Mathematiker *Poisson* hat aus den Versuchen über die linearen Ausziehungen oder Zusammendrückungen der Körper eine Formel für die kubische Zusammendrückung abgeleitet, durch die man Gröszen bekommt, welche in gewissen Fällen 20 bis 30 Mal gröszer sind, als die aus *Oersted's* Versuchen hervorgehenden. Diesz streitet indesz nicht gegen die Mathematik, sondern zeigt nur, dasz die Voraussetzungen über die innere Beschaffenheit der Körper, von denen der geehrte französische Chemiker ausging, nicht vollkommen richtig seyn können.

Bei diesen neusten Versuchen gebrauchte *Oersted* ein verbessertes Verfahren zur Messung des Luftvolums, welches als Kraftmesser angewandt wird. Die Vorrichtung besteht in einer oben verschlossenen Glasröhre, die in einer gewissen Entfernung von dem geschlossenen Ende in eine engere Röhre ausgezogen ist, und deren offenes Ende eine enge Röhre mit Maaszstab hat. Der verengte Theil hat ein Zeichen, bis wohin jedesmal die zusammengedrückte Luft reichen soll. Diesz giebt den Beobachtungen eine gröszere Genauigkeit als mit einer überall gleich weiten Röhre; die untere Röhre mit dem Maaszstabe zeigt jede Wärmeveränderung und jeden möglichen Luftverlust an.

