INSTITUTE OF MARINE ENGINEERS.

SESSION 1892-93.

FORTY-FIRST PAPER

(OF TRANSACTIONS).

THE EXPANSION OF WATER BY HEAT.

BY

MR. G. W. BUCKWELL

(MEMBER).

Read at 58, Romford Road, Stratford, E., on Monday, December 12th.

PREFACE.

58, Romford Road,

Stratford,

December 12th, 1892.

A meeting of the Institute of Marine Engineers was held here this evening, presided over by Mr. J. A. Rowe, when a Paper entitled "The Expansion of Water by Heat," by Mr. G. W. Buckwell (Member), was read by the Honorary Secretary, in the absence of the Author.

A brief discussion ensued after the reading of the Paper; further discussion of the subject was postponed.

Another Paper, contributed by Mr. Joseph Williams (Member)—which had been previously read by the Author in the University College, Cardiff—was also read; the discussion being likewise postponed.

JAS. ADAMSON,

Honorary Secretary.

THE EXPANSION OF WATER BY HEAT.

BY

MR. G. W. BUCKWELL

(MEMBER).

Read at 58, Romford Road, Stratford, Essex, on Monday, December 12th, 1892.

We have heard so much during the last few years of false water level, and the unreliability of water gauges, that in thinking the matter over, the idea occurred to me that possibly the scare might be caused by the high pressure at which our modern marine boilers work, rather than by any inherent defects in the water gauges themselves.

But little is known of the expansion of water above boiling point (212°), but I think that if the subject be considered theoretically, taking as a basis our experimental knowledge as far as it goes, some conception can be formed of its expansion above 212° Fahr., when taking place in a closed vessel, such as a boiler, and in contact with, and under the pressure of, the steam produced from it.

Water has been proved by the experiments of Grassi to contract only ·00005 of its volume under a pressure of one atmosphere. I maintain, as a consequence, that water being thus practically incompressible, its expansion by heat may be considered to take place in a steam boiler under the same conditions, and to the same extent under high steam pressures, as it would do if it could take place under the ordinary atmospheric pressure; but even supposing that we allow that this compression of ·00005 per atmosphere takes place, and that it varies directly as the pressure, the compression under a pressure of 180lbs. would be only ·0006, while the expansion due to the heat would be, as I hope to show further on, ·1426 of its volume at 39° Fahr., so that its compression would be a mere detail compared with its expansion. Even at a pressure of 1,000lbs. per square inch, corresponding to a temperature of about 546° Fahr., the compression would be only ·0033, very small compared with the expansion, say ·286 of its volume.

In Porter's work on the "Indicator," the author gives a table, which I reproduce; in this he corrects the expansion as given by Kopp, in order that the difference of expansion for each 5° Cent. may fall into a regular series of ordinates to a curve, which he concludes should, if continued, express the expansion at a higher temperature. The table is as follows. I have, however, altered the temperature to Fahr. instead of Cent.

TABLE I.

TEMP. FAHR. Deg.	VOLUMES KOPP.	CORRECTED VOLUMES.	1st DIFFER·NCE	2nd DIFFER'NCE
39	1·00000	1·00000		
41	1·00001	1·00001		
50	1·00025	1·00025	24	
59	1·00082	1·00083	58	34
68	1·00169	1·00171	88	30
77	1·00284	1·00286	115	27
86	1·00423	1·00425	139	24
95	1·00583	1·00586	161	22
104	1·00768	1·00767	181	20
113	1·00967	1·00967	200	19
122	1·01190	1·01186	219	19
131	1.01423	1·01423	237	18
140	1·01672	1·01678	255	18
149	1·01943	1·01951	273	18
158	1·02238	1·02241	290	17
167	1·02554	1·02548	307	17
176	1·02871	1·02872	324	17
185	1·03202	1·03213	341	17
194	1·03553	1·03570	357	16
203	1·03921	1·03943	373	16
212	1·04312	1·04332	389	16

The following table gives the expansion of water as determined by the three authorities named, with the mean of their results; but instead of expressing the temperature according to Cent., I have expressed it in degrees Fahr.:—

TABLE II.

TEMP. FAHR.	VOLUMES.			
Deg.	KOPP.	DESPRETZ.	VOLKMANN.	MEAN.
32	1·00013	1·00013	1·00012	1·00013
39	1·00000	1·00000	1·00000	1·00000
41	1·00001	1·000008	1·00001	1·000009
50	1·00025	1·00027	1·00026	1·00026
59	1·00082	1·00088	1·00085	1·00085
68	1·00169	1·00179	1·00173	1·00174
77	1·00284	1·00293	1·00287	1·00288
86	1·00423	1·00433	1·00425	1·00427
95	1·00583	1·00593	———	1·00588
104	1·00768	1·00773	1·00770	1.00770
113	1·00967	1·00985	———	1·00976
122	1·01190	1·01205	1·01197	1·01197
131	1·01423	1·01445	———	1·01434
140	1·01672	1·01698	1·01694	1·01688
149	1·01943	1·01967	———	1·01955
158	1·02238	1·02255	1·02261	1·02251
167	1·02554	1·02562	———	1·02558
176	1.02871	1·02885	1·02891	1 02882
185	1·03202	1·03225	———	1·03214
194	1·03553	1·03566	1·03574	1·03564
203	1·03921	1·03925	———	1·03923
212	1·04312	1.04315	1·04323	1·04317

It will be seen that the different experimenters have made a fairly considerable difference in their results.

With regard to the point at which water attains its maximum density, Münke and Stampfer made it 38·8°, Blagdon 39°, Hope and Rumford 40°, Hallström 39·4°, and Despretz —who examined the question with great care—made it 39·19°. Accordingly, the temperature is now universally accepted as 39·2° Fahr.; but as the determination varied with the different experimenters, it gives us a little latitude in the matter, and I think, for the purposes of calculation, we shall not err much, if we consider the point of maximum density to be 39° Fahr.

Dr. Matthiessen gave these two formulae to express the expansion of water between 4° and 32° Cent., and 30° and 100° Cent. respectively; but they are far too complicated for universal ordinary practice :—

$$(1)\ Vt = 1 - \cdot 00000253\,(t-4) + \cdot 0000008389\,(t-4)^2 + 00000007173\,(t-4)^3$$

$$(2)\ Vt = \cdot 999695 + \cdot 0000054723\ t^2 + \cdot 00000001126\ t^3$$

It may be mentioned that Ganot gives the volumes of water at boiling point thus:—

Distilled Water ...	...	...	1·0466
Saturated with Salt	...	...	1·05

Mr. Traill gives a formula, which shows results near enough for ordinary requirements, and has the advantage of being easy of manipulation if the ·2 be dropped :—

$$\text{Vol.} = 1 + \frac{(T - 39{\cdot}2)^2}{711\,(679 + T)}$$

T being the temperature in degrees Fahr.

