V. *On some Thermo-dynamic Properties of Solids.* By J. P. Joule, *LL.D., F.R.S., F.C.S., Hon. Mem. Phil. Soc. Cambridge, Vice-President of the Lit. and Phil. Soc. Manchester, Corresp. Mem. R.A. Sc. Turin, &c.*

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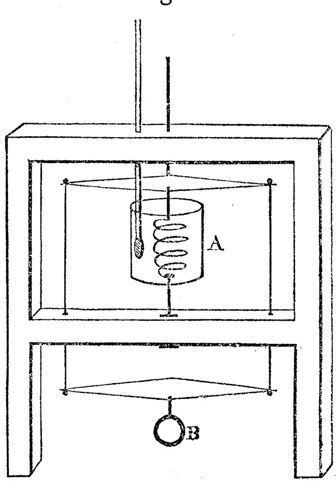
1. After finding the numerical relation between heat and work in 1843, it immediately occurred to me to investigate various phenomena in which heat is evolved by mechanical means, and of these one of the most interesting and important appeared to be the evolution of heat by the compression of elastic fluids. If the heat given out in this case proved to be the equivalent of the work spent, then the natural inference was that the elastic force of a gas and its temperature are owing to the motion of its constituent particles, both being proportional to the square of the velocity of the particles; and that the force of a falling body employed in compressing a gas is exhibited anew in the form of temperature. On the other hand it was possible, secondly, to conceive of an elastic fluid which would not give out any heat by compression. This would be the case if it was made up of mutually repelling particles, the temperature of which was that of the mass. The work required to compress the fluid would be the same on either hypothesis, but in one supposition the effect would be developed in actual energy, in the other in the potential form. Thirdly, we may suppose a fluid exhibiting as heat a portion of the force employed in its compression, and retaining the rest in the potential form. Or we may have a fluid giving out more heat than the equivalent of the work spent upon it when it is compressed and maintained at a constant temperature. Experiment proved that the heat actually evolved was very approximately that due to the compressing force. Nevertheless, it seemed desirable to demonstrate the possibility of a gas so constituted that heat shall not be evolved by its compression. It occurred to me that a bag full of elastic metallic springs would illustrate such a gas. If the springs were properly formed, the elasticity of the bag would follow the laws of gaseous pressure. To the question, Would such a bag evolve heat on compression? I could readily answer, no; for in the bending of a spring one part is extended while the other is compressed, and thus it might be expected that the thermal effect on the whole would be neutral. Still it seemed desirable to decide the point by experiment.

Fig. 1.



2. The apparatus I employed is represented by the adjoining sketch, where a spiral spring of tempered steel is seen immersed in the can A. By applying weights to a lever connected with the link B the spring could be compressed, and the heat evolved, if any, measured by the increase of temperature observed to take place in the water or mercury filling the can. The plan I pursued was to note the temperature successively; first, two minutes after the weight had been laid on; second, two minutes after the weight had been removed; and third, after two minutes more had elapsed. The mean of a number of these observations taken in succession, gave me,—first, the thermal effect resulting from the laying on of the weight and the atmospheric influence; second, that of the removal of the weight and the atmospheric influence; and third, the atmospheric influence alone.

3. The pressure applied was 318 lbs., which pushed down the spiral spring 1·136 inch. In the following summary of results, each number is the mean of eight or ten observations, given in terms of the graduation of a thermometer, of which each degree was equal to ·0558 of a degree Centigrade.

First Series. Spring immersed in 8 ozs. of water.

	Weight laid on.	Weight taken off.	Atmospheric influence.
First experiment	−·548	−·568	−·560
Second experiment	−·009	−·023	−·012
Third experiment	+·282	+·271	+·252
Mean	−·092	−·107	−·107

Second Series. Spring immersed in 7 lbs. of mercury.

	Weight laid on.	Weight taken off.	Atmospheric influence.
First experiment	+·180	+·175	+·169
Second experiment	+·066	+·092	+·059
Third experiment	+·041	+·039	+·020
Fourth experiment	−·060	−·059	−·053
Mean	+·057	+·062	+·049
Mean of both series	−·032	−·038	−·041

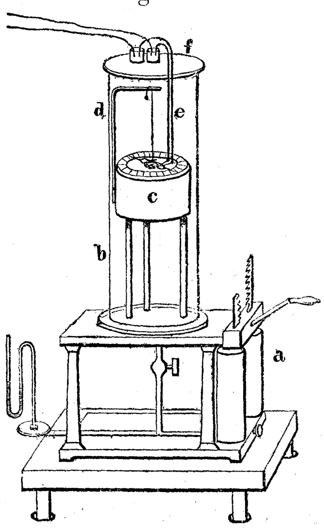
4. The capacity for heat of half a pound of water being about twice as great as that of 7 lbs. of mercury, I have divided the mean result of the second series by two, before combining it with the first series in a general mean. The mean of both series therefore represents the thermal effect in the capacity of half a pound of water. It indicates, on subtracting the effects of the atmosphere, a heating effect of ·009 after laying on the weight, and a heating effect of ·003 on taking off the weight. The highest of these numbers represents a temperature less than one thousandth of a degree FAHR.

5. Now the actual force expended in the compression of the spring was 14·268 foot-pounds, which is equivalent to 0°·037 FAHR. in half a pound of water, a thermal effect which would have been made manifest with the greatest facility. Hence it was

obvious that a gas might be conceived as so constituted that the heat evolved by its compression would be in no respect the equivalent of the mechanical force employed, and that therefore we had no right to assume such equivalency except as a hypothesis to be tested by experiment. Accordingly after this hypothesis had been proved by me approximately*, Professor THOMSON devised the experiments† by which we have succeeded in defining the limits of its accuracy. The same philosopher has also applied his powerful analysis to the investigation of the thermo-elastic properties of matter‡. The results of the experiments I have just given an account of can only be considered as negative, but it has been decided by Professor THOMSON that the compression of a spring gives a certain, though excessively small thermal effect, owing to the almost exact counterpoise of heating and cooling effects on the compressed and extended sides. The method of obtaining appreciable results was obviously to examine these opposite effects separately. I have, therefore, on the suggestion of Professor THOMSON, undertaken some experiments with a view to ascertain the heat developed by longitudinal compression, and that absorbed on the application of tensile force.

6. At the outset it was obvious that a very delicate test of temperature would be required, and no means appeared to offer so many advantages as that of thermo-electricity. Professor J. D. FORBES had constructed a thermo-multiplier capable of detecting temperatures not exceeding one thousandth of a degree FAHRENHEIT. Adopting some of the refinements introduced by MELLONI and FORBES, I have simplified the instrument so as to render its construction and management very easy, and also increased its sensibility by immersing it into the vacuum of an air-pump. My thermo-multiplier is represented by the adjoining sketch (fig. 2), where *a* is the air-pump firmly clamped to a strong stool, the legs of which pass through holes in the laboratory floor and are driven into the ground beneath; *b* is a glass chimney receiver; *c* a block of wood supported on feet which rest on the pump plate; *d* a piece of glass rod fixed to the block, over which is thrown the filament which supports the astatic needles. Two thick copper wires (*e*) dip into mercury cups formed in the block, and, being carried out of the receiver through holes drilled in the ground glass plate *f*, are bent into two mercury cups placed on the top of the instrument. Pitch was employed to close all orifices air-tight.

Fig. 2.



7. The details of the astatic needles, which are poised according to the plan first suggested by Professor THOMSON, will be better understood by inspecting fig. 3. The needles

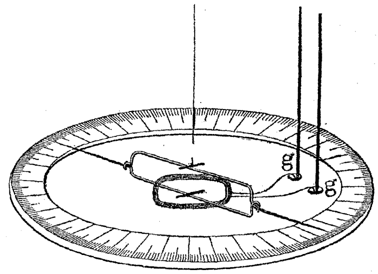
* Proceedings of the Royal Society, June 20, 1844; and Philosophical Magazine, May 1845.

† Philosophical Magazine, 1852, Supplement; Philosophical Transactions, 1853, Part III. p. 357, and 1854, Part II. p. 321.

‡ Quarterly Mathematical Journal, April 1855.

are parts of one sewing-needle magnetized to saturation, one part being a little longer than the other, so as to exceed it in magnetic moment and give direction to the system. A piece of glass tube drawn very fine, and bent as represented in the sketch, is attached at right angles to the upper magnetic needle and serves as the pointer. The lower needle is hooked to the pointer by means of the fine glass tube to which it also is attached. The coil consists of twenty turns of silked copper wire, $\frac{1}{40}$th of an inch in diameter, the ends of which dip into the mercury cups *gg* formed in the block of wood.

Fig. 3.



8. In order still further to increase the sensibility of the instrument, a steel magnet one yard long, the permanency of which had been tested, was placed so as to counteract and almost entirely overcome the action of the earth's magnetism in the locality of the needle. A small telescope placed at the distance of a few yards, and looking obliquely downwards through the chimney glass at the graduated circle, completed the apparatus.

9. With air in the receiver at the atmospheric pressure, the mere standing at the distance of two yards on one side of the instrument, would in a short space of time cause the needle to travel through 10° in consequence of the currents of air produced by the unequal heating of the walls of the glass receiver. But when the air was reduced to a pressure of only half an inch in the mercury gauge, this did not take place, though still, when the hand was put in contact with the receiver, a very considerable deflection of the needle was speedily produced.

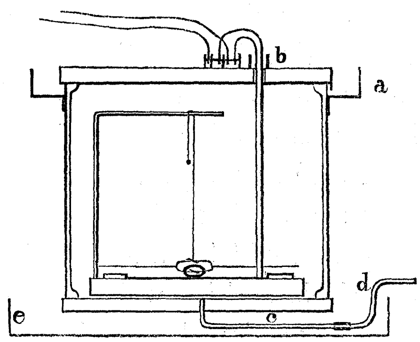
10. On working with my instrument, I was agreeably surprised to find that when the bar-magnet was placed so as to make the needle take up one minute in being deflected to a new position, no perceptible return swing of the needle took place, even when the rarefaction of the air was carried to half an inch pressure. If a small magnet was suddenly placed where it could deflect the needle 30°, the pointer would steadily travel towards that degree of deflection, and on arriving there would remain settled without any previous oscillation that could be discerned. When the time of a swing was reduced to 30″, a return swing was observed amounting to $\frac{1}{150}$, $\frac{1}{25}$, and $\frac{1}{18}$ of the first swing, according as the gauge was reduced to 1, $\frac{6}{10}$, and $\frac{1}{2}$ inch respectively.

11. As a test of the delicacy of the instrument arranged so as to give the swing in 45″, I may mention that, after increasing the resistance of the coil and its appendages a hundredfold by the addition of 100 yards of fine copper wire of $\frac{1}{40}$th of an inch diameter, a single degree Centigrade communicated to the junction bismuth and antimony produced a deflection of 2° 57′. Therefore, as it was quite possible to estimate a deflection amounting to 2′, it followed that a change of temperature in the junction bismuth and antimony directly connected with the multiplier would be estimable, if it were only $\frac{1}{8800}$ of a degree Centigrade.

12. An objection which might be raised on account of an air-pump being permanently

occupied, might be got rid of by the following arrangement:—A rim *a*, fig. 4, contains pitch or other cement to secure the joint between the chimney and top plate glass; a rim at *b* contains pitch to secure the orifices where the wires pass through the top plate. The bottom of the chimney rests upon a round metallic plate, into which a metal pipe *c* is screwed, which is attached by india-rubber tube to the glass tube *d*. This tube is hermetically sealed after the air of the receiver has been exhausted through it. All the lower joints are then rendered permanently tight, by putting the instrument in the shallow dish *e* filled with melted pitch.

Fig. 4.



Thermo-electricity of Iron in different states.

13. In my earliest experiments on the thermal effect of stretching a steel bar, I placed a copper wire in contact with the steel, and completed the circuit by an iron wire in contact with another part of the steel bar not under tension. I found anomalous results which I was ultimately able to refer to the strong thermo-electric relation between hard steel and iron. It was at once obvious that the existence of such marked differences between ferruginous metals in various states of aggregation or purity might render the thermo-multiplier a valuable test in the hands of practical men: I therefore allowed myself to be diverted awhile from the main object of inquiry in the endeavour to throw some light on so interesting a question.