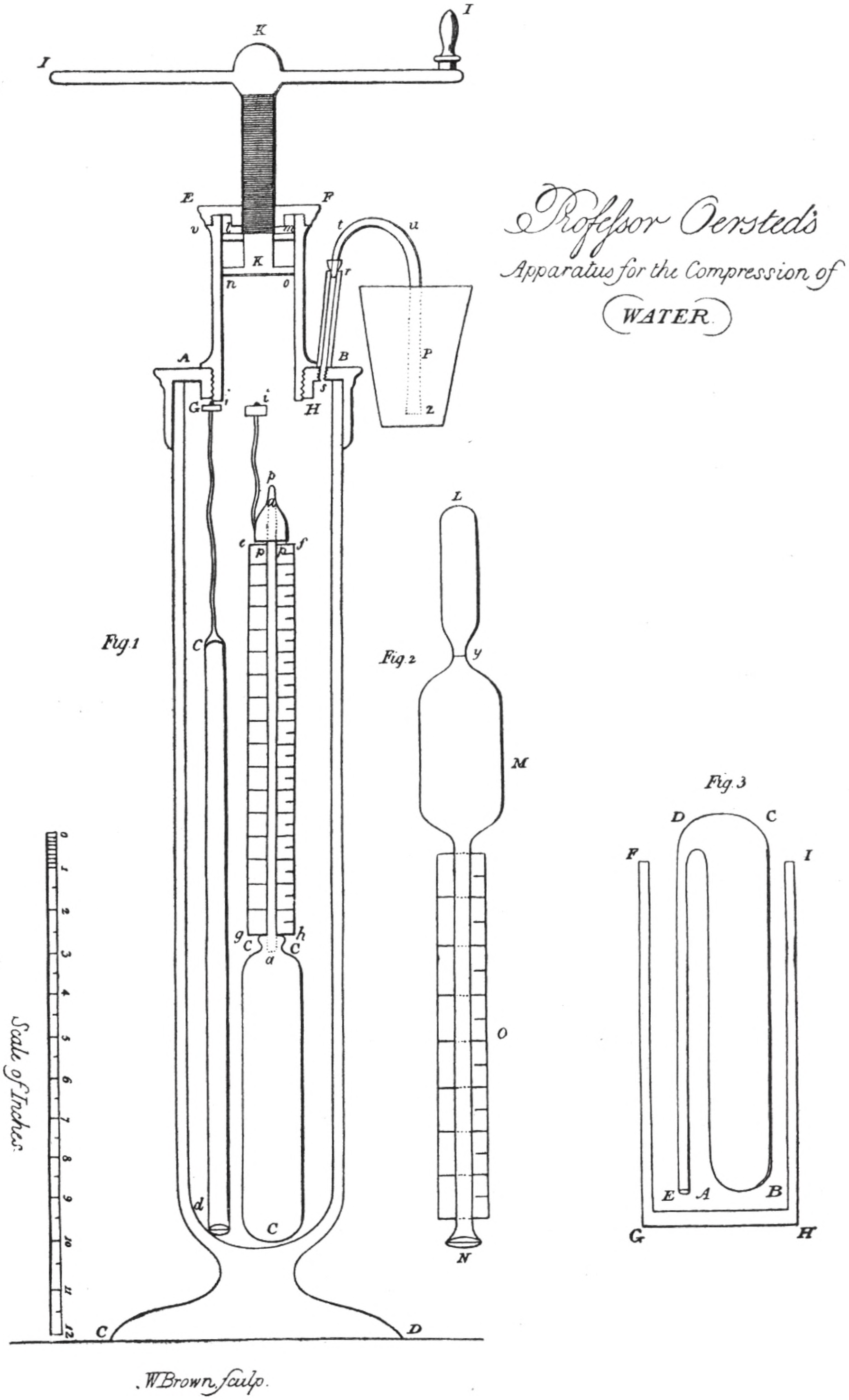
ON THE COMPRESSIBILITY OF WATER

BY PROFESSOR ŒRSTED

(FROM A LETTER TO THE REV. WILLIAM WHEWELL, DATED COPENHAGEN, JUNE 18, 1833)

(REPORT OF THE THIRD MEETING OF THE BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE; HELD AT CAMBRIDGE IN 1833. P. 353—60 LONDON 1834)

»Were I not withheld by official duties, I should certainly not omit so excellent an opportunity of renewing the very interesting and useful acquaintance I made during my last visit to England and Scotland, and of forming new ones with those distinguished scientific characters that I was not fortunate enough to meet with at that time, or such as have risen to eminence of late years. But though I must now forgo this advantage, I will not let


Professor Oersted's
Apparatus for the Compression of
WATER.
Fig. 1
Fig. 2
Fig. 3
Scale of Inches.
W. Brown sculp.

this opportunity pass without giving the illustrious assembly some mark of my high esteem, and of my desire to keep up the friendly intercourse which I have maintained with the British philosophers since my acquaintance with your happy country.

»You are, perhaps, aware that I have published several notices upon the compressibility of water, the first as early as 1818, and the first description of the improved method in 1822. Since that time I have still gone on improving my methods, and am now preparing a paper on the subject for the *Transactions of the Royal Society of Sciences at Copenhagen.* I will endeavour to give you a succinct account of my method and its results. It has been found that the apparatus for compressing water, a description of which I published in 1822, can give very accurate results; so that the results it has given in the hands of philosophers in different countries, have agreed more than might have been expected. Next to the accuracy of the measurements, however, one of the most important requisites of such an apparatus is, that the experiments be performed with the greatest celerity possible. When the experiment is protracted, the change of temperature produces great variations in the volume of the water, $^{1}/_{100}$ of the thermical measure (1^{0} centigrade)[1] causing at high temperatures the volume of the water to vary more than the pressure of 3, 4, or even 5 atmospheres.

»The improved apparatus is represented in the diagram fig. 1. Its principal parts are the same as in the earlier; in each of them, however, some change is introduced. *ABCD* is a strong glass cylinder, having at the top a cylinder *EFGH*, containing a piston *lmno,* moved by a screw *KK*, as in the first apparatus; but the handle *II* is now arranged in such a manner that the screw can be turned without interruption; by this means the effect is accelerated, and subitaneous strokes avoided. The bottle *ccc*, with its capillary tube *aa,* is different from the earlier only so far, that the tube is not soldered to the bottle, but merely adjusted by grinding. This alteration is not necessary except when solid bodies are to be compressed. The scale *efgh* is divided into parts of $^{1}/_{40}$ inch. In order

[1] The unit of thermical measurement is the distance between the freezing and the boiling point. I think that the most natural expression for the temperatures would be this unit and its fractions. Thus, the temperature 0·50 would be the same as 50^{0} centigrade, 19·30 the same as 1930^{0} centigrade. I will mark this metrical measure by Th. If this innovation should not please, I wish that it might be suppressed, and centigrade degrees put in the place, which is an easy change.

