theory for the formation of closed rings containing metal atoms.[6] This possibility was mentioned earlier by Pfeiffer and co-workers[7] but was not developed.

Various explanations for the formation of this type of atomic linkage have been advanced in terms of coeval theories. Thus partial valence was used by Winmill and others. Lewis wrote the following formula for the acid fluoride ion

$$:\underset{..}{\ddot{F}}:H:\underset{..}{\ddot{F}}:$$

whereas Pauling[8] pointed out that the binding must be electrostatic, $F^-H^+F^-$, since the Pauli exclusion principle, namely, that two electrons cannot have the same quantum numbers, did not

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[1] Moore and Winmill, *J. Chem. Soc.*, **101**, 1635 (1912).

[2] Huggins, Undergraduate Thesis, University of California, 1919.

[3] Latimer and Rodebush, THIS JOURNAL, **42**, 1419 (1920).

[4] See G. N. Lewis, "Valence and the Structure of Atoms and Molecules," Chemical Catalog Co., New York, 1923, p. 110.

[5] Sidgwick, *J. Chem. Soc.*, **127**, 907 (1925).

[6] Werner, *Ber.*, **34**, 2586 (1901); **41**, 1062 (1908); Morgan, *J. Chem. Soc.*, **117**, 1457 (1920).

[7] Pfeiffer, Fischer, Kuntner, Monti and Pros, *Ann.*, **398**, 137 (1913).

[8] (a) Pauling, *Proc. Nat. Acad. Sci.*, **14**, 359 (1928); (b) THIS JOURNAL, **53**, 1365 (1931).