14. Professor THOMSON has described* the changes in thermo-electric position which are produced by the various conditions under which metals are placed. He has shown that the process of hardening by plunging into cold water brings copper and most other metals nearer antimony in the thermo-electric series, but that iron is brought nearer bismuth: I find that in steel the change is in the same direction as in iron, but of enormously greater magnitude. In a softened state, the position of steel is about midway between copper and iron, but after hardening it by plunging it at a bright red heat into water, I have in some instances found it to be on the bismuth side of copper, the alteration of the thermo-electric position of the same specimen amounting to as much as $\frac{1}{15}$th of the entire range between bismuth and antimony. In all the specimens of wrought and cast iron I have examined, there is a notable effect in the same direction produced by plunging at bright red heat into water; but although a great change in the molecular state was thus occasioned, evinced by the iron bending with twice the difficulty it did when annealed, and the cast iron resisting the action of the file, either metal was only brought nearer bismuth by $\frac{1}{200}$ of the interval between bismuth and antimony. A fresh illustration of the extraordinary physical change produced in iron by its conversion into steel is thus afforded; and I believe that the

* Philosophical Transactions, 1856, Part III. p. 722.

excellence of the latter metal might be tested by ascertaining the amount of change in thermo-electric condition which can be produced by the process of hardening.

15. The different varieties of cast iron I have tried present a surprising range of thermo-electric intensities, extending almost from that of wrought iron on the one hand, to that of German silver on the other. By the kindness of Professor F. C. CALVERT, I have been enabled to examine several interesting specimens, of which he has furnished me with the analysis. The general conclusion arrived at is, that the metal is brought nearer bismuth as the quantity of carbon in combination is increased, but much more so than would be the case if cast iron exhibited merely the combination of thermo-electric intensities which carbon and iron separately possess, at least if the intensity generally assigned to carbon is correct. The intensity of the junction wrought iron and highly carbonized cast iron is as much as one-fifth of the intensity of antimony and bismuth.

Thermo-electric Intensities of Metals, Alloys, &c.

16. In constructing the following Table, I employed the thermo-multiplier already described, furnished with a variable extra resistance. I examined first those metals whose thermo-electric qualities were most widely separated, and then those which lay intermediate and differed less from each other. Small arcs of deflection were observed, so that the deviation of the needle was a sufficiently correct measure of the intensity of the current, and constantly repeated comparisons were made with a standard thermo-electric junction of copper and iron included in the same circuit with the junctions experimented on.

17. *Scale of Thermo-Electric Intensities at* 12° *Centigrade.*

Antimony, specimen of commercial	100
Antimony, pure, prepared by Mr. CALVERT	98·06
Antimony, pure, prepared by Mr. CALVERT, not well annealed	95·95
Alloy consisting of 5 equivalents of antimony +1 equivalent of bismuth	83·75
Alloy consisting of 4 equivalents of antimony +1 equivalent of bismuth	80·50
Alloy consisting of 3 equivalents of antimony +1 equivalent of bismuth	78·94
Alloy consisting of 2 equivalents of antimony +1 equivalent of bismuth	68·79
Alloy consisting of 1 equivalent of antimony +1 equivalent of bismuth	45·51
Iron, thick wire, Professor CALVERT'S	80·
Iron, thin wire	79·24
Iron, thick wire, very well annealed	78·24
Iron, thick wire, hardened by plunging at bright red into water	77·62
*Iron (Professor CALVERT'S No. 1) drawn into wire	77·23
†Iron (Professor CALVERT'S No. 1) after puddling, but previous to being drawn into wire	76·00
‡Iron (Professor CALVERT'S No. 1), cast, previous to puddling	65·21

Iron (Professor CALVERT'S No. 1), cast, previous to puddling, hardened by plunging it at bright red into water	63·89
Iron (Professor CALVERT'S No. 1), cast, white fracture, very hard	70·92
Iron (Professor CALVERT'S No. 1), cast, black fracture	57·77
Steel, small file, annealed	73·15
Steel, small file, hardened by plunging at bright red into water	65·8
Steel, large file, annealed	70·28
Steel, large file, hardened by plunging at bright red into water	64·06
Iron, cast, annealed	63·25
Iron, cast, hardened by plunging at bright red into water	62·7
Iron, cast, hardened by plunging at bright red into water, another specimen	60·83
Iron and copper wires, faggot of, in proportion 1 iron to 5 copper	68·29
Iron and copper wires, faggot of, in proportion 2 iron to 5 copper	69·83
Iron and copper wires, faggot of, in proportion 4 iron to 5 copper	71·17
Iron and copper wires, faggot of, in proportion 8 iron to 5 copper	72·71
Iron and copper wires, faggot of, in proportion 16 iron to 5 copper	75·53
Zinc	67·94
Zinc, amalgamated	67·77
Copper deposited by electricity (brittle)	67·9
Copper, thin wire	67·14
Copper, another specimen	66·2
Copper, another specimen	65·92
Gold, pure	67·71
Silver deposited by electricity (brittle)	67·08
Silver, sheet	66·81
Tin, pure	65·46
Lead, commercial	65·29
Lead, pure	64·42
Platina, annealed	65·02
Platina, unannealed	64·87
Platina, fine wire	64·15
Aluminium	64·68
Mercury	61·74
German silver	51·88
German silver, hardened by hammering	49·51
Bismuth, pure, prepared by Professor CALVERT	4·7
Bismuth, specimen of commercial	0

Professor CALVERT'S analysis of the specimens marked in the above Table *, †, and ‡, gave for the

	Carbon.	Silicium.	Sulphur.	Phosphorus.	Iron.	Total.
Cast iron . . .	2·275	2·720	0·301	0·645	94·059	100
Puddled bar . .	0·296	0·120	0·134	0·139	99·311	100
Iron wire . . .	0·111	0·088	0·094	0·117	99·590	100

From the above digression I now return to the main subject of the present paper, by describing my

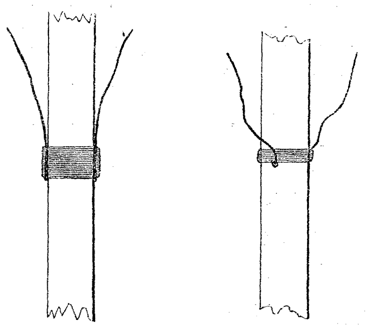
Experiments on the Thermal Effects of Tension on Solids.

18. All the metals employed, with the exception of lead, were in the form of cylindrical bars about a foot long and a quarter of an inch in diameter. The upper end of the bar was screwed into a piece of metal supported by a wooden framework, the lower end was attached to a lever, to the extremity of which weights could be hung without approaching the apparatus. In the first method the thermo-electric junction was made, as represented in the adjoining sketch, by binding to opposite sides of the bar copper and iron wires $\frac{1}{40}$th of an inch in diameter, hammered flat at the ends. In the second method, the junction of fine wires was inserted in a hole $\frac{1}{40}$th of an inch in diameter, bored through the centre of the bar, a small portion of wire being bound to the bar by means of cotton thread, but metallic contact prevented by an intervening slip of paper. The terminals of these wires were immersed in deep mercury cups formed in a solid block of wood, whence thick copper wires proceeded to the thermo-multiplier.

19. Immediately after each experiment on the effect of tension, the thermometric value of the deflections was ascertained by immersing the bar, to within one-third of an inch of the junction, in water of different temperatures. The deflections thus produced were about two-thirds of those occasioned by the same changes of temperature when the junction was completely immersed. The diminished effect in the former case is owing for the most part to the conduction of heat from the air by the thermo-electric wires. The experiments on tension were liable to be affected in the same way, but they were not subject to the loss arising from the conduction of heat from the surface of the bath to the junction. The error intervening from this latter circumstance could not be great, and was moreover in all probability almost exactly neutralized by a small error in the tension experiments, arising from the escape of $\frac{1}{14}$th of the thermal effect from the quarter-inch bars during the 40″ occupied by the swing of the needle.

Fig. 5.

First method. Second method.



20. *Iron.*—The weight of the bar per foot was ·1568 of a lb. The lever alone gave it a constant tension of 70 lbs. The additional tensions successively given were 194 lbs., 388 lbs., 583 lbs., and 1166 lbs., or as 1, 2, 3, and 6. The mean of five trials gave 20′·6 as the deflection indicating cold on applying the tension of 194 lbs., and 20′·2 as the

deflection in the opposite direction, indicating heat, when the weight was removed. With 388 lbs., I had 35′·8 and 42′·2: with 583 lbs., 56′·4 and 57′·8: and with 1166 lbs., 1° 55′·8 and 1° 58′·6. Hence it appeared that the quantity of cold produced by the application of tension was sensibly equal to the heat evolved by its removal; and further, that the thermal effects were proportional to the weights employed.

21. The above trials having been made without an accurate determination of the thermometric value of the deflections immediately afterwards (a practice I found it important to follow in order to obviate the effects of any alteration in the magnetic intensities of the earth, astatic needles, or controlling magnet, which might be taking place), I repeated the experiment, using the first method above described, and found a mean deflection of 1° 22′·8 with a tension of 775 lbs. The thermometric value of this deflection, determined in the manner already explained, was $-0^\circ{\cdot}115$ Centigrade.

22. Professor THOMSON, in his researches on the thermo-elastic properties of metals, has demonstrated the following formula as applicable to the phenomenon in question,—

$$H=\frac{t}{J}\times\frac{p}{1}\times\frac{e}{1}\times\frac{1}{s}\times\frac{1}{w},$$

where H is the thermal increase in degree Centigrade, t the temperature Centigrade from absolute zero, J the mechanical equivalent of the thermal unit, p the pressure applied in pounds, which in the case of tension is of course a negative quantity, e the longitudinal expansion per degree Centigrade, s the specific heat, and w the weight in pounds of a foot length of the bar*. Applied to the above experiment the formula gives

$$H=\frac{276{\cdot}7}{1390}\times\frac{-775}{1}\times\frac{1\dagger}{81200}\times\frac{1\ddagger}{{\cdot}11}\times\frac{1}{{\cdot}1568}=-0^\circ{\cdot}11017.$$

23. In another experiment by the first method, but with another thermo-electric junction, I obtained a thermal effect of $0^\circ{\cdot}124$; in this case the formula gave

$$H=\frac{276}{1390}\times\frac{-775}{1}\times\frac{1}{81200}\times\frac{1}{{\cdot}11}\times\frac{1}{{\cdot}1568}=-0^\circ{\cdot}1099.$$

24. A third experiment, in which the second method was used, and in which I had the advantage of Professor THOMSON'S assistance, gave a thermal effect of $-0^\circ{\cdot}1007$. In this case the formula gave

$$H=\frac{287}{1390}\times\frac{-725}{1}\times\frac{1}{81200}\times\frac{1}{{\cdot}11}\times\frac{1}{{\cdot}1568}=-0^\circ{\cdot}1069.$$

25. *Hard Steel.*—With stretching weights of 194, 388, and 775 lbs., I observed deflections of the needle amounting to 27′, 48′, and 1° 37′. Another experiment by the

* The formula signifies in fact that the heat evolved by compressing a solid is equivalent to the work required to compress the volume of it due to temperature, just as in the case of a perfect elastic fluid, applied to which the expression becomes simplified to $\frac{p}{Jsw}$. M. CLAPEYRON has given a theoretical estimate of the heat disengaged by the cubical compression of iron (Scientific Memoirs, vol. iii. p. 373).

† LAVOISIER and LAPLACE. ‡ DULONG and PETIT.

first method to obtain the absolute thermal effect gave 53′, which was found to indicate a temperature of $-0^\circ{\cdot}162$. The theoretical result in this case was

$$H=\frac{275{\cdot}4}{1390}\times\frac{-775}{1}\times\frac{1*}{81633}\times\frac{1\dagger}{{\cdot}1024}\times\frac{1}{{\cdot}1499}=-0^\circ{\cdot}125.$$

26. *Cast Iron.*—The deflections produced by tensile forces of 194, 388, and 775 lbs. were 17′, 31′, and 59′·9 respectively. The thermal effect indicated by the last was $-0^\circ{\cdot}1605$. The formula gives

$$H=\frac{277{\cdot}4}{1390}\times\frac{-775}{1}\times\frac{1\ddagger}{90139}\times\frac{1\S}{{\cdot}1198}\times\frac{1}{{\cdot}1281}=-0^\circ{\cdot}112.$$

27. In another experiment I obtained a thermal effect of $-{\cdot}1481$, theory giving

$$H=\frac{283}{1390}\times\frac{-784}{1}\times\frac{1}{90139}\times\frac{1}{{\cdot}1198}\times\frac{1}{{\cdot}1281}=-0^\circ{\cdot}115.$$

28. *Copper.*—With tensile forces of 191·6, 383·3, and 766·6 lbs. I obtained by the first method deflections of 21′, 41′, and 1° 12′·6 respectively, the absolute thermal effect indicated by the last being $-0^\circ{\cdot}174$. The formula gives

$$H=\frac{274{\cdot}9}{1390}\times\frac{-766{\cdot}6}{1}\times\frac{1\,\|}{58200}\times\frac{1\P}{{\cdot}095}\times\frac{1}{{\cdot}1781}=-0^\circ{\cdot}154.$$

29. With copper, and also with iron wires, I have observed the cooling effect of tension close up to the breaking-point. But whenever the pull occasioned permanent change of figure, the heat frictionally evolved overpowered the cooling effect.