to exclude the water with which the large cylinder is filled, from communication with that of the bottle, the top of the tube *aa* is covered with a small diving-bell, or rather diving-cap, *ppp*, whose conical shape has the advantage of preventing the water from reaching the top of the tube *aa,* even when the air is compressed to a tenth or twelfth part of its first volume. Its margin is loaded with a ring of lead or brass. *cd* is a glass tube with proper divisions, containing air, whose compression measures the pressure; its inferior part is loaded with some lead or a ring of brass. *tuz* is a siphon; *P,* a vessel containing water; *ii* are two buoys of cork for lifting up the bottle and the glass tube *cd; sr* is a tube of brass, which can be stopped by a screw. In the beginning and at the conclusion of the experiment it serves to introduce water into the space *EFGH,* or to get it out again. Before the experiments the calibre of the two tubes must be exactly ascertained, and the relative capacities of the bottle and its capillary tube determined by the quantities of mercury they can admit. I have had some tubes in which $^1/_{40}$ of an inch (making one division) held only 2 millionths of the capacity of the bottle, in others they have held more, in some even as much as 7 millionths. The capacity of the bottle was not less than $1^1/_2$ pound, often 2 pounds of mercury. It is next filled with water, which must be boiled in the bottle in order to expel the air, which might be suspected of having a great influence in these experiments, though *Canton* has already observed that this is not the case. When the large cylinder is filled with water, the bottle is to be immersed in it. If the tube *aa* is full of water, a little of it must be expelled, which can be done by heating it gently with the hand, or better, by introducing a wire into it. As the bottle may be considered as a water thermometer, it is easy to ascertain whether it is in thermical equilibrium with the water in the cylinder. The air in the tube *cd* must likewise be brought to the same temperature with the water, before it is ultimately immersed. When the pumping cylinder shall be placed in its box, the piston must be at *GH.* If the large cylinder is full of water, part of it will be expelled through the siphon *tuz.* Now the piston is to be lifted up by means of the screw, whereby the pumping cylinder is filled with water. When this is done, the siphon is taken away, and the tube *rs* is stopped by a screw appertaining to it. The experiment is most conveniently performed by three persons; one turning the screw, the second observing the height of the water in the tube *aa,* and the third observing the volume of the air in the tube *cd:* the last writes down the numbers observed. Now, the point where the water stands in the tube of the bottle is to be noted. The descending piston having reduced the volume of the air in the tube *cd* to the point desired, the observer of it takes hold of the handle of the screw, and keeps the volume unchanged until the other observer has settled the point to which the water is brought down, and writes down the observation. When the piston is lifted up to its first place, the screw at *r* is to be opened, and the state of the water in the capillary tube again noted down. I commonly make ten or more such observations, one after another, which is performed in less than ten minutes when the operators are accustomed to work together. An example will illustrate the use of the observations.

HEIGHT OF THE WATER IN THE CAPILLARY TUBE

Before the pressure.	Mean.	When the pressure has ceased.	Length of descent in the capillary tube.	Point to which the pressure has driven the water down.
248·9	248·95	249·0	50·35	198·6
249·0	249·2	249·4	50·20	199·0
249·4	249·7	250·0	49·90	199·8
250·0	250·5	251·0	50·10	200·4
251·0	251·5	252·0	49·90	201·6
252·0	252·65	253·3	49·85	202·8
253·3	254·1	254·9	49·90	204·2
254·9	255·5	256·1	49·70	205·8
256·1	256·95	257·8	49·95	207·0
257·8	258·4	259·0	49·80	208·6
259·0	259·5	260·0	49·70	209·8
Mean of descents = 49·96.				

»The height of the mercury in the barometer, reduced to the freezing point, was at the same time 332·36 French lines. The volume of the air was in each experiment reduced to 5·264, or the pressure added to that of the atmosphere was 4·264 atmospheres. The pressure reduced to lines of mercury is thus, $332·36 \times 4·264 = 1417·18$; yet this reduction was not produced by the united pressure of the atmosphere and the piston alone, but was aided by a pressure of 40 lines of water, whose effect is equal to that of 2·94 lines of mercury, which is to be deducted, leaving then a pressure of 1414·24. Now, when a pressure of 1414·24 produces a descent of 49·96 parts, a pressure of 336 must produce a descent of nearly 11·87 parts. Each part makes in the instrument here employed 3·497 millionths of the whole capacity. $11{\cdot}87 \times 3{\cdot}497$ gives ultimately 41·51. The temperature of the water was at the beginning 0·20 Th., at the end 0·2025 Th., by the thermometer. The water stood 10·1 parts, about 35 millionths, higher at the end of the experiments than at the beginning. This gives 0·202 Th., which is as perfect an agreement as could be desired, the difference being only 0·0005 of the thermical measure, or 0·09 degree of the scale of Fahrenheit. During the last three months I have not made use of the tube *cd* for measuring the compression of air, but I have employed a glass tube *LMN* (fig. 2.), whose shape is better seen in the diagram than it can be described. The capacity of the part above the line *y*, and that of the whole, are measured by weights of mercury. When the instrument is sunk in the water, the liquid mounts in the tube which has the scale *O*, whose parts are likewise measured by mercury. This has the double advantage of giving a more accurate measure, and of showing whether or not the volume of air has changed. In the series of experiments above mentioned this measure has been employed. By a considerable number of experiments, I have found that the compressibility of water is not so great in high temperatures as in lower. *Canton* had already obtained this result, but some doubts might remain, because his experiments were made by means much more troublesome to make use of, and at a time when all instruments were less perfect. Here, as well as in the whole research into the compressibility of water, the new experiments prove the great skill and acute judgement of this distinguished philosopher. My experiments are much more numerous than his, and have been extended to a greater range of temperatures. Their results[1] may be expressed by supposing that the pressure of one atmosphere equivalent to 336 French lines' height of mercury develops a heat 0·00025 Th. = 0·045^0 Fahr. In calculating this I have made use of the tables of Professor *Stampfer* at Vienna, who finds the highest contraction of water at 0·0375 Th., or 38·75^0 Fahr. At this point the recession of water by the pres-