Professor Rankine's formula for density of water takes the following form for volume :—

$$V = \frac{(T + 461)^2 + 500^2}{2 \times 500 \times (T + 461)}$$

Following out the line of reasoning suggested by Porter, I have constructed the following table, making a slight change in the figures for 41° Fahr.

TABLE III.

TEMPERATURE.		EXPANSION.	1st DIFFERENCE.	2nd DIFFERENCE.
FAHR. Deg.	ABOVE 39° Deg.			
41	2	·000008		
50	11	·00025	25	33
59	20	·00083	58	30
68	29	·00171	88	27
77	38	·00286	115	24
86	47	·00425	139	22
95	56	·00586	161	20
104	65	·00767	181	19
113	74	·00967	200	19
122	83	·01186	219	18
131	92	·01423	237	18
140	101	·01678	255	18
149	110	·01951	273	17
158	119	·02241	290	17
167	128	·02548	307	17
176	137	·02872	324	17
185	146	·03213	341	16
194	155	·03570	357	16
203	164	·03943	373	16
212	173	·04332	389	16
221	182	·04737	405	16
230	191	·05158	421	15
239	200	·05594	436	15
248	209	·06045	451	15
257	218	·06511	466	15
266	227	·06992	481	15
275	236	·07488	496	15
284	245	·07999	511	14
293	254	·08524	525	14
302	263	·09063	539	14
311	272	·09616	553	14
320	281	·10183	567	14
329	290	·10764	581	14
338	299	·11359	595	14
347	308	·11968	609	13
356	317	·12590	622	13
365	326	·13225	635	13
374	335	·13873	648	13
383	344	·14534	661	13
392	353	·15208	674	13
401	362	·15895	687	13

TABLE III. (CONTINUED).

TEMPERATURE.		EXPANSION.	1st DIFFERENCE.	2nd DIFFERENCE.
FAHR. Deg.	ABOVE 39° Deg.			
410	371	·16595	700	13
419	380	·17308	713	13
428	389	·18033	725	12
437	398	·18770	737	12
446	407	·19519	749	12
455	416	·20280	761	12
464	425	·21053	773	12
473	434	·21838	785	12
482	443	·22635	797	12
491	452	·23444	809	12
500	461	·24265	821	12

It will be seen that the second difference is a decreasing quantity, and at some high temperatures the volume of water will be a maximum, and at still higher temperatures the volume should decrease until it eventually comes back to 1, as at the temperature of 39° Fahr. This statement that water at some high temperature (possibly between 7000° and 8000° Fahr.), if it could remain as water at that temperature, should only occupy the same volume as at 39° Fahr., may be rather startling, but is it not just as startling to know that below 39° it expands on cooling, for which there is no physical reason, though we all know there is a Providential one? The temperature of maximum volume I make to be about 3900° Fahr.

As it is known that at some temperature above 1000° Cent., water decomposes into its constituent elements; might I suggest that this temperature will be about 2000° Fahr., when the first difference in the table has reached a maximum?

As marine engineers are accustomed to deal with pressures rather than with temperatures, the following table shows the volumes of water at gauge pressures from 0 to 300 lbs. The curves at the end of the Paper also show the changes graphically, and should be compared with the tables, more especially the curve of the second differences. For each of these curves there should be a corresponding formula, but I have not investigated that part of the subject.

TABLE IV.

GAUGE PRESSURE. Lbs.	TEMP.		VOLUME.
	FAHR. Deg.	ABOVE 39·2° Deg.	
0	212·0	172·8	1·04332
5	227·1	187·9	1·05021
10	239·4	200·2	1·05613
15	249·7	210·5	1·06130
20	258·7	219 5	1·06599
25	266·7	227·5	1·07029
30	273·9	234·7	1·07427
35	280·5	241·3	1·07800
40	286·6	247·4	1·08150
45	292·3	253·1	1·08483
50	297·5	258·3	1·08793
55	302·5	263·3	1·09093
60	307·2	268·0	1·09382
65	311·6	272·4	1·09656
70	315·8	276·6	1·09918
75	319·9	280·7	1·10177
80	323·8	284·6	1·10428
85	327·4	288·2	1·10683
90	331·0	291·8	1·10896
95	334·4	295·2	1·11121
100	337·7	298·5	1·11340
105	340·9	301·7	1·11555
110	343·9	304·7	1·11758
115	346·9	307·7	1·11962
120	349·8	310·6	1·12161
125	352·6	313·4	1·12355
130	355·4	316·2	1·12549
135	358·0	318·8	1·12731
140	360·6	321·4	1·12913
145	363·1	323·9	1·13091
150	365·6	326·4	1·13268
155	368·0	328·8	1·13441
160	370·4	331·2	1·13613
165	372·7	333·5	1·13779
170	374·9	335·7	1·13939
175	377·1	337·9	1·14100
180	379·3	340·1	1·14262
185	381·4	342·2	1·14416
190	383·5	344·3	1·14571
195	385·5	346·3	1·14717
200	387·5	348·3	1·14871

TABLE IV. (CONTINUED).

GAUGE PRESSURE. Lbs.	TEMP. FAHR. Deg.	TEMP. ABOVE 39·2° Deg.	VOLUME.
205	389·5	350·3	1·15020
210	391·5	352·3	1·15171
215	393·5	354·3	1·15322
220	395·4	356·2	1·15467
225	397·2	358·0	1·15605
230	399·0	359·8	1·15742
235	400·8	361·6	1·15880
240	402·5	363·3	1·16011
245	404·3	365·1	1·16151
250	405·9	366·7	1·16276
255	407·6	368·4	1·16408
260	409·3	370·1	1·16541
265	410·9	371·7	1·16666
270	412·5	373·3	1.16792
275	414·1	374·9	1·16919
280	415·7	376·5	1·17046
285	417·2	378·0	1·17165
290	418·7	379·5	1·17285
295	420·2	381·0	1·17404
300	421·6	382·4	1·17517

This comparatively great expansion of water at high temperatures and pressures opens up the subject of false water level.