30. *Lead.*—The bar employed was half an inch in diameter, and weighed 6308 grains to the foot. The stretching weights were, first, 193 lbs. with 70 lbs., the weight of the lever, constant; and second, 263 lbs., the weight of the lever itself being used along with the 193 lbs. laid on it. Using the first method, I obtained with the above weights deflections of 21′·5 and 30′·7, indicating thermal effects of $-0^\circ{\cdot}0531$ and $-0^\circ{\cdot}0758$. The formula gives in the two cases,

$$H=\frac{278{\cdot}5}{1390}\times\frac{-193}{1}\times\frac{1**}{35100}\times\frac{1}{{\cdot}0303}\times\frac{1}{{\cdot}901}=-0^\circ{\cdot}0403,$$

and

$$H=\frac{278{\cdot}5}{1390}\times\frac{-263}{1}\times\frac{1}{35100}\times\frac{1}{{\cdot}0303}\times\frac{1}{{\cdot}901}=-0^\circ{\cdot}0550.$$

31. *Gutta Percha.*—The piece used was half an inch in diameter, and weighed 1246 grains per foot. The thermo-electric junction, formed of very thin copper and iron wires, was inserted in a slit made two-thirds through the substance of the gutta percha. The weights employed were, first, that of the lever alone amounting to 70 lbs.; and second, the lever with the further addition of 80 lbs., making in all 150 lbs. As with the metals, cold was produced when the gutta percha was stretched, and the heat restored when the stretching weight was removed. With the first-named tensile force a mean deflection of 16′·4 was observed, and with the second a mean deflection of 30′·2.

* SMEATON. † POTTER. ‡ ROY. § Myself.
‖ LAVOISIER and LAPLACE. ¶ DULONG and PETIT. ** LAVOISIER and LAPLACE.

In order to turn the above into thermal measure, the gutta percha was plunged into water of different temperatures, deep enough to immerse the part in which the thermo-electric junction was imbedded; the former plan of operation being inapplicable in this instance, on account of the low conducting power of the substance used. It was found in this way that the quantities of thermal effect due to the above deflections were $-0^{\circ}\cdot0284$ and $-0^{\circ}\cdot0524$, quantities, however, which are likely to err in defect by a very small quantity, owing to the nature of the method of finding the value of the deflections. The theoretical results, assuming as I did for the metals that the expansion of gutta percha by heat is the same whether suffering tension or not, are

$$H=\frac{276\cdot4}{1390}\times\frac{-70}{1}\times\frac{1}{6354}\times\frac{1}{\cdot402}\times\frac{1}{\cdot178}=-0^{\circ}\cdot0306,$$

and

$$H=\frac{276\cdot4}{1390}\times\frac{-150}{1}\times\frac{1}{6354}\times\frac{1}{\cdot402}\times\frac{1}{\cdot178}=-0^{\circ}\cdot0656.$$

32. The values just given for the expansion and specific heat of gutta percha are those which I arrived at by experiments on a part of the same sheet out of which the cylinder above used was made. The method pursued in obtaining the expansion was one I have frequently found very convenient. It consists in weighing the body in water at two temperatures, one as much below as the other is above the point of maximum density. In this way I found the linear expansion between $2^{\circ}\cdot4$ and $5^{\circ}\cdot8$ to be $\frac{1}{6354}$ per 1°, and the specific gravity to be 1·00462 at 4°. The specific heat at $4^{\circ}\cdot5$ was found by the method of mixtures to be ·402.

33. *India-rubber.*—The extraordinary physical properties of this substance appear to have been first remarked by Mr. GOUGH*. By placing a slip of it in slight contact with the edges of the lips, and then suddenly extending it, he experienced a sensation of warmth arising from an augmentation of the temperature of the rubber; and then by allowing the slip to contract again, he found that this increase of temperature could be destroyed in an instant. In his next experiment, he found that "if one end of a slip of caoutchouc be fastened to a rod of metal or wood, and a weight be fixed to the other extremity, in order to keep it in a vertical position, the thong will be found to become shorter with heat and longer with cold†." The third experiment described by Mr. GOUGH has indicated the means of using this substance in the production of textile fabrics; he says, "If a thong of caoutchouc be stretched, in water warmer than itself, it retains its elasticity unimpaired; on the contrary, if the experiment be made in water colder than itself, it loses part of its retractile power, being unable to recover its former figure; but let the thong be placed in hot water, while it remains extended for want of spring, and the heat will immediately make it contract briskly."

* Memoirs of the Literary and Philosophical Society of Manchester, 2nd Series, vol. i. p. 288.

† Ibid. p. 292. From the context it appears that the weight was used to give tension, as well as to keep the slip vertical.

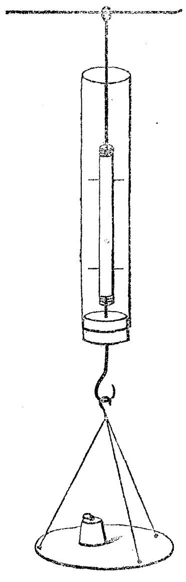
34. In addition to the above, my own experience has led me to the curious fact that a piece of india-rubber, softened by warmth, may be exposed to the zero of FAHRENHEIT for an hour or more without losing its pliability; but that a few days rest at a temperature considerably above the freezing-point will cause it to become rigid.

35. The ends of a piece of elastic india-rubber, about $\frac{4}{10}$ths of an inch square, were attached to an apparatus by means of which it could be stretched by various weights. A thermo-electric junction of thin copper and iron wires was placed in an orifice pierced through the centre of the slip; and at either side, at $\frac{6}{10}$ths of an inch distance from one another, pins were stuck which afforded the means of knowing the exact length to which the rubber was stretched. With small tensile forces no thermal effects were observed, but when the rubber was stretched by a weight of 6 lbs., a sensible deflection of the needle took place, indicating heat; the needle returning to zero, and thus indicating absorption of heat when the weight was removed. Experiments with different weights gave the following results:—

Stretching weight in pounds.	Length of rubber in inches		Deflection of thermo-multiplier.	Thermal effect indicated by deflection.
	When stretched.	After weight was removed.		
0	0·59	0·59	° ′ 0	° 0
2	0·67	Not observed.	0	0
4	0·77	Not observed.	− 1	−0·002
6	0·94	Not observed.	11	0·020
8	1·13	Not observed.	32	0·059
10	1·45	0·71	1 15	0·139
12	1·75	0·9	2 47	0·370
14	Not observed.	Not observed.	4 50	0·537
16	2·14	Not observed.	5 55	0·657
18	2·36	1·02	6 45	0·750

36. The low temperature (about 6° Centigrade) at which the above experiments were tried considerably interfered with the perfection of the elasticity of the india-rubber, which in consequence became gradually elongated on the removal of successively increasing weights. This circumstance no doubt interferes slightly with the absolute quantity of thermal effect recorded in the last column of the Table. Still the essential characteristics of the phenomena are plainly indicated, viz. that little heat, or even a reverse effect, is produced by moderate stretching weights, but that after a certain weight is reached, a rapid increase of thermal effect takes place.

Fig. 6.



37. The same piece of rubber was afterwards immersed in water in the manner represented by the adjoining sketch. A wire attached to the rubber at the upper extremity was made fast, and another wire affixed to the lower end passed through a cork in the glass tube, and being bent into a hook, supported a scale for weights. The temperature of the water in the tube was kept uniform by constant

additions and removals of water, which was kept well mixed by a current of bubbles of air blown from time to time through a narrow tube into the lower end. The positions of the pins, showing the length of the rubber, were ascertained by means of a graduated scale placed behind the tube, viewed through a telescope which was raised or depressed according to the level of the pins.

38. In my first experiment the stretching weight, inclusive of the weight of the tube, was 3 lbs., and the water in the tube being adjusted to 7° Cent., the length of the thong between the pins was 1·026 inch. The temperature of the water was then raised to 17°, and kept there for ten minutes, when the length was found to be reduced to 0·964 inch. A third observation at 28° gave the length 0·9. It was evident that this contraction was partly owing to the recovery by heat of the rubber from the constrained state in which it was left by the experiments of the preceding Table; for the lengths observed on lowering the temperature successively to 16°·6 and 7°·4, namely, 0·91 and 0·922, indicated a lengthening effect from the application of cold, only one quarter of the amount of the previous shortening by heat. I now used a stretching weight of 6 lbs., which immediately increased the length to 1·22, and in the course of thirty-six hours further increased it to 2·548 inches at the temperature 5°·4. Raising the temperature successively to 12° and 17°, the length was diminished to 2·527 and 2·459. Then on depressing it to 9°·5 and 4°·3, I observed 2·476 and 2·490. After leaving the same weight on for five hours longer, I observed lengths of 2·559, 2·514, and 2·47 with the temperatures 6°·2, 12°·4, and 20°·2, and 2·483 and 2·498 at temperatures successively depressed to 12° and 5°. After the lapse of twenty-two hours more, I found the lengths 2·624, 2·568, and 2·51 at the temperatures 6°·2, 13°·6, and 22°; and 2·523 and 2·548 on depressing the temperature to 13° and 6°·4. All these observations show the gradual elongation effected by tension, the tendency of heat to restore the original length, and the increase or decrease of elastic force with the elevation or depression of the temperature of the rubber.

39. I now reduced the stretching weight to 1 lb., being that of the tube and the water contained by it. The observed length was 1·63, and in forty-five minutes further decreased to 1·621. Afterwards it began to increase gradually; in five hours attaining to 1·635, in seventeen more to 1·724, and after a further lapse of forty hours to 1·751. These observations were at 7°·1. Then raising the temperature to 21°·6, the length was reduced to 1·191; and on depressing it again to 7°·4, the length was further reduced to 1·181. Keeping the rubber at the same temperature it still continued to contract, and in two hours its length was only 1·17. Then on raising the temperature to 23°, and afterwards depressing it to 7°·2, the length was successively reduced to 1·151 and 1·141. These and similar observations were continued for several days with like results, confirming my previous remarks, and also developing the curious fact, that when a piece of india-rubber, which has been previously gradually lengthened by stretching, is shortened by the temporary application of heat, the shortening effect continues to go on for some time, even if the rubber has been reduced to its previous temperature.

40. Although my experiments, already detailed, on the thermal effects of stretching india-rubber were not, on account of the imperfect elasticity of that substance at low temperatures, well calculated to give exact numerical results, the general conclusion derived from them is perfectly in accordance with Professor THOMSON'S formula, where, in this instance e, the expansion, being negative, the result indicated is a rise of temperature on the application of the tensile force.

41. When, by keeping india-rubber at rest at a low temperature for some time, it has become rigid, it ceases to be heated when stretched by a weight, and, on the contrary, a cooling effect takes place as in the metals and gutta percha. The experiment by which I ascertained this fact was made with a piece of india-rubber $\frac{1}{4}$ of an inch square, which had been exposed for several days to a temperature not lower than 5° Cent. In this state it was found that the application of a tensile force of 14 lbs. produced a deflection of 20′, indicating cold, and that a contrary deflection, indicating heat, was produced by removing the weight. After raising the temperature of the rubber to 15°, the elasticity of the rubber was restored, and the reverse phenomenon of heat on stretching produced, indicated by a deflection of 15′.

42. "*Vulcanized*" *India-rubber.*—I observed the principal physical characters of this substance before I was acquainted with Mr. GOUGH'S discovery of the properties of simple india-rubber, above noticed. The superior permanency of the elasticity of rubber in combination with sulphur, and its unimpaired existence at low temperatures, rendered it better qualified for experiments in which accurate numerical results were desired.