[1] [The following results are briefly summed up in a letter from *Ørsted* to *Chevreul* read in the Academie des sciences $^{22}/_{6}$ 1833 and printed in: Revue encyclop. Tome 59. P. 287. Paris 1833.

sure of one atmosphere is 46·77 millionths. At 0·08125 Th.[1] the volume of the water augments 71·75 millionths, having its temperature augmented 0·01 Th. The heat developed by the pressure thus augments its volume $0·00025 \cdot \frac{71·75}{0·01} = 1·79$ millionth, or the recession is $46·77 - 1·79 = 44·98$ millionths. Actual experiments have given it 44·89, or 0·09 millionth greater. The coincidence is often less perfect. At 0·1775 Th. the quantity calculated is 42·65, the

[1] PART OF STAMPFER'S TABLE

Temperatures according to the centigrade thermometer.	Volumes of the water.	Differences.
— 3	1·000373	104
2	1·000269	87
1	1·000182	69
0	1·000113	52
+ 1	1·000061	36
2	1·000025	20
3	1·000005	5
3·75	1·000000	1
4	1·000001	11
5	1·000012	26
6	1·000038	41
7	1·000079	56
8	1·000135	70
9	1·000205	84
10	1·000289	98
11	1·000387	110
12	1·000497	123
13	1·000620	137
14	1·000757	149
15	1·000906	160
16	1·001066	173
17	1·001239	183
18	1·001422	195
19	1·001617	205
20	1·001822	217
21	1·002039	226
22	1·002265	237
23	1·002502	247
24	1·002749	256
25	1·003005	266
26	1·003271	274
27	1·003545	283
28	1·003828	291
29	1·004119	299
30	1·004418	

quantity given by experiment 43·03, a difference of 0·38 millionth. The experiment mentioned above gave a recession = 41·51 at 0·20125 Th. (mean of the temperatures of the beginning and end of the series). The calculation gives 41·63, or a difference of 0·12 millionth. At [–] 0·005 Th. the change of volume produced by one 0·01 is 60·5 millionths, but inversely, as the water at low temperature loses in volume by augmented heat; thus an addition is to be made equal to $\frac{60·5}{0·01} \cdot 0·00025 = 1·5$. Now $46·77 + 1·5$ gives 48·27, experiment 48·02. At 0·019 the quantity calculated is 47·72, that given by experiment 47·97. I have not yet finished the tedious discussion of all the experiments, but as far as I have proceeded the agreement of the hypothesis with facts is satisfactory. Messrs. *Colladon* and *Sturm* have in the calculation of their experiments introduced a correction founded upon the supposition that the glass of the bottle in which the water is compressed should suffer a compression so great as to have an influence upon the results. Their supposition is, that the diminution of volume produced by a pressure on all sides can be calculated by the change of length which takes place in a rod during longitudinal traction or pression. Thus, a rod of glass, lengthened by a traction equal to the weight of the atmosphere as much as 1·1 millionth, should by an equal pression on all sides lose 3·3 millionths, or, according to a calculation by the illustrious *Poisson*, 1·65 millionth. As the mathematical calculation here is founded upon physical suppositions, it is not only allowable, but necessary, to try its results by experiment. Were the hypothesis of this calculation just, the result would be, that most of the solids were more compressible than mercury. For this purpose I have procured cylinders of glass, of lead, and of tin, which filled the greater part of a cylinder, to which a stopple of glass, perforated by a capillary tube, was adjusted by grinding. I have not yet exactly discussed all the experiments on this subject, but the numbers obtained are such as to show that the results are widely different from those calculated after the supposition above mentioned. The quantity assigned by this calculation to the glass is very small indeed, yet the experiment gives it much less. Lead, which extends, according to *Tredgold*, 20·45 millionths by a weight equal to that of the atmosphere, and thus much more by the pressure on all sides, does not change one millionth. Tin is not more compressible. The inverse experiment is, perhaps, still more striking. I published it some years ago: however, as I have now repeated these experiments, and as they appear hitherto not to have satisfied philosophers, I shall here mention, that in all my experiments upon the subject, I have invariably found that the recession of the water in the capillary tube is about 1·5 millionth greater in bottles of lead or tin than in in those of glass. Supposing the compressibility of the solid bodies to be so small that it cannot be observed in those experiments, yet the heat developed by the compression, feeble as it is, produces a small augmentation of the recession of the water in the capillary tube. If the dilatation of a rod of glass by 1 Th. is 0·0009, its cubical dilatation is 0·0027, and the dilatation by an increase of 0·00025 is 0·000000675, or nearly 7 ten millionths. The dilatation of lead is about 3 times greater, and the bottle containing it must get an increase of 0·00000225, which exceeds the former by more than 1·5 millionth. The dilatation of tin should give only one millionth more than glass, but it seems to give a little more, yet the quantity is not great. After all this, I think that the true compressibility of water is about 46·1 millionths, and that the apparent compressibility depends upon the effect of the heat developed by the compression, by which the liquid and the bottle are dilated.