Some years ago, one of the steamers trading between Liverpool and New Orleans had water gauges fitted to the boiler front, one being of the ordinary marine standard type, having pipe connections to the top and bottom of the boiler, and the other being of the locomotive pattern, with cocks screwed direct into the boiler front. The standard gauge glass always showed three to four inches less water than the locomotive glass. On blowing them through the locomotive glass returned to its former level, and the standard glass rose the three or four inches it had been deficient, afterwards gradually sinking to nearly its former level. This was puzzling at first, and both gauges were thoroughly overhauled to discover any defect that might exist, but none could be discovered. The matter was then explained by the expansion due to the heat of the water. The locomotive glass being directly connected to the boiler, the water contained in it would probably be nearly of the same temperature as the water in the boiler, whereas the water in the standard gauge, having a length of pipe to traverse, and this pipe being exposed to a stokehold temperature of perhaps not more than 120°, the water would rapidly lose its heat, and as a consequence, decrease in volume. I do not know the pressure at which the boiler worked, but assuming it to have been 80lbs., which gives the water in the boiler a temperature of 323·8°, while the water in the standard pipe might be only 212°, or even less (I have frequently taken hold of water gauge pipes without experiencing any discomfort due to the heat of them, showing that the temperature must have been low), and taking the height of the pipe from the boiler cock to the water level in the boiler to be 6ft., we arrive at the following result :—

Vol. of Water in Boiler (323·8°)	=	1·10428
Vol. of Water in Pipe (212°)	=	1·04332
Difference	=	·06096
Height of Water Level in inches	=	72
		12192
		42672
Difference of Level in inches	=	4·38912

There is no doubt that constantly blowing the glass through, will have a tendency to keep the water in the pipe nearer the temperature of the water inside the boiler, as it will not have time to properly cool down between each blow, and the water level in the glass would be nearer the truth, otherwise it stands to reason that it will be less than it should be. Fortunately this is to be on the safe side, and if an engineer loses sight of his water, he is likely to still have plenty in the boiler. No doubt it has often been noticed that when the water is just bobbing in the glass, blowing the glass through always has the effect of raising the level, but it gradually sinks back again, due to the cause above explained.

Some years ago I was on board a yacht which had put into port with her feed pump broken down, and had charge of the repairs. In course of conversation with the engineer, in reference to the boiler (which carried a pressure of 500lbs., and was of the water tube type), he informed me that he could not carry the water in the glass above the bottom nut ; if it got any higher the boiler was sure to prime, and he had to be content with seeing the water bob in and out of sight occasionally. It has struck me since that if he had blown his gauge glass through oftener, he would have had plenty of water, as, probably, it was well up inside the boiler, and that partly accounted for the tendency to prime.

Another point also crops up in this connection. If the water cools down due to the radiation of heat from the gauge pipe, should not the steam also cool down in a like ratio? But in that case the level of the water in the glass would rise far in excess of what it may contract by cooling. Thus, steam at 180lbs. pressure would need to cool only half of a degree Fahrenheit to reduce its pressure 1lb., when the water level would rise $27\frac{1}{2}$ inches at once, which would make our water gauges completely unreliable. Is it that steam is a far better conductor of heat than water, and that its cooling in the gauge pipe causes a flow of heat to be constantly kept up, and thus prevents too great a loss of heat?

We are accustomed to suppose that fluids transmit pressure equally in all directions in a closed vessel, but will this apply to a large steam boiler with a comparatively small pipe connection, the said boiler constantly receiving fresh increments of heat, and the said pipe as constantly radiating it away? Should we not rather treat the steam in the pipe as being in a dynamical instead of a statical condition, and account for its not losing its pressure on the assumption that there is this constant flow of heat?

We know that a valve through which steam is constantly passing, if placed too near the upper gauge cock on the boiler, has a tendency to raise the water level in the glass, and it is commonly explained on the assumption that there is a species of suction which takes place. Should it not rather be explained on the theory that it prevents the proper flow of heat to the steam in the gauge pipe, and thus prevents it being kept at its proper temperature and pressure?

This is a subject I think fully worthy of Experimental Research!

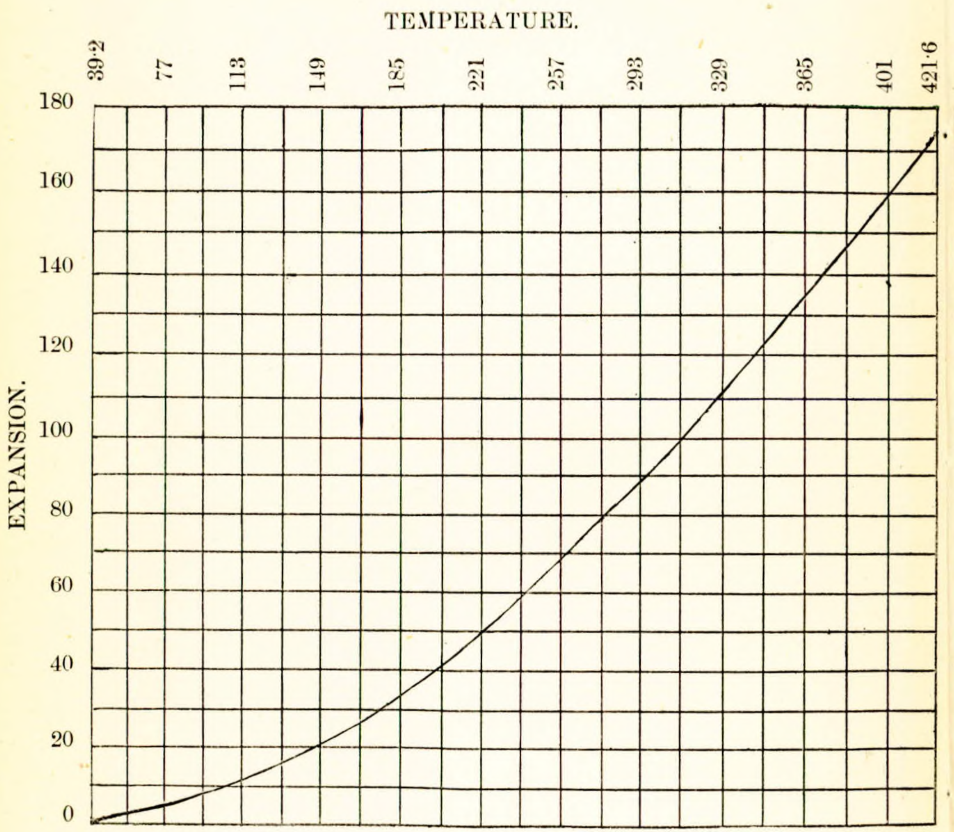


DIAGRAM I.

Expansion of Water from 39·2° Fahr. to 421·6° Fahr. in Thousandths of its Volume at 39·2° Fahr.