43. I determined the *specific heat* of vulcanized india-rubber from portions of the specimens used in the experiments about to be detailed. The method of mixtures was employed, a quantity in small bits being raised to a given temperature in a bath of air, and then plunged into a thin copper can partly filled with cold water. The result, reliable to at least one-tenth of its amount, was 0·415.

44. The *expansion by heat* was found by weighing in water 2°·25 above and 2°·25 below the maximum density. The result showed a cubical dilatation of 0·000526 per degree Centigrade, an expansion greater than that of any other solid hitherto examined.

45. Mr. GOUGH has stated that the specific gravity of india-rubber is increased by stretching it; and to this he attributes the heat thereby evolved. The experiment, however, is a very delicate one, and it does not appear that this philosopher possessed the means of arriving at a reliable result. My experience with vulcanized india-rubber leads me to doubt the accuracy of Mr. GOUGH'S conclusion. I weighed elastic bands alternately stretched and unstretched in water. The result of the first series of experiments was, that the bands unstretched had a specific gravity ·996057, but when pulled twice their natural length, ·994641. The second series gave me for the specific gravity of the unstretched bands ·990918, but when pulled to two and a half times the natural length, ·988483. The same vulcanized india-rubber bands were used in both series, and the diminution of the specific gravity in the second series is owing to the constant loss of sulphur taking place. On account, however, of the alternation of the experiments in

each series, this circumstance does not affect the conclusion that the action of tension on a band of vulcanized india-rubber sensibly diminishes its specific gravity.

46. In my experiments on the thermal effects of stretching vulcanized rubber, a piece about $\frac{3}{8}$ths of an inch square, and weighing 1452 grs. to the foot, was employed. The upper end was made fast, and to the lower, weights could be applied and removed at pleasure. A thermo-electric junction of thin copper and iron wires was inserted in a slit made in the direction of the length of the thong and near its middle. Also pins were stuck into the rubber at 4 inches distance from each other, in order to measure its length under various tensile forces. The following is a Table of results:—

Stretching weight in pounds.	Length of measured part, under tensile force, in inches.	Deflection of thermo-multiplier.	Thermal effect indicated by the deflection.
0	4	0° $0'$	0°
2	4·06	−1·4	−0·003
4	4·12	−2	−0·004
7	4·3	−2·4	−0·004
14	4·8	−0·5	−0·001
21	5·21	7·9	0·014
28	5·87	29·1	0·053
35	6·6	51·9	0·095
42	7·25	1 15·7	0·137
49	7·75	1 39·3	0·180

47. The data for turning the deflections in the third column into the thermal effects in the fourth, were obtained by immersing the rubber, to a point above the place where the thermo-electric junction was inserted, in water of different temperatures.

48. These experiments developed the following facts:—1st. That the effect of laying on the weights was not sensibly different in quantity from the reverse effect of removing them. 2nd. That with light weights and a low temperature there was a slight cooling effect on the application of tensile force, which, first increasing with the weights laid on, ultimately changed into a heating effect, increasing much more rapidly than the stretching weight.

49. The temperature of the thong during the experiments was 7°·8. I found that at temperatures a few degrees higher, the reverse action with weak tensile forces did not take place, but that there was, on the contrary, a very slight heating effect.

50. Professor THOMSON suggesting to me that in those circumstances in which the rubber was heated by being stretched, it would contract its length under tension when its temperature was raised, I arranged the same piece with which the foregoing experiments were made in the manner already described in the case of common india-rubber. The method pursued was to observe the lengths at several temperatures successively raised, and then at similar temperatures descending. The necessity for this arose from the circumstance that a gradual elongation took place, particularly at the higher temperatures, and by taking the mean of the ascending and descending series, I hoped to eliminate the error thus arising. I give the following experiments in the order in which they were made:—

Tensile force in pounds.	Temperature successively raised.	Length in inches.	Temperature successively lowered.	Length.	Mean temperature of the two series.	Mean length.	Shortening per degree Cent. from 0°.
14	13°·4	4·899	9°·2	5·008	11°·3	4·953	$\frac{1}{2854}$
	22·5	4·894	21·5	4·979	22	4·936	
	32	4·888	30·8	4·952	31·4	4·920	
	48·6	4·888	……	……	48·6	4·888	
7	7·95	4·569	8	4·476	7·97	4·522	$\frac{1}{3536}$
	22	4·526	19·1	4·480	20·55	4·503	
	33·2	4·481	31·5	4·481	32·35	4·481	
	50·1	4·468	……	……	50·1	4·468	
21	2·8	5·497	6	5·661	4·4	5·579	$\frac{1}{2124}$
	18	5·468	17·4	5·612	17·7	5·540	
	33	5·458	32·4	5·540	32·7	5·499	
	50	5·459	……	……	50	5·459	
28	1·4	6·398	4·4	6·513	2·9	6·455	$\frac{1}{1001}$
	18	6·298	18	6·435	18	6·366	
	33·6	6·224	34	6·302	33·8	6·263	
	49·6	6·153	……	……	49·6	6·153	
35	1·8	7·467	3·4	7·589	2·6	7·528	$\frac{1}{687}$
	19	7·264	18	7·432	18·5	7·348	
	34	7·121	33	7·250	33·5	7·185	
	49·8	7·009	……	……	49·8	7·009	
42	−0·4	8·604	2·6	8·792	1·1	8·698	$\frac{1}{628}$
	17	8·415	16·6	8·575	16·8	8·497	
	34	8·195	32	8·327	33	8·261	
	50	8·020	……	……	50	8·020	

51. The above results completely justify the anticipation of Professor THOMSON, and, as we shall presently see, afford a remarkable confirmation of his theory. Before, however, instituting a comparison between theory and experiment, it will be proper to observe that the length of the rubber at the low temperatures beginning and ending each experiment show a gradual elongation. To this circumstance chiefly is it owing that so considerable a shortening effect took place with 7 lbs. tension; for a tensile force of 14 lbs. having been just previously tried, a certain amount of increased length of the nature of *set* was produced, which being taken out by heating the rubber under less tension, caused a greater apparent contraction by heat. On lowering the temperature again, a small contraction took place, which, being corrected for the gradual elongation of the rubber, gave me $\frac{1}{9009}$ as the expansion by heat under the tension of 7 lbs.

52. The following Table gives the theoretical estimate, compared with the experimental result, for each additional tensile force of 7 lbs. :—

Weight laid on in pounds.		$\frac{t}{J}$.	p.	e, or mean expansion by heat between permanent and temporary tension.	$\frac{1}{s}$.	$\frac{1}{w}$, or reciprocal of mean weight per foot.	Theoretical result, or product of the preceding five columns.	Experimental result taken from the foregoing Table.	Experimental result corrected for elongation of rubber by use.
Permanent.	Temporary.								
0	7	$\frac{281}{1390}$	−7	$+\frac{1}{9009}$	$\frac{1}{\cdot 415}$	$\frac{1}{\cdot 1917}$	$-0^{\circ}\cdot 002$	$-0^{\circ}\cdot 004$	$-0^{\circ}\cdot 004$
7	14	$\frac{281}{1390}$	−7	$-\frac{1}{5003}$	$\frac{1}{\cdot 415}$	$\frac{1}{\cdot 1759}$	+0·004	+0·003	+0·003
14	21	$\frac{281}{1390}$	−7	$-\frac{1}{2435}$	$\frac{1}{\cdot 415}$	$\frac{1}{\cdot 1576}$	+0·009	+0·015	+0·016
21	28	$\frac{281}{1390}$	−7	$-\frac{1}{1360}$	$\frac{1}{\cdot 415}$	$\frac{1}{\cdot 1383}$	+0·018	+0·039	+0·043
28	35	$\frac{281}{1390}$	−7	$-\frac{1}{814}$	$\frac{1}{\cdot 415}$	$\frac{1}{\cdot 1194}$	+0·035	+0·042	+0·047
35	42	$\frac{281}{1390}$	−7	$-\frac{1}{656}$	$\frac{1}{\cdot 415}$	$\frac{1}{\cdot 1031}$	+0·050	+0·042	+0·050
0	42						+0·114	+0·137	+0·155

53. In the last two columns of the above Table are recorded the actual quantities of heat observed in the experiments given in (46), and the same corrected on account of the thong not having then been so much stretched by use. I am of opinion, however, that this circumstance would not cause any material difference in the thermal effect of a given strain, and that therefore the last column but one is the proper one to compare with theory, which it will be found to do quite as well as could have been expected.

54. After the experiment on the contraction by heat of the thong when it was stretched by 42 lbs., I removed all the weights except 2 lbs., and then a day or two afterwards observed as follows:—

Temperature successively raised.	Length.	Temperature successively lowered.	Length.	Contraction per degree of temperature raised.	Contraction per degree of temperature lowered.
$-0^{\circ}\cdot 4$	4·445	$3^{\circ}\cdot 2$	4·236		
25	4·339	26	4·251	$\frac{1}{1212}$	$\frac{1}{8260}$
50	4·26	50	4·26		

55. It will be observed that the effect of a rise of temperature in the above experiment was to take out the *set* which had been given to the thong by previous experiments at higher tension. Afterwards, the effect of cooling, as shown in column 4, is a contraction so great, as to prove that the *set* continued to be taken out after the heat which commenced its removal was withdrawn. That this was the case was proved by repeating the experiment several times, using the same weak tension of 2 lbs.; when the lengths at $8^{\circ}\cdot 8$ and $52^{\circ}\cdot 8$ were found to be 4·241 and 4·254 respectively, indicating an expansion of only $\frac{1}{14376}$ per degree.

56. On removing all tensile force, and applying a moderate warmth, the thong

returned to the same length it had at the commencement of my experiments with it, viz. exactly 4 inches.

57. In order to try the thermal effects of stretching vulcanized india-rubber for a greater range of tensions, I inserted a very fine thermo-electric junction into the breadth of an elastic ring 2 inches in diameter and weighing 30 grains. The ring, when pulled sufficiently to make the two sides parallel, became a double band 3·3 inches long, which elongated further to 6·8 inches with a tension of $2\frac{1}{2}$ lbs. The results I arrived at are as follow:—

Permanent weight in pounds.	Length with permanent weight in inches.	Weight laid on in addition to the permanent weight.	Length with the additional weight.	Thermal effect in degree Centigrade.
0	3·3	2·5	6·8	0·110
2·5	6·8	2	10·9	0·242
4·5	11	2	14·6	0·330
6·5	14·8	2	17·2	0·132
8·5	17·8	2	18·5	0·088
10·5	18·9	2	19·4	0·068
12·5	19·7	2	20·1	0·004
14·5	20·5	4	20·9	0·001
18·5	21·1	2	21·3	0·009
20·5	21·7	4	22	0·044
24·5	22	4 band broke.		
			Sum ...	1·028

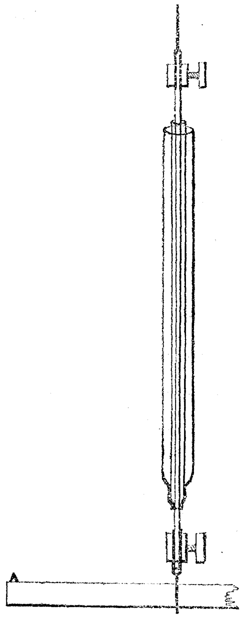
58. The Table shows that the rise of temperature occasioned by stretching vulcanized india-rubber bands up to their breaking-point is about 1° Centigrade, a quantity which I regard as erring somewhat in deficiency, owing to the attenuation of the band under high tension preventing the full communication of heat to the junction. The thermal effect is evidently greatest when the rubber receives the greatest elongation by an additional weight. When the band was stretched to six times its original length, little further elongation took place by increasing the tensile force, very little thermal effect being at the same time produced. I thought it possible that in this case a small cooling effect might exist, but after many trials did not succeed in finding it, owing probably to frictional generation of heat near the breaking-point.

59. *Wood.*—The physical properties of this substance have great interest, from its various applications to the wants and luxuries of mankind. On making experiments on the thermal effects of its extension and compression, I soon found anomalies which induced me to investigate at some length its expansion by heat, its elasticity, and the variations of these arising from such modifying influences as temperature, moisture, and tension.

