in the reports of the Twelfth Census of the United States that "Probably no science has done so much as chemistry in revealing the hidden possibilities of the wastes and by-products in manufactures. This science has been the most fruitful agent in the conversion of the refuse of manufacturing operations into products of industrial value . . . . . Chemistry is the intelligence department of industry." It does not skim the cream of other men's labors but is itself a creator of wealth.

I have touched but incidentally upon the chemist's services in conserving the health of the community, a field in which his prominence is recognized more clearly every day. Our food and drink is scrutinized by him to shield us from fraud and disease, our clothing bears the imprint of his handiwork, our homes are better lighted through his labors, and in times of serious sickness it is from his hands that the physician receives some of his most potent drugs for the relief of pain, for the production of anesthesia, and for the rescue of the sufferer from the very brink of the grave. In his fight with disease and death, the physician has no more powerful ally than the chemist.

In view of all this, I cannot agree with President Howe's statement in a recent number of *Science* (**28**, 547. Oct. 22, 1908) that "This work of conservation is the work of the engineer." The engineer can contribute largely to the solution of the problems involved, he will perhaps be the largest single contributor. but there are others who can also render valuable service in this direction, of which number the chemist is certainly one.

Of the various factors upon which the success of this conservation movement depends, none is more important, in my estimation, than that of awakening the producer and manufacturer to a proper realization of the value of science to our industries.

Bacon has said "I hold every man a debtor to his profession," and here, gentlemen, in assisting in the conservation of our natural resources, is an unrivaled opportunity to pay that debt and in so doing to bring added dignity and honor to our profession.

THE COMPRESSIBILITIES OF THE ELEMENTS AND THEIR PERIODIC RELATIONS.

By Theodore W. Richards, W. N. Stull, F. N. Brink, and F. Bonnet, Jr.

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In a series of papers upon the significance of changing atomic volume, it has been shown that, at least in some cases, atomic volume is probably in part dependent upon the intensity of the affinities concerned in holding the material together.

[1] Richards, *Proc. Am. Acad.*, **37**, 1 (1901); 99 (1902); **38**, 293 (1902) **39**, 581 (1904). *Z. physik. Chem.*, **49**, 15 (1904).

If this is the case, the inference is inevitable that both chemical affinity and cohesion exert pressure; and if they exert pressure, this pressure must have more effect upon the volume of a compressible substance than upon that of a relatively incompressible one. To have any important meaning, the volume-change must be considered in relation to the compressibilities of the substances concerned.

If then, compressibility is not merely an isolated physical fact, but rather a phenomenon of chemical significance immediately connected with the most important chemical properties of material, it becomes a highly interesting problem to determine the compressibility of as many simple substances as possible.

It was with these inferences in mind that seven years ago the study of compressibility was begun in the Chemical Laboratory of Harvard College. In the first place a new method was devised, because none of the already existing methods were adequately convenient or precise. This method has already been described in detail in Publication 7 of the Carnegie Institution of Washington.[1] Its essential feature is the comparison of the unknown compressibility with the compressibility of mercury in a given apparatus, measuring both pressure and change of volume, and then displacing most of the mercury by the substance to be studied, and again noting the relationship of pressure to volume. Obviously in such a method as this, the compressibility of the apparatus itself is eliminated, occurring in both series of measurements. The relation of volume to pressure was easily determined by causing the mercury meniscus to make contact with a very fine platinum point in a tube of narrow diameter; and the decrease in volume was determined by adding weighed globules of mercury and noting the pressures needed to cause similar contact. As the apparatus and method are described in full elsewhere,[2] and are suggested in the following paper also, further details are unnecessary in this brief account.

In all, the compressibilities of thirty-five elements and many single compounds were studied with sufficient care to leave no doubt as to their relative values. Highly interesting relationships were found between these values, showing not only that compressibility is closely related to cohesive pressure as indicated by the boiling point and is, therefore, periodic in the system of the elements, but also other important connections between the fundamental properties of material.

Following are the results with the elements. In this table of com-

[1] This paper by Richards and Stull appears also in more abbreviated form in THIS JOURNAL, **26,** 399 (1904), and *Z. physik. Chem.*, **49,** 1 (1904).

[2] The present paper is an abstract of a monograph published by the Carnegie Institution of Washington, Publ. **76**, where yet other details are given. See also *Z. physik. Chem.*, **61,** **77,** 171 (1907).

pressibilities the values are given in terms of the megabar—a megadyne per square centimeter—as the unit of pressure, instead of the kilogram per square centimeter. This absolute unit is about 2 per cent. greater than the latter-named technical unit, and 1.3 per cent. less than the "atmosphere." In most of the present cases the difference between these standards does not exceed greatly the experimental limit of error. The values may be easily transposed into terms of the atmosphere by adding

THE COMPRESSIBILITIES, ATOMIC WEIGHTS, AND ATOMIC VOLUMES OF A MAJORITY OF THE COMMONLY SOLID AND LIQUID ELEMENTS.

(Compressibility of Mercury = 0.00000379).