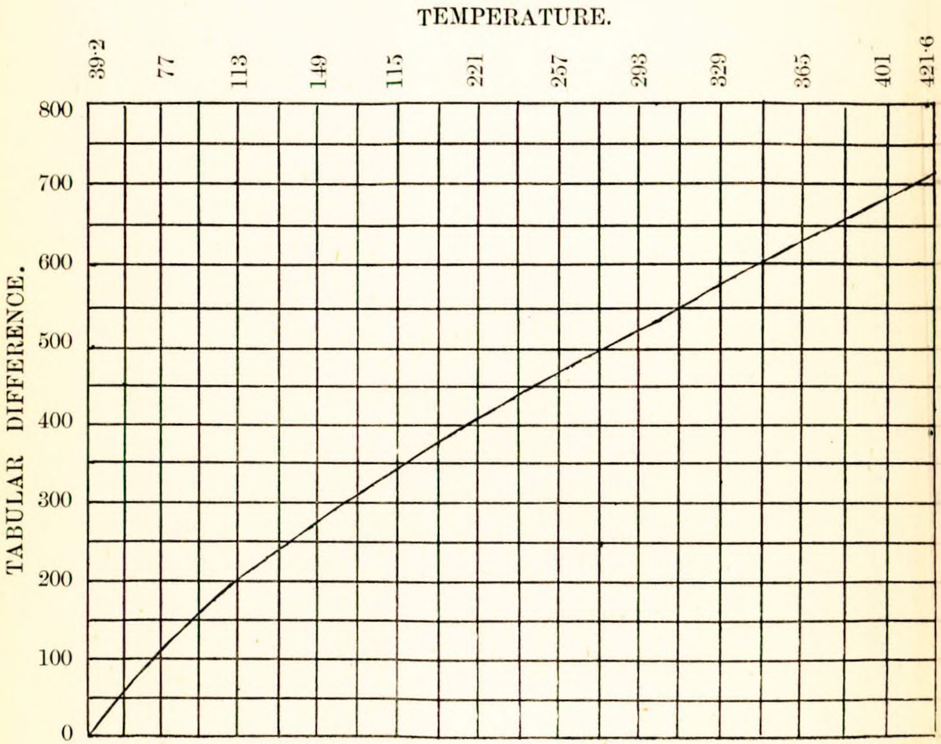


DIAGRAM II.

First Difference in Table III.

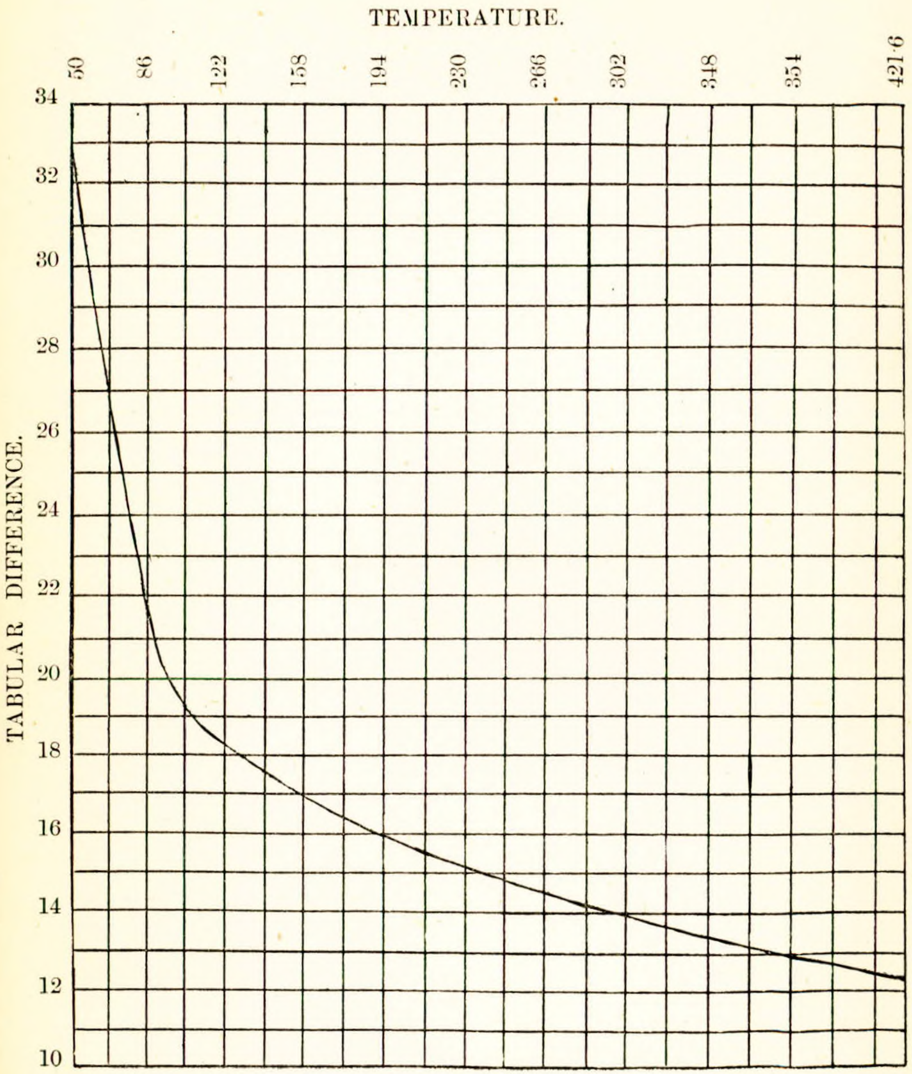


DIAGRAM III.

Second Difference in Table III.