60. The apparatus I employed will be understood from the following sketch, in which a wooden rod is represented as passing through a glass tube, which again passes through a wide tube of gutta percha. This latter fits tightly at its lower end on the glass tube, which again is made tight to the wood by means of a piece of india-

rubber tube. Mercury or water may be poured into the interstice between the glass tube and the wooden rod, and so serve as the means of convection of heat from the water with which the gutta-percha tube is filled. A stopcock enables one to change this water when desired. The ends of the rod are held by suitable clamps, which are attached, one to a firm upper support, the other to a lever of which one extremity has a knife-edge resting on a steel plate, and the other is furnished with a micrometer consisting of a glass plate, divided into $\frac{1}{200}$ths of an inch, examined by a microscope. The weight of the lever alone produced a tension of 35 lbs., which could be further increased by the addition of weights. When a very weak tension was desired, a lighter lever was employed.

Fig. 7.



61. Preliminary trials informed me of the time (never exceeding five minutes) required to bring the rod sensibly to the temperature of the water in the gutta-percha tube; I also found that the most ready means of obtaining uniform temperature in this water was to fill the tube twice, allowing a little intervening time. The observations of the micrometer were generally made at intervals of five minutes; the first observation being at a low temperature, the second at a high temperature, and the third at a low temperature again. The mean of the first and third observations gave me the length at the low temperature, the difference between which and the length at the high temperature, gave me the expansion of the rod. When a high tension was employed, gradual elongation frequently took place for so long a time, that I did not wait till it had entirely ceased. The system of observation employed was, however, such as prevented error arising from this circumstance; and since the gradual elongation was more rapid as the temperature was raised, the precaution was taken to expose the rod to the high temperature for the same space of time immediately before and after each micrometer observation at the high temperature.

62. *Bay Wood.*—The piece selected was well seasoned and very straight in the grain. Its length was 46·63 inches; the part passing through the glass tube and exposed to change of temperature measuring 33 inches. The diameter of the rod was $\frac{3}{8}$ths of an inch, and its weight, in the first instance, about 196 grains to the foot. Mercury poured into the inner glass tube formed the means of conducting heat from the surrounding water to the rod. The following Table contains the observed expansions after various intervals of time:—

Interval of time between the successive determinations.	Tension on the rod, in pounds.	Expansion per degree Centigrade.
	35	·000004612
A few hours	435	·000005665
Two or three days	35	·000004372
A few hours	435	·000005685
Two or three days	35	·000003952
A few hours	435	·000004699
Two or three days	35	·000004003
A few hours	435	·000004850
Mean for	35	·000004235
Mean for	435	·000005225

63. The above experiments manifest most strikingly the effect of tension in increasing the expansibility of wood, that with 435 lbs. being nearly one quarter greater than that with only 35 lbs. The gradual diminution of the coefficient perplexed me a good deal at first, particularly as the mercury in contact with the wood prevented the access of air to its sides, but I was ultimately able to refer it to the gradual absorption of moisture through the pores in the direction of the length of the rod.

64. The rod was now exposed to a tension of 435 lbs. for twenty-two days, at the end of which time its expansion by heat was found to be ·000004784. The weights were then removed so as to reduce the tension to 35 lbs. After remaining two days in this state, the first effect was found not to be expansion, but, on the contrary, a contraction amounting to ·000002408 per degree. Then the subsequent application of cold produced a contraction of ·000005705. On raising the temperature again after an interval of five minutes I found an expansion of ·000002170, and then on cooling, a contraction of ·000005017. After twenty minutes I found that the expansibility by heat, indicated by the mean effect of raising and depressing the temperature alternately, was ·000003575.

65. From the above it appears that wood has to a certain extent the property possessed by india-rubber, of returning from a state of strain on the application of heat. Mr. HODGKINSON has observed this property in iron; I have noticed it in whalebone, hair, leather, and to a slight extent in copper.

66. The increase of expansibility with tension suggested that the force of elasticity of wood decreases with a rise of temperature. To try this I affixed a graduated glass plate to the top of the glass tube (see fig. 7), while parallel and close to it another divided glass plate was affixed to the wooden rod. The extension of the rod under various tensile forces was thus read off by means of a microscope in $\frac{1}{200}$ths of an inch and fractions of the same appreciable to $\frac{1}{20}$th of the actual divisions. The mean of several series of trials gave me, at a low and high temperature, the following indications of the micrometer, with stretching weights increased by 100 lbs. at a time until 435 lbs., and then decreased by the successive removal of the weights again.

Tension.	Micrometer observations, the temperature of the wood being 15°·99.	Micrometer observations, the temperature of the wood being 41°·78.
35	0	0
135	4·199	4·381
235	8·539	8·914
335	12·890	13·415
435	17·135	17·743
335	12·830	13·392
235	8·579	8·968
135	4·373	4·602
35	0·231	0·268

67. $17{\cdot}135-\frac{{\cdot}231}{2}=17{\cdot}02$, and $17{\cdot}743-\frac{{\cdot}268}{2}=17{\cdot}609$, which are therefore the elastic strains in $\frac{1}{200}$ths of an inch, produced by a tension of 400 lbs. at the respective temperatures 15°·99 and 41°·78, the length of the rod being 33 inches. These results, reduced to unity of length and temperature, give the difference between ·000099953 and ·000103410, or ·000003459, as the quantity by which the expansion by heat of the wood ought to be increased by adding a tension of 400 lbs. Referring above, it will be seen that this increment is actually only about ·000001. I believe that two causes are concerned in producing this discrepancy. In the first place, I have reason to think that when tension is applied to wood and various other substances, a strain takes place of the nature of *set* besides the true elastic strain, which set is almost instantaneously taken out again on the removal of the tension; also that this temporary set increases with the temperature. Secondly, I think that when the expansion by heat of a body under tension is observed, the tendency of heat to take out *set* operating in a contrary direction to the expansive action, causes a slight apparent diminution of the latter. It will thus happen that the apparent decrease of elasticity by heat is greater than the real, while the apparent increase of expansion by heat, in consequence of the application of tension, is less than the real. These observations will be found to receive further confirmation from the phenomena of the elasticity of moistened wood, and also in the case of whalebone, a substance in which the characteristics of wood as regards *set* are very strongly developed.

68. YOUNG'S modulus of elasticity, deduced from the above data in terms of the length of a rod weighing one lb. to the foot, which would be extended by unity by the tensile force of one lb., is 5539710 and 5354349 for the temperatures 15°·99 and 41°·78 respectively.

69. The same rod of bay wood was now employed to determine the effects of hygrometric condition on its expansion and elasticity. Mercury or water was employed as the medium for conducting heat between the glass tube and the wood. When mercury was employed, some inconvenience resulted from its entry into the pores of the wood. Ultimately I found that the heat was conveyed with sufficient rapidity when air only occupied the narrow space intervening between the glass and the wood.

Remarks.	Weight of rod per foot in grains.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear expansion or contraction per degree Centigrade.	YOUNG's modulus of elasticity or length of rod, 1 lb. per foot, which would be extended unity by one lb.
				° °		
Moistened by immersion in water a short time. Experiment made half an hour afterwards	201	Mercury ...	35 435	42·27 and 15·2 42·3 and 16·01	·000002255 E. ·000004109 E.	
Moistened further by immersion under water forty hours. Experiment made shortly afterwards	227	Mercury ...	35 35 35 435	21·6 and 10·8 33 and 13·3 49·6 and 11·7 37·33 and 13·4	0 ·000000176 E. ·000000436 E. ·000001140 E.	 5721154 at 38°·2 6086956 at 12·4
Dried before a fire for twenty hours	196	Mercury ...	35 435	40·6 and 12·3 40·6 and 13·6	·000004555 E. ·000005481 E.	7472530 at 13
Immersed in alcohol for two days	215	Alcohol ...	35 435	31·5 and 12·8 37·05 and 14·72	·000002692 E. ·000003000 E.	
After immersion for one week in water, sp. gr. being then 0·82	291	Water	35 435	39·3 and 12·7 36·5 and 13·5	·000000388 C. ·000000327 E.	5948141 at 10·4 5242724 at 37
After it was kept warm before a fire for five days in frosty weather it became electrified on rubbing it with the hand, and retained its charge a long time	176	Mercury ...	35	39·3 and 11·7	·000004516 E.	7309582 at 13

70. *Deal.*—My next experiments were on a rod of St. John's Pine, perfectly free from knots and straight in the grain. Its diameter was $\frac{3}{8}$ths of an inch, and the length subjected to thermal influence 33 inches, as before.

Remarks as to the condition of the wood.	Weight of rod per foot in grains.	Proximate specific gravity.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear contraction or expansion per degree Centigrade.
Dried by remaining before a fire a few hours	132·4	......	Mercury ...	35 235	41°·7 and 13°·43 41·5 and 15·41	·000004277 E. ·000004379 E.
Moistened by immersion for a few hours in water..........................	172	·557	Water	35	48·7 and 15·36	·000000768 E.
Boiled in water, and then left immersed in cold water some hours ...	241·2	·761	Water	35 35	41 and 12·78 24·5 and 12·98	·000000377 C. ·000000360 C.
Left immersed in water three days longer	272·4	·854	Water	35	48·7 and 14·62	·000000636 C.
Left several days longer immersed in water	303·6	......	Water	35	12·7 and 2·7 36·4 and 7·5 40·8 and 28·8 63·6 and 38·6	·000000235 C. ·000000260 C. ·000000088 E. ·000000446 E.
Dried before a fire for several days, until it could be electrified by rubbing with the hand.....................	128·8	......	Air	35	37·16 and 11·57	·000004342 E.
Covered with pitch..........................	141·8	......	Air	35	32·2 and 10·83	·000004030 E.

71. *Deal cut across the grain.*—The specimens were cut at right angles to the pores of the wood, but obliquely in respect to the concentric rings which indicate the growth of the tree. The length subjected to thermal influence was 12 inches.

Remarks on the condition of the wood.	Weight of rod per foot in grains.	Proximate specific gravity.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear contraction or expansion per degree Centigrade.	YOUNG's modulus of elasticity or length of rod, 1 lb. per foot, which would be extended unity by 1 lb. tension.
				lbs. oz.	° °		
Dried before the fire for several days until it could be electrified by rubbing with the hand, and retain the charge a long time	204·2	·428	Mercury ...	4 5 16 5	36·9 and 7·35 38·5 and 8·9	·000041666 E. ·000045928 E.	203732
Boiled in water a few minutes, then left immersed in water for one day.........	593·2	1·122	Water	4 5 4 5	33·1 and 4·38 52 and 6·1	·000004497 C. ·000006455 C.	

72. The length of the wood saturated with water was 1·062 of its length in the dry state. In the saturated condition it broke after a tension of $17\frac{1}{3}$ lbs. had been applied for half a minute. The specific gravity of the wood, considered apart from the air or water absorbed, was found to be 1·506.

73. The following Table contains the results of experiments with a rod of deal, similar to the last, also cut across the grain:—

Remarks on the condition of the wood.	Weight of rod per foot in grains.	Extreme length in inches.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear contraction or expansion per degree Centigrade.	YOUNG's modulus of elasticity or length of rod, weighing 1 lb. per foot, which would be extended unity by 1 lb. tension.
Dried before a fire until it could be electrified by friction	193·5	15·625	Mercury	4·3	37°·5 and 10°·9	·000042470 E.	188120
On immersion in water, the wood absorbed in a few minutes sufficient moisture to make it weigh 243 grs. per foot. Its length was then 15·8; but after allowing it to rest two hours its length became 16·24, without receiving any additional water in the interim. Twelve hours afterwards its length was 16·3, and its weight per foot 228·2 grs.	228·2	16·3	Mercury	4·3	35·1 and 10·7	·000065153 E.	104600
Further immersion in water ...	270·5	16·594	Mercury	4·3	41·3 and 10·91	·000000380 E.	60033
Immersed several hours in water; specific gravity then was found to be ·891	446	16·625	Mercury	4·3	43·2 and 10·95	·000005404 C.	38257
Boiled in the exhausted receiver of an air-pump, and afterwards left immersed in water several hours; sp. gr. 1·143	573·4	16·7	Water ...	4·3 7·3	34·5 and 13·25 27·2 and 12·12	·000002201 C. ·000001105 C.	29618
Dried a little by placing it a short time before a fire ...	434·4	16·63	Air	4·3	39·03 and 12·8	·000003159 E.	
	444·0	16·63	Water ...	4·3	34·9 and 12·7	·000001561 C.	
Dried still further	358	16·62	Air	4·3	37·38 and 13·3	·000010390 E.	
	370	16·62	Water ...	4·3	43·8 and 15	·000001356 C.	