Element.	Average compressibility (*i. e.*, average fractional change of volume caused by 1 megabar pressure) between 100 and 500 megabars, $\times 10^6$.	Approximate atomic weight (O = 16).	Atomic volume.
Lithium	8,8	7,0	13,1
Carbon, diamond	0,5	12,0	3,4
Carbon, graphite	3		5,4
Sodium	15,4	23,0	23,7
Magnesium	2,7	24,4	13,3
Aluminium	1,3	27,1	10,1
Silicon	0,16	28,4	11,4
Phosphorus, red	9,0	31,0	16,6
Phosphorus, white	20,3		14,4
Sulphur	12,5	32,1	15,5
Chlorine	95	35,5	25
Potassium	31,5	39,1	45,5
Calcium	5,5	40,1	25,3
Chromium	0,7	52,1	7,7
Manganese	0,67	55,0	7,7
Iron	0,40	55,9	7,1
Nickel	0,27	58,7	6,7
Copper	0,54	63,6	7,1
Zinc	1,5	65,4	9,5
Arsenic	4,3	75,0	13,3
Selenium	11,8	79	18,5
Bromine	51,8	79,9	25,1
Rubidium	40	85,5	56
Molybdenum	0,26	96	11,1
Palladium	0,38	107	9,3
Silver	0,84	107,9	10,3
Cadmium	1,9	112,5	13,0
Tin	1,7	119	16,2
Antimony	2,2	120	17,9
Iodine	13	127	25,7
Caesium	61	132,9	71
Platinum	0,21	195	9,1
Gold	0,47	197	10,2
Mercury	3,79	200	14,8
Thallium	2,1	204	17,2
Lead	2,2	207	18,2
Bismuth	2,8	208	21,2

in each case 1.3 per cent. In comparing these results it must be borne in mind that all depend upon the still somewhat uncertain compressibility of mercury, and that any change in this latter value would affect each other value by the same actual amount (not the same percentage amount). No change of the value for mercury could affect the sequence in the order of magnitude of the results, which for the present purpose is the really essential matter. There are given also the atomic weights and the atomic volumes of these various substances.

Evidently, compressibility is a property as definitely periodic as any other property of the elements. This is clearly demonstrated by the diagram appended, which shows the relation between the atomic weight and the compressibility of the elements, plotted in the same manner as the well-known atomic volume curve of Lothar Meyer.

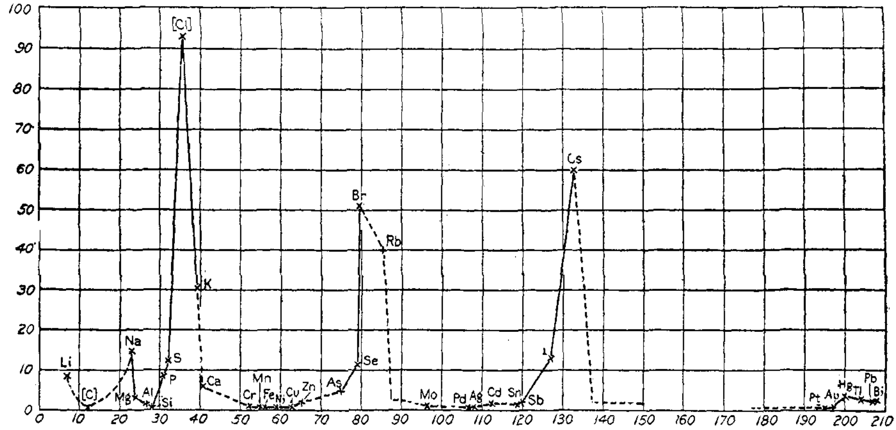

Fig. 1.—Atomic weight-compressibility curve.

Upon comparing the individual data concerning the compressibilities and atomic volumes, it is seen that in many cases these are more or less parallel properties. This parallelism, however, seems to hold, even approximately, only between similar elements. The comparison of magnesium, calcium, zinc, cadmium, and mercury gives the compressibilities and the atomic volumes in parallel sequence, as in the case of the alkali metals. Tin and lead bear a similar relation to each other; but with the less compressible elements possessing very high boiling points, this parallelism seems to cease, and on comparing elements of different character, the relation completely fails.

Often the coefficients of expansion are seen likewise to be parallel with the values of the compressibilities, especially in those cases where the atomic volumes are nearly identical. Evidently, however, the relationship between these quantities is not that demanded by the empirical rule of Dupré:

$$\beta' = \frac{\beta\alpha'\Delta^2T'}{\alpha\Delta'^2T}.$$

For example, according to Dupré's rule, sulphur should be ten times as compressible as selenium; but they are, as a matter of fact, almost alike. It is not necessary, however, to go as far afield as this to discover the uncertainty of Dupré's rule. The single case of water, having at 1° and 100° the coefficient of expansion of —0.000006 and +0.00077 respectively, and the compressibilities of 0.000051 and 0.000048 respectively, would prove that it is not infallible—although it takes cognizance of causes which undoubtedly affect compressibility. No surprise need be excited by this lack of parallelism, for compression always tends towards producing a smaller volume in a system, while warming does not necessarily tend to produce a greater volume. In every case it will be observed that volatility, which may be ascribed to lack of cohesive tendency, seems to be associated with increased compressibility, other things being nearly equal. This is seen most strikingly on comparing the compressibility of chlorine, bromine, and iodine, but it is manifest also in other cases; for example, in the cases of arsenic and antimony, or sulphur and selenium. This effect of decreasing the cohesive tendency is entirely in accord with principles which were laid down in the recent communications from this laboratory concerning the significance of changing atomic volume.[1] It is reasonable to suppose that substances already much compressed by their own great internal pressure would not be sensitive to outside pressure. Further consideration of these relationships will be taken up in the following paper.

In conclusion, it is a pleasure to acknowledge the generous support of the Carnegie Institution of Washington which alone has made this and the following investigation possible.

THE COMPRESSIBILITIES OF THE CHLORIDES, BROMIDES, AND IODIDES OF SODIUM, POTASSIUM, SILVER AND THALLIUM.

BY THEODORE WILLIAM RICHARDS AND GRINNELL JONES.

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Table of Contents.

Introduction.

In a recent series of papers on the significance of changing atomic volume it has been pointed out that the volumes of both solids and liquids are probably in part dependent upon both the chemical and the cohesive

[1] Richards, *Loc. cit.*