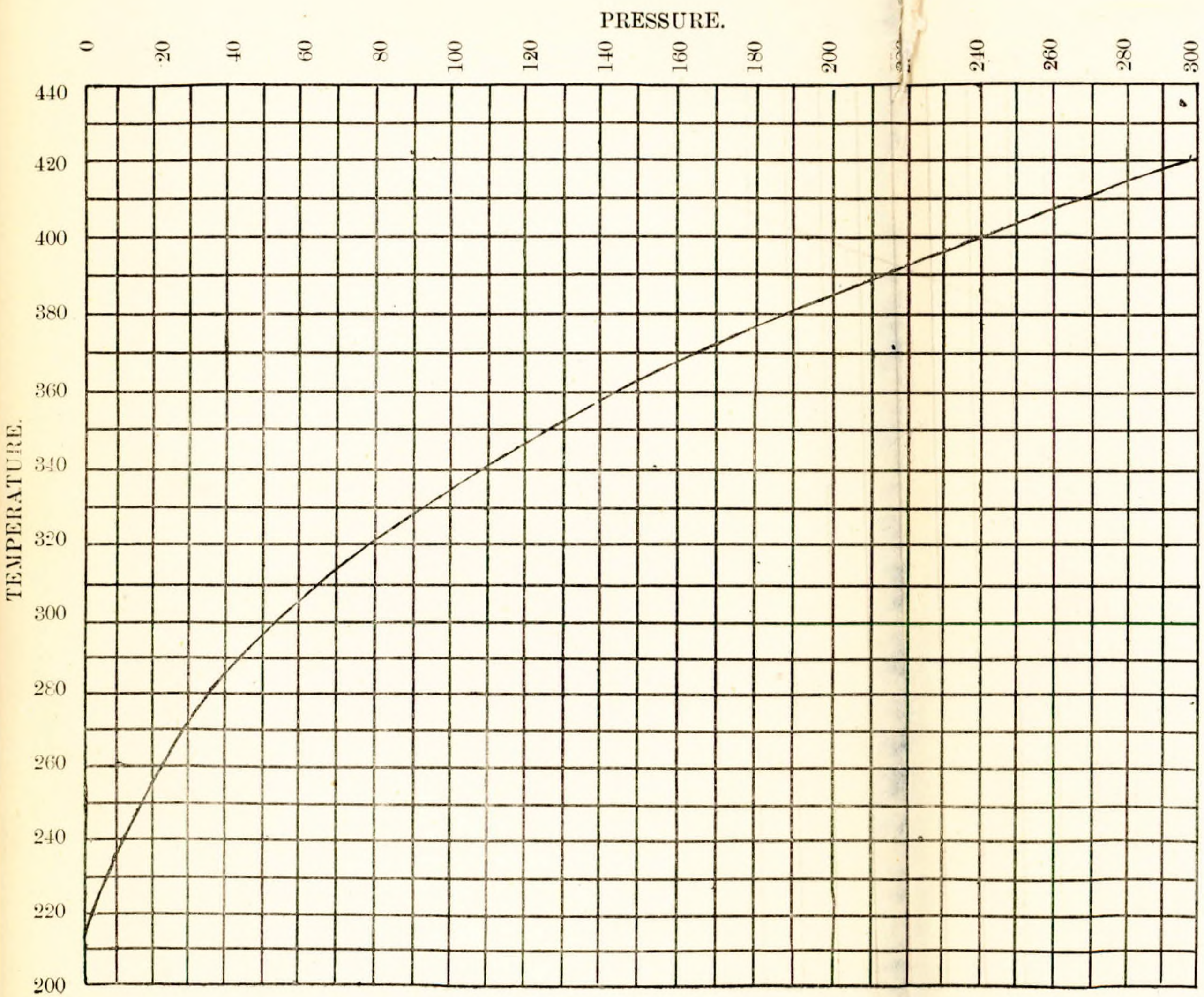


DIAGRAM IV.

Pressure and Temperature of Steam.

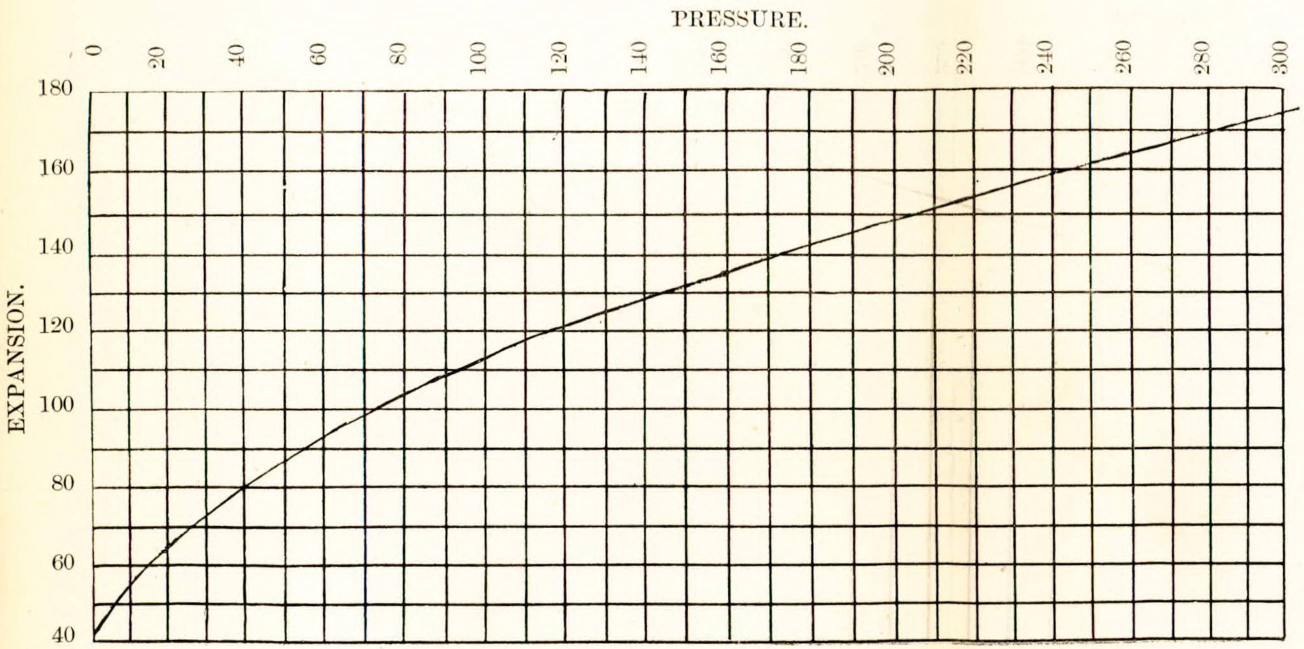


DIAGRAM V.

Pressure of Steam, and Expansion of Water in Thousandths of its Vol. at 39·2° Fahr.

INSTITUTE OF MARINE ENGINEERS.

(INCORPORATED.)

SESSION, *1892-3.*

PRESIDENT:

LORD KELVIN.

VOL. IV.

DISCUSSION

ON THE

FORTY-FIRST PAPER

(OF TRANSACTIONS),

ENTITLED

"THE EXPANSION OF WATER BY HEAT,"

BY

MR. G. W. BUCKWELL

(*MEMBER.*)

READ AT

58, ROMFORD ROAD, STRATFORD, E.,

ON MONDAY, 12TH DECEMBER, 1892.

PREFACE.

58, Romford Road,

Stratford, E.,

December 12th, 1892.

A Meeting of the Institute of Marine Engineers was held here this evening, when a paper on "The Expansion of Water by Heat," by Mr. G. W. Buckwell (Member), was read, in the absence of the Author, by the Honorary Secretary.

Mr. J. A. Rowe (Member) presided. The Paper has already been published ; the Discussion which ensued will be found in the following pages.

JAS. ADAMSON,

Honorary Secretary.

INSTITUTE OF MARINE ENGINEERS.

(INCORPORATED.)

SESSION, *1892-3.*

President:

LORD KELVIN.

DISCUSSION

ON THE PAPER ENTITLED

"The Expansion of Water by Heat,"

BY

MR. G. W. BUCKWELL.

(*Member.*)

Read at 58, ROMFORD ROAD, STRATFORD,

On Monday, 12th December, 1892.

THE CHAIRMAN.

Mr. J. A. ROWE (*Member.*)

I have now to invite discussion on the paper just read. Of course it is impossible to discuss it adequately this evening, but I think there are several interesting little points which must have occurred to some of those present during the reading of the paper, in regard to which the benefit of your views and experiences might be given.