TABLE (continued).

Remarks on the condition of the wood.	Weight of rod per foot in grains.	Extreme length in inches.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear contraction or expansion per degree Centigrade.	YOUNG's modulus of elasticity or length of rod, weighing 1 lb. per foot, which would be extended unity by 1 lb. tension.
Dried still further	231·5	16·48	Air	4·3	37°·7 and 10°·24	·000084212 E.	96170
Water poured between the glass tube and the rod. Then after a short time ...	......	......	Water ...	4·3	37·2 and 10·3	·000058836 E.	82430
After ten minutes more had elapsed	......	......	Water ...	4·3	40·9 and 12·15	·000019457 E.	
After another ten minutes	......	......	Water ...	4·3	37·6 and 12·3	·000004815 E.	
After another ten minutes	......	......	Water ...	4·3	42 and 12·3	·000001017 C.	
After another ten minutes; sp. gr. ·5646	272·3	16·656	Water ...	4·3	39·34 and 12·53	·000002951 C.	
			Air	4·3	37·5 and 9·7	·000000817 C.	
Dried some hours in a moderately heated oven	206	15·55	Air	4·3	41·5 and 9·77	·000038620 E.	
Immersed in oil under the exhausted receiver of an air-pump	329	15·54	Air	4·3	38·8 and 10·6	·000043670 E.	

74. The specific gravity of the wood, considered apart from the air or water in its pores, was in the above specimen found to be 1·595.

75. The following are deductions from the above experiments:—1st. That tension increases the expansibility of wood by heat. 2nd. The expansibility of dry wood cut across the grain is about ten times as great as its expansibility when cut in the direction of the grain. 3rd. The length of wood cut longitudinally is a little increased by the absorption of water; but when cut crossways, a very great augmentation, as is well known, takes place. 4th. When water is absorbed into the pores of wood cut longitudinally its expansibility decreases, until ultimately it passes into contraction by heat. 5th. When water is absorbed into the pores of wood cut across the grain, its expansibility appears to increase in the first instance, then decreases until it changes into contraction, which, after increasing with the absorption of water to a certain point, seems to diminish as the wood becomes completely saturated. 6th. Cut lengthways, the elasticity of wood appears to be lessened by the presence of water; when, however, it is cut across the grain, the effect of moisture is very greatly to impair the elastic force. 7th. A short period of immersion enables wood cut crossways to take up sufficient water to make it contract by heat; but, on the contrary, wet wood partially dried on the surface is expanded by heat. So that we may have contraction or expansion of wood charged to the same extent with water, according probably to peculiarities in the distribution of the water among the pores.

76. When wet wood, cut across the grain, is dried, it gets shorter very gradually, in consequence of a tendency to retain its former dimensions. The strain thus arising may be removed by raising the temperature, which speedily reduces the wood to the length due to its state of dryness. The same kind of effect takes place, but in the reverse

order, in wood which is taking up water. It does not immediately assume the length due to the state of hygrometry, but if heated the set is taken out, and the wood expands to its proper length.

77. Inasmuch as at a certain degree of humidity wood contracts in every direction with a rise of temperature, it might be inferred that on weighing it in water its specific gravity would be found to increase on the elevation of temperature. Such, however, is not the fact. A piece of saturated wood, being part of the specimen employed in the last series of experiments, was found to weigh 392·6 grs. in air, 42·26 grs. in distilled water at 0°, and 42·01 grs. in distilled water at 8°. Hence the cubical expansion was ·0000892 per degree, but calculated on the wood considered apart from the water in its pores, ·000396. Therefore on raising the temperature a decrease of specific gravity occurs simultaneously with a diminution in the external dimensions of the wood. This can only take place in consequence of a contraction of the surfaces of the walls of the cellular structure, while the actual bulk of the material of which they are composed is increased, a certain minute quantity of water exuding at the same time.

78. The phenomenon in question is therefore, I believe, owing to capillary attractions, which, diminishing with elevation of temperature, has the effect of removing a part of the swelled condition due to that action. Dr. YOUNG has given $\frac{1}{555}$ as the descent of water in a narrow tube due to a rise of temperature of 1° Cent. The fraction arrived at by M. C. WOLF is $\frac{1}{525 \cdot 67}$. To apply the latter estimate to the foregoing results, we find from the last Table that between extreme dryness and perfect humidity the wood increased in length from unity to 1·068. Hence, on the hypothesis that the contraction by heat is owing to diminution of capillary attraction, it ought to be equal to ·0001293 minus the expansion in the dry condition. An examination of the foregoing Tables will be found to afford ample support to this view.

79. *Ratan Cane.*—My observations of the expansion and elasticity of this substance are comprised in the following Table. The length exposed to thermal influence was 33 inches.

Remarks on the condition of the wood.	Weight of rod per foot in grains.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear contraction or expansion per degree Centigrade.	YOUNG's modulus of elasticity, or length of rod, weighing 1 lb. per foot, which would be extended unity by 1 lb. tension.
Dried by placing it before a fire for a short time ...	150·2	Mercury ...	35 91	25°·3 and 11°·67 28·05 and 12·09	·000024750 E. ·000027000 E.	1094242 at 10°·6 918179 at 34 956720 at 29 1048546 at 12
Wetted by immersion under water for a few hours...	208	Water	35	26·6 and 11·04	·000001436 C.	
Dried by exposure before a fire for several hours ...	145	Mercury ...	35	27·8 and 11·1	·000016740 E.	1214179 at 12

80. The following are the results of my experiments on rose, vine, and poplar. These were sprouts of recent growth, selected for their straightness. They were cut from

the tree in November, directly before the experiments. I have also inserted in the Table the expansion and elasticity of wheat-straw.

Kind of wood, &c.	Weight of rod per foot in grains.	Medium of communication of heat between the glass tube and the rod.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear expansion or contraction per degree Centigrade.	YOUNG's modulus of elasticity, or length of rod, weighing 1 lb. per foot, which would be extended unity by 1 lb. tension.
Rose wood in the green state, the bark not removed; sp. gr. ·638 ...	171·6	Water	35 91	46° and 14°·53 42 and 16	·000000240 E. ·000001101 E.	
Vine in the green state, bark not removed	116	Water	35	28·6 and 11·3	·000002121 E.	
Poplar in the green state, bark not removed	158·6	Water	35 40	23·2 and 10 39 and 9	·000000773 C. ·000000037 E.	
Wheat-straw dried before a fire	14·8	Air	5·2	33·4 and 11	·000004865 E.	3520625
Wheat-straw moistened by immersion in water ...	38·1	Air	5·2	16·8 and 12·13	·000000329 C.	982978

81. Cane, like wood cut in the direction of the grain, increases slightly in length in consequence of being moistened. The expansion by heat being diminished at the same time, it follows that the increment due to moisture is less when taken at a high than at a low temperature.

82. The following Table records my observations on the expansion and elasticity of paper, leather, and whalebone. The length exposed to thermal influence was 33 inches.

Remarks.	Weight per foot in grains.	Medium of communication of heat between the glass tube and the substance.	Tension in pounds.	Limits of temperature between which the experiments were made.	Linear expansion per degree Centigrade.	YOUNG's modulus of elasticity, or length, weighing 1 lb. per foot, which would be extended unity by 1 lb. tension.
A strip of cardboard one-third of an inch broad, dried before a fire	35	Air	5·2	39°·4 and 9°·4	·000015780	
A strip of cardboard one-third of an inch broad, moistened with water, which increased its length $\frac{1}{48}$th.	39·8	Air	5·2	40·3 and 11·5	·000026520	
A strip of cardboard one-third of an inch broad, moistened still further, which increased its length still further, $\frac{1}{120}$th.	47	Air	5·2	39·45 and 12·2	·000028950	
Cowskin leather dried before a fire. A narrow strip	17·55	Air	5·2	27·77 and 11·5	·000038720	227586
Cowskin leather moistened with water	19·95	Air	5·2	29 and 10·47	·000047116	167813
Cowskin leather moistened still further	25·8	Air	5·2	24·25 and 9·75	·000054401	118642
Whalebone, a strip one-third of an inch broad. Dry	60	Air	35 70	24·4 and 9·27 24·35 and 9·9	·000052200 ·000055020	1176554 at 10°
Whalebone, a strip one-third of an inch broad, moistened with water...	71·8	Air	5·2	23·7 and 11	·000024270	

83. It will be observed that an increase in the expansibility by heat of paper and leather was produced by moisture. It is probable, however, that had they been more thoroughly saturated, the expansion would again diminish, as in the case of wood cut across the grain, in which, although the expansibility in the first instance increased with the application of moisture, it ultimately changed into contraction when the wood became more completely saturated. I think that a cause tending to increase the expansibility in consequence of the application of moisture exists in every case; but that it is modified, and in wood sometimes completely overcome, by the effect of decreased capillary attraction with rise of temperature, to which I have already adverted.

84. Upon the facility with which hot moistened whalebone can be moulded into form, and the permanency with which it keeps the shape in which it is cooled, much of its use in the arts depends. When heat is applied to whalebone, thus cooled in a constrained state, it at once returns to its original shape. Even when cold moistened whalebone is strained, it returns almost immediately to its original dimensions on the application of heat. The slip of moistened whalebone employed in the experiments recorded in the last Table, 46 inches long and weighing 71·8 grains to the foot, became rapidly stretched 7 inches longer by a tension of 64 lbs. Left to itself after the tensile force was removed, it began to return gradually towards its original length, which however it at once assumed on immersion in hot water.

85. The apparent elasticity of whalebone is always somewhat less than the real, owing to the observed elongation, when tension is applied, consisting of a considerable amount of *set* as well as of elastic strain. Also when the tensile force is removed, the contraction which takes place consists of the return from *set* as well as of the elastic recoil. The interesting phenomena connected with imperfect elasticity might, I think, be very advantageously studied in this substance. The limits I had set myself did not, however, allow me to do more than obtain the following determinations of its elasticity in the dry state at two different temperatures, and with various intervals between the application or removal of tension and the corresponding observations.

Time allowed to elapse between laying on or taking off a tensile force of 35 lbs., and making the observation of length.	YOUNG's modulus of apparent elasticity, or length of rod, weighing 1 lb. per foot, which would be extended unity by 1 lb. tension.	
	At 10°·1.	At 30°·1.
15″	1176554	962450
30″	1147383	927100
1′	1119624	894545
2′	1080415	
4′	1043860	
15′	1028395	
1h	922481	

86. *Thermal effect of tension on Wood.*—My first experiment was tried on a square rod of straight-grained pine, dried, and weighing 132·4 grains to the foot. A thermo-electric junction of thin copper and iron wires having been inserted into it, its upper extremity

was clamped to a firm support, and the lower attached to a lever giving a tension of 35 lbs. On applying an additional tension of 200 lbs., the motion of the needle of the thermo-multiplier indicated cold; on removing the tension, a reverse motion of equal extent indicated the evolution of heat. The mean of several trials gave me 9′·87, the thermal value of which, determined by immersing the junction in water of various temperatures, was ·01364. Owing to the large surface of the wood as compared with its capacity for heat, it was affected by the temperature of the surrounding atmosphere nearly three times as much as the quarter-inch metal bars. I found, in fact, that during the time occupied by a swing of the needle, viz. 45″, one-fifth of the thermal effect was lost. Adding, therefore, one quarter to ·01364, we find ·01705 for the thermal effect, which, it may be observed, errs a trifle in defect, owing to the conduction of a small portion of heat along the wires of the thermo-electric junction.

87. In order to arrive at the theoretical result, it was necessary to determine the specific heat of the wood in the condition it was in when used. This was done by raising the temperature of a faggot of it in a bath of mercury, and then plunging it in a thin copper can filled with mercury at the atmospheric temperature. The fall of temperature of the wood and the rise of temperature of the can and mercury, corrected for the atmospheric influence, indicated the specific heat; which, in the case of dried St. John's pine, was found to be ·3962, and in that of dried bay wood, ·3582.