»My continued experiments have confirmed my earlier result, that the differences of volume in the compressed water are proportionate to the compressing power. I do not know if the method I have made use of to try the effects of high compression has been published in England. These experiments cannot be made in a cylinder of glass; one of metal is required. As, in this case, the opacity prevents direct observations being made, an index, nearly like that in *Six's* register-thermometer, is placed in the capillary tube of the bottle. This tube is dilated a little at the top, so as to form a minute funnel. Some drops of mercury are poured into it, which being pressed, pushes the index forward; thus the recession may be seen when the bottle is taken out of the large cylinder. The compression of the air is measured in another way: a bent tube, of the form shown in fig. 3, is fixed in a glass vessel *FGHI* containing mercury, and exposed to the pressure together with the bottle. The pressure of the piston upon the water in the cylinder is communicated to the mercury, and pushes it into the wide part of the tube, as far as the resistance of the air will permit. The weight of the mercury driven into the wide part *ABCD,* together with that which has filled *DE*, and which may be computed, compared with the weight of mercury which the whole tube can admit, gives the volume of the air compressed. By this kind of experiment I have found that the decrease of volume produced by pressure preserves the same proportion to the pressing power as far as the pressure of 65 atmospheres, and probably much further; but how far, I have not hitherto been able to try, my apparatus not having resisted a greater pressure.

»I have thus given you a short abstract of my researches into the compressibility of water. They may be considered as a continuation of those of *Canton.* I should feel much flattered if they should obtain the approbation of the philosophers of the country where the first good experiments upon the subject have been made.«

UEBER EIN NEUES ELEKTROMETER

VON J. C. OERSTED

(ANNALEN DER PHYSIK UND CHEMIE. HERAUSGEGEBEN ZU BERLIN VON J. C. POGGENDORFF. BD. 53. P. 612—13. LEIPZIG, 1841)[1]

Diesz Instrument, welches der K. Gesellschaft der Wissenschaften zu Kopenhagen vorgezeigt wurde, sieht man in Fig. 1 in halber Grösze abgebildet.

aa ist ein dünner ausgeglühter Messingdraht, der den Zeiger ausmacht; *bbb* ein Bügel von sehr dünnem Eisendraht, der einen äuszerst schwachen Magnetismus haben musz, *cccccc* ist eine Messingröhre, welche sich in einem Bügel endet; *ee* ein Stift, um den das eine Ende eines Coconfadens gewunden ist; dieser Faden trägt den Zeiger.

dddd ist eine Glasröhre, worin die Messingröhre, die sich in einem Bügel endigt, mit Gummilack eingekittet ist. Man läszt den

[1] [Man findet dasselbe Thema in: Forhandlinger ved de skandinaviske Naturforskeres første Møde i Kjøbenhavn 1840. P. 213. Kjøbenhavn 1841. — Det kgl. danske Videnskabernes Selskabs Oversigter. 1840. P. 24. Kjøbenhavn. Sämtliche Aufsätze der »Oversigter« finden sich zu Ende dieses Bandes.]