Mr. F. W. SHOREY.

(Member of Council.)

There are some very important tables included in this paper, and doubtless Mr. Buckwell has been to great trouble in collecting these figures and working them from Centigrade to Fahrenheit. During the last few years we have heard much about the unreliability of water gauges, and at the beginning of this paper I thought we were going to have some information or explanation on that subject, but I fail to see what I expected. Towards the end of his paper Mr. Buckwell says he was on board a yacht which had a boiler carrying a pressure of 500 lbs. We all know that with pressures like that water will give a little trouble. Mr. Buckwell, alluding to this yacht boiler, then says: "The engineer informed me that he could not carry the water in the glass above the bottom nut; if it got any higher the boiler was sure to prime, and he had to be content with seeing the water bob in and out of sight occasionally." I dare say most of us have had that experience, but we did not consider that it was due to the cause to which Mr. Buckwell attributes it in this paper. We had great trouble with a boiler in which I was interested at one time, but we did not put it down to the cause assigned by Mr. Buckwell. We came to the conclusion that the steam space was too small, and if we opened out the engines the boiler commenced to prime. Very likely that was the cause in the case of the boiler referred to by Mr. Buckwell, although he puts it down to the difference of temperature. I have only just heard the paper read, but it strikes me that Mr. Buckwell is not right on that point: at any rate I differ from him. If boilers are made with plenty of steam space I do not think we shall have so much trouble with the water. With reference to water gauges, I think that engineers are often at fault in ordering the glasses too thick. They think a thick glass is necessary to stand the high pressure, but that is not so. We have had many glasses tested, and thick glasses are not necessary. Engineers have come to us for glasses of a particular thickness, but I have said to them—"Will you try these of half the thickness?" They have tried them and with satisfactory results. I must confess I am rather disappointed with this paper, as I thought we were going to have something which we have not got. I thought we were going to have some explanation of why the gauge glasses break, but we have had nothing of the kind.

Mr. GREER.

(*Member.*)

I question the grounds for Mr. Buckwell's dogmatic statement about it being "startling to know that below 39° Fahrenheit water expands on cooling, for which there is no physical reason, though we all know there is a providential one." I suppose the author refers to the fact that the ice floating on the surface of the water saves the lives of the fishermen. Then again, in another part of the paper, the author says, "If the water cools down due to the radiation of the heat from the gauge pipe, should not the steam also cool down in a like ratio?" I would reply that the steam does cool down also. Mr. Buckwell then goes on, "but in that case the level of the water in the glass would rise far in excess of what it may contract by cooling." I do not see that there are any grounds for that statement.

THE CHAIRMAN.

Mr. Greer has criticised the remark in the paper about there being a providential reason why water expands during the process of freezing. Doubtless, however, most of us know that this expansion of water during freezing is generally recognised by people who believe in a Deity as a peculiarly providential circumstance, and this should be understood by considering what would be the condition of things if water on freezing became heavier. Then water in becoming ice would fall like blocks of granite to the bottom of the ocean, with no hope of ever rising to the surface again. Ice would accumulate upon ice and gradually fill the entire ocean, because heat would not penetrate downward to any appreciable extent. The world would therefore rapidly become encrusted with ice and consequently uninhabitable. There is, however, at least one other article in nature (viz., bismuth) which possesses this singular property of expanding during the process of congealing or solidifying. In this connection it should be borne in mind that it is the act of freezing which bursts our water pipes. The common notion is that pipes burst when the thaw takes place—that, indeed, the *thaw* bursts the pipes. Engineers, however, ought to know that water pipes burst during the process of freezing. The thaw simply reveals the casualty. Hence the necessity for draining all pipes of water in very cold climates. Mr. Greer has referred to the remarks of the author of the paper about the difference of water level and the tendency to condensation, but I think the criticism is principally due to the fact that the author has not expressed himself very clearly on this point. As there are some young engineers present, I would take the opportunity of explaining one or two matters, to which attention has already been called some hundred of times, with regard to false water levels. I would also call attention to the excellent paper on "False Water Levels," &c., read by Mr. Harry Gray before the North-East Coast Institute of Engineers and Shipbuilders. These illustrations (by means of these sketches on the blackboard) show various defects in boiler fittings which I would urge should be avoided. It is unfortunately a fact that boilers occasionally come to grief owing to false water levels. Engineers ought especially to see that the pipe leading from the standard of the gauge glass to the steam space in the boiler is free from bends constituting water traps. I would illustrate the effect of this when a pipe leading from the steam space to the gauge glass is constructed with a bend where water can accumulate, and may say my attention was first called to the difficulty arising from pipes carried in this way when I was on the Tyne some seven or eight years ago. Since then I have seen quite half-a-dozen cases in which the pipe to the gauge glass has been arranged in this objectionable manner, and have always found that it has given trouble. Priming sometimes chokes the steam orifice of the gauge glass, and this occasionally produces false water level. Another point well worth attention and discussion is the position of the bottom of the gauge glass with regard to the combustion chamber crowns. Concerning Mr. Greer's objection to what he called Mr. Buckwell's "dogmatic statement," &c., I am also unable to follow the meaning of the author, when he says that there is no physical reason for water to expand "when cooling below 39° Fahrenheit." There must be a sufficient physical reason, otherwise it would not occur. It is one of the thousands of interesting circumstances connected with natural phenomena that we see but cannot understand. I never could understand, for instance, why a human being should cease growing after having reached the height of about six feet. The functions of life appear to proceed with the same precision and efficiency after the growing period is over as before. Why is growth arrested? No physiologist can give a satisfactory reply. But there must be a physical reason, and I also believe there is a moral reason. The universe seems to be constructed on a plan best adapted to the development of man's highest powers. Mr. Buckwell deserves great credit for the industry he has shown in the preparation of his paper, and the tables I hope will be tested and found to contain information of a reliable and useful character.

For the benefit of the younger engineers present, I might call attention to another point in connection with water gauges as further showing the importance of attending to trifling matters. In consequence of violent ebullition, water is often thrown up into and against the orifice of the pipe leading to the gauge glass and, owing to deposits formed around and in the opening, the orifice gradually becomes choked. This is sometimes a cause of false water level, and analagous to the closing of the upper cock or valve.

Mr. SHOREY : It is like congealed foam in the orifice.

THE CHAIRMAN : Yes.

Mr. J. G. LATTA.

(*Member.*)

Referring to the sketch on the blackboard made by the Chairman, showing a steamer's boiler fitted with two water gauges, one being of the ordinary marine standard type and the other of the locomotive pattern, with cocks screwed direct into the boiler front, I should like to ask which of these gauges we should rely upon, assuming they showed different levels of water ?