88. The theoretical thermal effect of tension in the foregoing experiment, derived from the above data and the expansion by heat at the mean tension, is

$$H=\frac{279{\cdot}4}{1390}\times\frac{-200}{1}\times\frac{1}{231053}\times\frac{1}{{\cdot}3962}\times\frac{1}{{\cdot}0189}=-0^{\circ}{\cdot}02322.$$

89. *Bay Wood.*—The rod I employed was dried until it could be electrified by rubbing. A tensile force of 400 lbs. produced a deflection of 25′·8, which the test experiment on the junction proved to indicate 0°·0475. This, increased one quarter, gives ·0594 as the actual thermal effect at the moment of the application of the tension.

90. The theoretical result, using my own determination of the specific heat of the wood, and its expansion by heat at the mean tension 235 lbs., is

$$H=\frac{278}{1390}\times\frac{-400}{1}\times\frac{1}{196858}\times\frac{1}{{\cdot}3582}\times\frac{1}{{\cdot}01886}=-0^{\circ}{\cdot}06016.$$

91. *St. John's Pine, cut across the grain.*—This specimen was dried slowly until it became electrical by rubbing. A tensile force of 14 lbs. produced a deflection of 3′·4, indicating a thermal effect of ·00494. This, increased by one quarter, gives ·00617 as the cold produced by the tension. The theoretical result is

$$H=\frac{276}{1390}\times\frac{-14}{1}\times\frac{1}{23256}\times\frac{1}{{\cdot}3962}\times\frac{1}{{\cdot}03214}=-0^{\circ}{\cdot}0093.$$

92. *Bay Wood saturated with water.*—The specific gravity of this specimen was ·933; it weighed 333 grains per foot, 157 grains being imbibed water. The mean of twenty experiments gave me ·0073 of *heat* on applying a tension of 200 lbs., and ·0013,

likewise of heat, on removing the tensile force. There could be no doubt that in this instance the imperfect elasticity of the moist wood caused a considerable quantity of heat to be generated frictionally. It may therefore be safely concluded that the thermal effect, considered apart from the result of friction, was, as in the case of india-rubber, *one of heat on the application of tension, and cold on its removal.* Its actual value would be over-estimated by $\frac{\cdot 0073-\cdot 0013}{2}=0^\circ\cdot 003$, on account of the set communicated by tension being always greater than that taken out when the tension is removed. The approximate theoretical result is

$$H=\frac{277}{1390}\times\frac{-200}{1}\times-\frac{1}{2000000}\times\frac{1}{\cdot 68}\times\frac{1}{\cdot 0476}=0^\circ\cdot 0006.$$

93. For the sake of ready comparison I have collected in the following Table the results of the foregoing experiments on the thermal effects of tension, placing by their side the results of Professor THOMSON'S theory.

Material.	Experiment.	Theory.	Theoretical thermal effect of 1 lb. tension on a prism weighing 1 lb. to the foot, at the temperature 0° Cent.
Iron	—·115	—·110	
Iron	—·124	—·110	—·0000220
Iron	—·101	—·107	
Hard steel	—·162	—·125	—·0000235
Cast iron	—·160	—·112	—·0000168
Cast iron	—·148	—·115	
Copper	—·174	—·154	—·0000355
Lead	—·053	—·040	—·0001847
Lead	—·076	—·055	
Gutta percha	—·028	—·031	—·0000769
Gutta percha	—·052	—·066	
Vulcanized india-rubber	+·114	+·137	
Pine wood	—·017	—·023	—·0000021
Bay wood	—·059	—·060	—·0000028
Pine, cross-grained	—·006	—·009	—·0000213
Wet bay wood	+·003	+·001	+·00000015

On the Thermal Effects of Longitudinal Compression on Solids.

94. *Wrought Iron.*—A pillar 2 inches long and one-quarter of an inch in diameter had a fine hole bored through it, in which a thermo-electric junction of fine copper and iron wires was inserted, as described in § 18. It was placed under the lever which had served for the tension experiments, the weight of which alone gave a pressure of 50 lbs. When, in addition to this, a pressure of 1060 pounds was applied, a deflection of 21′·3, indicating heat, was produced; and a like deflection in the opposite direction, indicating cold, was produced by removing the pressing weight. The value of the deflection, ascertained by immersing the pillar, in water of various temperatures, to within one-eighth of an inch from the thermo-electric junction, was 0°·1517. The theoretical result is

$$H=\frac{287\cdot 8}{1390}\times\frac{1060}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{\cdot 1491}=0^\circ\cdot 1645.$$

95. My next experiment was with a pillar of the same length, but half an inch in diameter, using a pressure of 1060 lbs. In pillars of this and greater diameters the experiment to test the value of the deflections was made by plunging the pillar in water, which rose a little above the orifice in which the thermo-electric junction was inserted. Thus in the present instance I found the deflection of 8′·94 to indicate a rise of temperature equal to 0°·0319. The theoretical result is

$$H=\frac{289}{1390}\times\frac{1060}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{\cdot 632}=0^{\circ}\cdot 039.$$

96. Wishing to try higher pressures, I employed a very excellent hydraulic press, the pressure exerted by which I had ascertained by experiment as far as 2000 lbs. The friction amounted to only one-seventh of the exerted force. By supplying the correction thus indicated, I had a very convenient and tolerably accurate mode of applying pressure by simply placing weights on the handle of the pump. A pressure of 6458 lbs. applied in this way, gave a deflection of 42′ at the thermo-multiplier, placed at a distance of 40 yards, which deflection was found to indicate a thermal effect of 0°·2344. The theoretical result is

$$H=\frac{285\cdot 5}{1390}\times\frac{6458}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{\cdot 632}=0^{\circ}\cdot 235.$$

97. Next I tried a pillar 2 inches long and 1 inch in diameter. When a pressure of 1780 lbs. was applied to this by the lever, the needle was deflected 10′·6, indicating a rise of temperature of 0°·01803. The theoretical result is

$$H=\frac{290\cdot 6}{1390}\times\frac{1780}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{2\cdot 533}=0^{\circ}\cdot 01642.$$

98. With the hydraulic press, pressures of 4154, 8762, and 20282 lbs., produced deflections of 9′, 21′·6, and 1° 15′·3 respectively, indicating temperatures of 0°·03157, 0°·07578, and 0°·2642. The theoretical results are—

$$H=\frac{289\cdot 8}{1390}\times\frac{4154}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{2\cdot 533}=0^{\circ}\cdot 03822,$$

$$H=\frac{289\cdot 8}{1390}\times\frac{8762}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{2\cdot 533}=0^{\circ}\cdot 08063,$$

and

$$H=\frac{289\cdot 8}{1390}\times\frac{20282}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{2\cdot 533}=0^{\circ}\cdot 1866.$$

99. On applying a pressure of 47930 lbs., the pillar was squeezed to the length of 1·88 inch, giving out about 6°, or nearly the thermal equivalent of the work thus done. Then using the lighter pressure of 37744 pounds I obtained a deflection of 2° 6′, indicating a thermal effect of 0°·442. The theoretical result is

$$H=\frac{290}{1390}\times\frac{37744}{1}\times\frac{1}{81200}\times\frac{1}{\cdot 11}\times\frac{1}{2\cdot 694}=0^{\circ}\cdot 3266.$$

100. *Cast Iron.*—A pillar 2 inches long and one-quarter of an inch in diameter being

pressed by the lever to the extent of 730 lbs. produced a deflection of 41′, which was proved to indicate a rise of temperature equal to 0°·1123. The theoretical result is

$$H=\frac{287\cdot6}{1390}\times\frac{730}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{\cdot1281}=0^\circ\cdot1091.$$

Another experiment, with 1010 lbs. pressure on another bar, gave a thermal effect of 0°·1667, theory giving

$$H=\frac{288\cdot6}{1390}\times\frac{1010}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{\cdot1346}=0^\circ\cdot1443.$$

101. Pillar, 2 inches long and half inch in diameter. A pressure of 1060 lbs. applied by the lever, produced a deflection of 6′·5, indicating a thermal effect of 0°·0454. The theoretical result is

$$H=\frac{285\cdot3}{1390}\times\frac{1060}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{\cdot57}=0^\circ\cdot0353.$$

102. Using the hydraulic press, pressures of 1850, 4154, and 8762 lbs., produced thermal effects of 0°·0822, 0°·1883, and 0°·3423 respectively. The theoretical results are

$$H=\frac{285\cdot3}{1390}\times\frac{1850}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{\cdot57}=0^\circ\cdot0616,$$

$$H=\frac{285\cdot3}{1390}\times\frac{4154}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{\cdot57}=0^\circ\cdot1385,$$

and

$$H=\frac{285\cdot3}{1390}\times\frac{8762}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{\cdot57}=0^\circ\cdot2923.$$

Under a pressure of 20282 lbs. the pillar broke diagonally, the deflection of the needle indicating an evolution of 4°·16.

103. Pillar, 2 inches long, 1 inch in diameter. A pressure of 1781 lbs. applied by the lever, gave a thermal effect of 0°·01365. The theory gives

$$H=\frac{290\cdot8}{1390}\times\frac{1781}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{2\cdot352}=0^\circ\cdot01466.$$

Using the hydraulic press, pressures of 4154, 8762, and 20282 lbs. gave thermal effects of 0°·0364, 0°·0511, and 0°·1463 respectively, the theoretical results being

$$H=\frac{290}{1390}\times\frac{4154}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{2\cdot352}=0^\circ\cdot0341,$$

$$H=\frac{290}{1390}\times\frac{8762}{1}\times\frac{1}{20139}\times\frac{1}{\cdot1198}\times\frac{1}{2\cdot352}=0^\circ\cdot0719,$$

$$H=\frac{290}{1390}\times\frac{20282}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{2\cdot352}=0^\circ\cdot1666.$$

Under 47930 lbs. the pillar was squeezed to the length of 1·78 inch. Then with the same pressure I obtained a thermal effect of 0°·4708. The theoretical result is

$$H=\frac{290}{1390}\times\frac{47930}{1}\times\frac{1}{90139}\times\frac{1}{\cdot1198}\times\frac{1}{2\cdot643}=0^\circ\cdot3505.$$

104. *Copper.*—A pillar 2 inches long and one-quarter of an inch in diameter, being pressed by 717 lbs., gave a deflection of 10′·1, indicating a thermal effect of 0°·1359. The theoretical result is

$$H=\frac{292}{1390}\times\frac{717}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{\cdot1744}=0^{\circ}\cdot156.$$

105. Pillar, 2 inches long and half an inch in diameter. A pressure of 1325 lbs. applied by the lever, gave a deflection of 30′, indicating a rise in temperature of 0°·08316. The theoretical result is,

$$H=\frac{291\cdot7}{1390}\times\frac{1325}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{\cdot7207}=0^{\circ}\cdot06972.$$

Pressures of 1850 and 4154 lbs., communicated by the hydraulic press, produced deflections of 24′·1 and 56′, indicating temperatures of 0°·1182 and 0°·2747 respectively. The theoretical results are

$$H=\frac{292}{1390}\times\frac{1850}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{\cdot7207}=0^{\circ}\cdot0974,$$

and

$$H=\frac{292}{1390}\times\frac{4154}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{\cdot7207}=0^{\circ}\cdot2188.$$

106. Pillar, 2 inches long and 1 inch in diameter. A pressure of 1792 lbs. communicated by the lever, gave a deflection of 9′·7, indicating a rise equal to 0°·0278. The theoretical result is

$$H=\frac{291\cdot2}{1390}\times\frac{1792}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{2\cdot953}=0^{\circ}\cdot023.$$

Pressures of 4154, 8762, and 20282 lbs., communicated by the hydraulic press, produced deflections of 10′·6, 33′, and 1° 9′, which were found to indicate elevations of temperature of 0°·0494, 0°·1538, and 0°·3216 respectively. The theory gives

$$H=\frac{291}{1390}\times\frac{4154}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{2\cdot953}=0^{\circ}\cdot05322,$$

$$H=\frac{291}{1390}\times\frac{8762}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{2\cdot953}=0^{\circ}\cdot1122,$$

and

$$H=\frac{291}{1390}\times\frac{20282}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{2\cdot953}=0^{\circ}\cdot26.$$

A pressure of 57146 lbs. squeezed the pillar to the length of 1·32 inch. Then, when the full amount of set had taken place, the application of the same weight gave 2° 18′ of deflection, indicating a rise of temperature equal to 0°·643. The theoretical result is

$$H=\frac{291}{1390}\times\frac{57146}{1}\times\frac{1}{58200}\times\frac{1}{\cdot095}\times\frac{1}{4\cdot474}=0^{\circ}\cdot4832.$$