THE CHAIRMAN : I would prefer to rely on the marine type of gauge. If it erred it would err on the side of safety.

Mr. LATTA.

I am also inclined to think that the locomotive gauge would not be the one to be relied upon, and I have heard of these two types of gauges being tried on a marine boiler, when it was found that the water in the locomotive gauge glass was not "solid" water, so that the water in that glass did not accurately indicate the height of water in the boiler.

THE CHAIRMAN.

With regard to the high-pressure boilers referred to by Mr. Buckwell, one possible reason for the boilers priming, if the water was above the bottom of the gauge glasses, is that the glasses might have been fixed too high. This would naturally cause the engineer to work with an abnormally high water level.

Mr. J. H. THOMSON.

(*Member of Council.*)

It was my intention to bring to your notice this question of the fixing of gauge glasses and the effects that follow. If the glasses are set too high there is always a difficulty through priming. To give you an idea of the wide range of opinions that prevail on some matters of this kind, I may mention that within this last few months an upright donkey boiler on board a steamer had given a lot of trouble through priming, and after an examination the superintending engineer gave instructions for the gauge glasses to be lowered 18 inches! They were lowered, and the result showed that they were 18 inches too high originally.

Mr. SHOREY: That is not at all an exceptional case.

Mr. THOMSON.

I have been with boilers that could never be run safely with more than two inches in the glass, but that was from the same reason—because the gauges had been placed too high. Mr. Buckwell says that on one steamer, the boiler of which was fitted with these two types of gauges, the standard glass showed four inches less water than the locomotive glass. I should like to know if anybody here has had any actual experience of this kind.

THE CHAIRMAN.

It is quite possible to realize the difference in water levels referred to. The locomotive type of gauge glass, where the lower cock is near the furnace crown or side, generally shows too high a water level. The marine type on the other hand, where pipes are led from the column to the boiler, usually shows too low a water level, arising from want of circulation throughout the guage, the cooling of the water and its diminution in bulk.

Mr. L. P. COUBRO.

(*Member of Council.*)

I have read with much interest Mr. Buckwell's paper on the expansion of water by heat, and his ingenious theory to account for that "bogey" of the sea-going engineer—false water level. The two cases he quotes of steamers showing false water both point to the necessity that exists for some means, more reliable than the present water gauge, of indicating exactly where the water level in a boiler really is when it is not to be seen in the gauge glass, either through a decrease of volume due to loss of heat or through priming. This necessity appears to me to have been met by a recent invention of one of our Members (Mr. Churchill). His invention consists of a test cock, with an internal pipe screwed on to the end of a plug, so that the only outlet is through the tube. When the handle is in a vertical position the cock is shut off; on turning the handle round, through about an angle of about 25 degrees, it gradually opens and steam begins to pass through the hollow plug of the cock. As soon, however, as the handle is turned far enough round to enable the tube to dip in the water, steam and water mixed will blow through, and the end of the handle (which is exactly the same length as the internal pipe) will indicate at a glance the height of the water in the boiler. This simple accessory will not only indicate correctly to the engineer on watch the position of the water in his boilers at any time, but will also save the chief engineer much anxiety when (as not infrequently happens) a careless junior allows the water to fall below the bottom of the gauge cock.

Mr. J. G. LATTA.

(*Member.*)

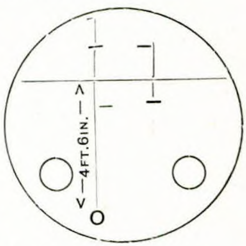
I should say that there are three different causes which may be at work in a marine boiler to cause a rise of water in the gauge glasses, as described in this paper :—

1st.—The expansion of water by heat.

2nd.—The circulation of the water in the boiler.

3rd.—The fact that when a boiler is steaming rapidly, the water in the boiler, especially near the back end of the tubes, is partly composed of large bubbles of steam rising to the surface.

The first item has been explained in the paper. With regard to the second cause, it seems to be well established that there is usually a strong downward current at the front of a boiler where very little evaporation is being done, the greatest amount of evaporation taking place at the first two or three feet of the tubes. With regard to the third item, the natural law of water is to find its own level, but in this case, where we have a column of water supporting a column of water and steam, it is very evident that a column of water and steam will stand higher than a column of water, and, in fact, it is quite possible to calculate the proportion of steam in the water, in the form of bubbles, by noting the heights of the two gauge glasses ; for example, take the case of the "Reina Maria Christina," which was experimented on a year or two ago when running her trials on the Clyde. In this case they had the ordinary connection from top and bottom of boiler to the gauge standard, and alongside they had a gauge standard fitted as shown in the sketch.



When steaming full speed, the difference of height in the gauge glasses was 9 inches—highest of course being in the small one. Now, leaving out the temperature, this would mean that a column of water 54 inches high balanced the column of water and steam 63 inches high, or that the column was composed of 54 water to 9 steam $=\frac{9}{54}=\frac{1}{6}=16$ per cent.—that is, that 16 per cent. of the volume of water in the boiler was composed of steam bubbles rising to the surface.

I have noticed that when a boiler is started, the water seems to expand a little, but, after you get the engines away and you press the boiler hard to make the steam supply, that the water will rise a great deal more after the engines are away than before ; this cannot be due to expansion, but I should say it is due to the presence in the water of steam bubbles rising to the surface.

Mr. JOSEPH WILLIAMS.

(Member.)

Mr. Buckwell's paper impresses one with the conviction that its author studies books as well as boilers, but it is to be regretted that in his attempt to be brief some of the more important causes of false water level in gauge glasses have been passed over in silence, while prominence has been given to a phenomenon (the dilatation of water by heat) which is probably well known to the majority of marine engineers, who are not at all likely to be "scared" by knowing that the true water level in the boiler is higher than that shown in the glass.

The co-efficients of expansion from which the tables have been constructed are only strictly applicable to pure water, which, it is scarcely necessary to remark, is not the usual condition of the water in a marine boiler. Herman Kopp—

whose observations are quoted in the paper in the second columns of Tables I. and II.—carried out other experiments which tended to show that the co-efficient of expansion varied somewhat with the density of the water, so that when the total apparent expansion between the temperatures of 32° and 212° Fahrenheit is 0·0466 with pure water, it is increased to 0·05 between the same limits of temperature when the water is saturated with salt. This difference would not be worth mentioning if the density of the boiler water had no more influence on the apparent water level than is to accounted for by the slight change in its co-efficient of expansion, but if we eliminate all considerations of density in the phenomena of false water level we may experience difficulty in accounting for some facts which appear to have escaped the attention of Mr. Buckwell, as otherwise he would not have stated that "blowing the glass through always has the effect of raising the level." Such a statement is only generally true when the boiler water is comparatively fresh, but when working at high densities it may be often found that if the glass is blown with the water just "bobbing" it will be lost to sight for some considerable time, a condition of things more likely to scare one than to see it rise gaily above its former level. It is some years ago—before the days of evaporators—since I first observed that in blowing through a gauge glass the rise in the water level gradually diminished with the length of the voyage and as the readings of the salinometer increased; say the glass is blown through after standing three hours with the boiler water fresh: then, after the cocks are shut, the water will first show at a higher level and then gradually sink back as explained in the paper; but if the water is dense when the blowing takes place it will be observed that the water will often rest somewhere *below* the level observed before the cocks were opened and then sinks much the same as before, but after sinking some time *it commences to rise again* and continues to do so until "false water" is shown. I attribute this rise to the condensation of the steam in the upper part of the glass and its connections to the boiler. This condensation is always taking place (when steam is up) and is often rendered visible by a dribble down the inside of the gauge glass—which most of you have observed. The distilled water, owing to its lower specific gravity—due to its temperature as well as to its purity—remains on top of the denser water in the lower pipe, without intimately mixing with it, owing to the absence of circulation. The fact that a column of water may have a variable density, apart from any influence due to temperature, is well known to others besides engineers, and many shipmasters are aware of the unreliability of the indications derived from surface water to form the basis on which to estimate the rise in salt water after loading their ships in some of our seaports. The difference in height between two columns of water producing the same unit pressure on their base would be about 10 per cent., at equal temperatures, if one column was pure water and the other one of the not uncommon density of $\frac{35}{32}$. This is equivalent to 7·2 inches in 6 feet. No rule can be given which is applicable to every boiler, as much depends on the position and protection of the upper and lower pipes and on the condition of the water as regards oil and scum. If false water was simply due to the differences of temperature, it could be cured to a great extent by using internal pipes, and thereby render the application of the tables unnecessary. There are several causes which produce "false water," other than those mentioned by the author of the paper or the one I have made a partial attempt to deal with, and perhaps some of them will be alluded to by other members. I cannot, however, conclude without expressing dissent from Mr. Buckwell's dogmatic assertion that there is no physical reason for the expansion of water after it falls below a certain temperature, as Professor Tyndall has suggested a physical reason which is based on a wider and more extensive experimental knowledge than Count Rumford possessed when he resorted to the interposition of "Providence" to account for a phenomenon which he believed to be unique in the operations of nature—a belief which subsequent discovery has proved to be untenable.

Mr. G. W. BUCKWELL.

With regard to the compression of water under high pressures, I beg to quote the following paragraph, which recently appeared in one of our scientific journals.

"In some experiments on the laws of compressibility of liquids, by M. E. H. Amagat, deformations of the piezometers were investigated and allowed for, and the pressures carried as far as 3,000 atmospheres. The liquids operated upon were ether, alcohol, carbon, bisulphide, acetone, the ethyl halides, and chloride of phosphorus. In every case the co-efficient of compressibility was found to decrease regularly as the pressure increased. At 300 atmospheres that of water was reduced by nearly one-half its ordinary value, that of ether by two-thirds. This diminution, again, is greater the higher the temperature. The ratio of the difference of the co-efficient to the corresponding difference of temperature increases rapidly with the temperature, and decreases rapidly as the pressure increases."

It would thus appear that at very high temperatures and pressures the compressibility of some liquids becomes extremely minute.

My "dogmatic"—(Query. Does "dogmatic" mean diffutative, arrogant, or authoritative ?)—assertion that there is no physical reason for the expansion of water below 39° Fahrenheit has been strongly commented upon. I did not quite mean it in the sense in which it has been taken, but as it has gone forth so it had better remain. Like Mr. Rowe, I believe there is a physical reason for everything. Mr. Williams refers to Professor Tyndall's suggested physical reason, and, as its introduction here may perhaps show that I am not "dogmatic" on the subject, I beg to give the explanation.

The change from contraction to expansion by decrease of temperature does not occur till the water is approaching the solid or crystallized form. The ice occupies a volume one-eighth larger than the water from which it is produced, and this enlargement must be due to the re-arrangement of the molecules on crystallization, this re-arrangement being due, in its turn, to molecular polar forces which are only apparent at or near the freezing point. The water molecules are similar to minute magnets, having attracting and repelling poles, but the polar forces do not come into play till the lowness of temperature has contracted the total volume sufficiently to bring the poles within the range over which the forces can be exerted. According to the mechanical theory of heat, all the molecules of a body are in a state of rapid motion : the higher the temperature, the more rapid the motion and the greater the amplitude, which is apparent to the senses by an expansion of total volume. Hence lowering the temperature decreases or contracts both the rapidity and the amplitude till, as the temperature approaches 39° Fahrenheit, the molecules of water remain a sufficient space of time within the range of the polar repelling forces for them to be felt and to partially counteract the contraction of volume, that is, the contraction of rapidity and amplitude of molecular motion. At 39° Fahrenheit these polar repelling forces are exactly equal to the temperature contracting forces, and below 39° Fahrenheit the polar repelling forces predominate, resulting in an increase of volume.

In reference to Mr. Williams' remarks on the density of water increasing as the voyage is prolonged, I may state that one of our Liverpool Superintendent Engineers has come to the conclusion that modern steamers trading from Liverpool to Kurrachee and Rangoon and back, should neither increase the coal consumption from the day of sailing to the day of re-arrival at Liverpool, nor require the boilers opened for scaling at the end of the voyage.

Mr. Greer has, I think, misunderstood me. If the steam cools down, it must either condense, in which case the water level in the glass is raised by the water of condensation, as explained by Mr. Williams, or else the pressure of the steam in the upper gauge pipe must fall, in which case the water would be forced up the glass by the pressure of the steam within the boiler transmitted through the lower gauge pipe. Mr. Rowe has explained the remark in reference to the providential reason for the expansion of water on freezing. I was not thinking of the lives of a few fishermen, but of the life on the whole globe.

Besides water and bismuth, there are other exceptions to the general law of contraction by cooling. Iodide of silver and stretched indiarubber contract on being heated, and, according to one authority, an alloy of two parts of bismuth, one part of lead and one part of tin behaves in an exceedingly eccentric manner. It expands between 32 degrees and 112 degrees, contracts between 112 degrees and 131 degrees, at the latter temperature occupying the same volume as at 32 degrees, then expands again between 131 degrees and its fusing point, 203 degrees, at which temperature it occupies the same volume as at 112 degrees.

The discussion has not been so antagonistic as I expected it would be, but, as most discussions do, it has brought to light certain facts in the experiences of engineers with which they have had to deal, and which form a basis for future reference.

In conclusion, there is one point I would call attention to. At high temperatures the density of water decreases and the density of steam increases; hence these densities are always approaching one another, and at some very high temperature will be the same. Shall we then have steam or water or what, or will it be, as I have previously asserted, that decomposition would ensue before this point is reached?