107. *Lead.*—A pillar, 2 inches long and half an inch in diameter, being pressed by the

lever with a force of 350 pounds, produced a deflection of 12′·4, indicating a rise of temperature of 0°·0805. The theory gives

$$H=\frac{292}{1390}\times\frac{350}{1}\times\frac{1}{35100}\times\frac{1}{\cdot0303}\times\frac{1}{\cdot8796}=0^{\circ}\cdot0786.$$

Pillar, 2 inches long and 1 inch in diameter. A weight of 1500 lbs. applied by the lever, produced a deflection of 33′, indicating a thermometric rise of 0°·0944. Theory gives in this case,

$$H=\frac{290}{1390}\times\frac{1500}{1}\times\frac{1}{35100}\times\frac{1}{\cdot0303}\times\frac{1}{3\cdot717}=0^{\circ}\cdot0792.$$

4154 lbs. laid on by the hydraulic press, squeezed the pillar to the length of 1·8 inch. Then, when this set was fully established, the same pressure gave a deflection of 41′·6, indicating a temperature equal to 0°·1835. The theoretical result is

$$H=\frac{288\cdot6}{1390}\times\frac{4154}{1}\times\frac{1}{35100}\times\frac{1}{\cdot0303}\times\frac{1}{4\cdot13}=0^{\circ}\cdot1964.$$

108. *Glass.*—A cylindrical pillar of flint-glass, 10 inches long and $\frac{9}{10}$ths of an inch in diameter, had a thermo-electric junction of thin wires tightly bound to its side by cotton thread. A pressure of 900 lbs. applied by the lever, gave me a deflection of 10′·6, the thermometric value of which, estimated by immersing the pillar above the junction in water of various temperatures, proved to be 0°·01684. The theory gives

$$H=\frac{290\cdot8}{1390}\times\frac{900}{1}\times\frac{1}{124800}\times\frac{1}{\cdot19}\times\frac{1}{\cdot9576}=0^{\circ}\cdot0083.$$

In another experiment I obtained a deflection of 11′·3, indicating a rise of 0°·01774 when a weight of 1622 lbs. was laid on by means of the lever. In this case the theoretical result is

$$H=\frac{292}{1390}\times\frac{1622}{1}\times\frac{1}{124800}\times\frac{1}{\cdot19}\times\frac{1}{\cdot9576}=0^{\circ}\cdot015.$$

109. *Wood.*—A pillar of seasoned pine, 13 inches long and 1·4 inch in diameter, had a junction of fine copper and iron wires inserted into its centre. When 869 lbs. were laid on this pillar, a deflection of 6′·05 occurred, which was found to indicate a rise of temperature equal to 0°·0068. The theoretical result, taking my own results for expansion and specific heat, is

$$H=\frac{290\cdot4}{1390}\times\frac{869}{1}\times\frac{1}{238000}\times\frac{1}{\cdot4}\times\frac{1}{\cdot311}=0^{\circ}\cdot0061.$$

110. My next experiments were with a 3-inch cube of pine, which, being furnished with a junction of fine wires in its centre, had pressures of 4154 and 8762 lbs. applied by the hydraulic apparatus. The deflections obtained were 3′·8 and 5′·9, indicating thermal effects of 0°·0093 and 0°·0145. Theory gives in these cases,

$$H=\frac{290}{1390}\times\frac{4154}{1}\times\frac{1}{238000}\times\frac{1}{\cdot4}\times\frac{1}{1\cdot766}=0^{\circ}\cdot00516,$$

and

$$H=\frac{290}{1390}\times\frac{8762}{1}\times\frac{1}{238000}\times\frac{1}{\cdot4}\times\frac{1}{1\cdot766}=0^{\circ}\cdot01088.$$

111. When the same block was pressed, in a direction perpendicular to the grain, with a weight of 1792 lbs. communicated by the lever, a deflection of 37′·3 was produced; but when the pressure was removed, the deflection in the reverse direction amounted only to 31′·2. I believe that the excess in the result of pressure is owing to frictional evolution of heat through the imperfect elasticity of wood cut crossways to the grain. The mean, 34′·25, represents a thermal effect of 0°·0461. Theory gives

$$H=\frac{288\cdot6}{1390}\times\frac{1792}{1}\times\frac{1}{20160}\times\frac{1}{\cdot4}\times\frac{1}{1\cdot766}=0^{\circ}\cdot0261.$$

112. A second experiment gave a thermal effect of 0°·016, the theoretical result being 0°·0264. In this latter experiment the position of the block was reversed. I attribute the discordance between the two results to the difficulty I experienced in obtaining with my lever apparatus a perfectly even distribution of pressure over so large a surface as 3 inches square.

113. On exposing the block, still crossways to the grain, to a greater pressure by means of the hydraulic press, I obtained a deflection of 40′·5, indicating a rise of 0°·1 whenever a weight of 4154 lbs. was laid on, but observed no perceptible effect whatever when the pressure was removed. In this case the bulging of the wood under pressure extended to about half an inch. It was evident that frictional heat increased to a great extent the thermal effect of pressure, and that a similar though smaller frictional effect diminished the cooling effect on removal of pressure. The theoretical result, if bulging had not taken place, and supposing perfect elasticity, is

$$H=\frac{290}{1390}\times\frac{4154}{1}\times\frac{1}{20160}\times\frac{1}{\cdot4}\times\frac{1}{1\cdot766}=0^{\circ}\cdot0609.$$

114. *Vulcanized India-rubber.*—A pillar, 1·92 inch long, 1·22 inch in diameter, and weighing 692 grains, had a thermo-electric junction of thin copper and iron wires inserted into its centre. On applying pressure, the multiplier showed a rise of temperature, and when the pressure was removed, a depression took place, sensibly equal to the previous rise. The following is a Table of the results:—

Weight laid on the pillar, in pounds.	Deflection.	Heat by laying on the weight, or cold by removing it.
28	° ′ 3	° 0·0058
33	3·7	0·0072
47	6·7	0·0131
62	16	0·0312
93	32	0·0625
124	1 4·3	0·1254

With the pressure of 124 lbs. the pillar was compressed to the length 1·05 inch, and returned to 1·78 when the weight was removed.

115. The expansion of the pillar by heat, in the direction in which the pressure was applied, was found to be about $\frac{1}{1660}$ per degree Cent. Hence the theoretical result for a pressure of 124 lbs. would appear to be

$$H=\frac{287}{1390}\times\frac{124}{1}\times\frac{1}{1660}\times\frac{1}{\cdot 415}\times\frac{1}{\cdot 77}=0^{\circ}\cdot 05.$$

The excess of the actual result may be attributed to the central part, in which the junction was placed, bearing an undue share of pressure in consequence of the bulging of the waist of the pillar.

116. On examining the above Table, it will be remarked that the thermal effect increases more rapidly than the pressure. This is owing partly to the influence of a rise of temperature in increasing the elasticity of rubber under strain, to which we have already alluded, and partly to the unequal distribution of pressure to which I have just adverted. The longitudinal expansion of a pillar of vulcanized india rubber, 2·21 inches long and 1·44 inch in diameter, under various pressures, was found to be

Pressure in pounds.	Expansion per degree Cent. on the length under pressure.
0	$\frac{1}{5700}$
55	$\frac{1}{3730}$
135	$\frac{1}{2228}$

117. Being desirous of ascertaining the thermal effects of higher pressures, I made the experiments tabulated below, on a pillar 1·7 inch long and 2·5 inches in diameter.

Pressure applied or removed, in pounds.	Heat on applying pressure, or cold on removing it, in degrees Centigrade.	Length of the pillar when under pressure.	Length of the pillar after the pressure was removed.
70	0°·011	......	1·7
113	0·015		
134	0·029		
162	0·036		
242	0·052		
275	0·078		
386	0·114		
547	0·130	1·43	
1426	0·384	1·00	
2742	0·750	·72	
4058	0·885	·64	
6692	1·192	·51	1·66
11958	1·463		
22400	1·426	·36	1·68

118. After a few experiments with the last pressure the rubber burst, being ruptured in a singularly symmetrical manner at the four quadrants of its circumference. Placed in hot water, it almost immediately regained its original shape.

119. I have collected in the following Table the results of the foregoing experiments on the thermal effects of pressing pillars. In reckoning the mean, the last result in each of the series for wrought iron, cast iron, copper, and lead is rejected on account of having been obtained with a pressure nearly up to the limit of strength, and after the form and structure of the pillar had been changed by the force to which it had been subjected.

Material.	Diameter of pillar.	Experimental thermal effect.	Theoretical thermal effect.
	inch.		
Wrought iron	$\frac{1}{4}$	$^{\circ}$·152	$^{\circ}$·164
	$\frac{1}{2}$	·032	·039
	$\frac{1}{2}$	·234	·235
	1	·018	·016
	1	·032	·038
	1	·076	·081
	1	·264	·187
	1	·442	·327
	Mean	·115	·108
Cast iron	$\frac{1}{4}$	·112	·109
	$\frac{1}{4}$	·167	·144
	$\frac{1}{2}$	·045	·035
	$\frac{1}{2}$	·082	·062
	$\frac{1}{2}$	·188	·139
	$\frac{1}{2}$	·342	·292
	1	·014	·015
	1	·036	·034
	1	·051	·072
	1	·146	·167
	1	·471	·350
	Mean	·118	·107
Copper	$\frac{1}{4}$	·136	·156
	$\frac{1}{2}$	·083	·070
	$\frac{1}{2}$	·118	·097
	$\frac{1}{2}$	·275	·219
	1	·028	·023
	1	·049	·053
	1	·154	·112
	1	·322	·260
	1	·643	·483
	Mean	·146	·124
Lead	$\frac{1}{2}$	·080	·079
	1	·094	·079
	1	·183	·196
	Mean	·087	·079
Glass	$\frac{9}{10}$	·017	·008
	$\frac{9}{10}$	·018	·015
	Mean	·017	·011
Wood	1·4	·007	·006
	3	·009	·005
	3	·014	·011
	Mean	·010	·007
Wood cut across the grain	3	·046	·026
	3	·016	·026
	3	·050	·061
	Mean	·037	·038
Vulcanized india-rubber	1·22	·125	·050

120. The above results, as in the case of the tension experiments, indicate a slight excess of experiment over theory. I at first thought that this might be owing to the diminution of elastic force by heat in metals, of which I had not taken account as in wood, for in applying or removing tension the thermal effect would be increased in consequence of the increased expansion by heat in such a case. This cause would, however, diminish the thermal effect of the application or removal of pressure. The discrepancy must therefore be referred to experimental error, or to the incorrectness of the various coefficients which make up the theoretical results. Having, however, been led to believe that with a rise of temperature a certain change of elasticity takes place in metals, although too minute to be appreciated in the foregoing results, I made some experiments in which spirals weighted at one end were measured when exposed to cold air, and then again after they had been heated in the atmosphere of an oven. In the latter case there was considerable elongation, indicating, in the case of steel, a diminution of elasticity amounting to ·00041 per degree Centigrade, and in the case of copper, to ·00047. After I had made these experiments, I became acquainted with M. KUPFFER'S valuable researches on this subject, by which, using the method of vibrations, he finds the decrement of elasticity per degree Centigrade in steel and copper to be ·00047 and ·00048 respectively.

121. Another source of error exists, which, although not of sufficient amount to make a sensible alteration in the thermal effects of tension and pressure on metals, yet ought not to be neglected in a complete view of the subject. Mr. HODGKINSON has long ago shown that any force, however small, is able to produce a certain permanent deflection in a bar, and that this deflection increases rapidly with the force which has produced it. Professor THOMSON has added the observation, that even after a metal has been exposed to great tensile force, its elasticity is not thereby rendered perfect for smaller degrees of stress. Thus he finds that when weights are successively hung to a wire so as gradually to increase its tension, and then successively removed, the wire never assumes immediately its just length, but is always shorter during the putting on of the weights than during their removal. Hence work is done on the wire which must necessarily evolve a certain quantity of heat; and if, as is probable, a greater quantity of work is thus done whilst the tensile force is being removed than whilst it is being applied, the result will be that the cold of tension will not be diminished to the same extent as the heat, in consequence of the removal of tension, will be increased, and so the mean thermal effect will be increased. On the other hand, it is probable that in the act of compression less work is done on the wire than during the removal of the compressing force, the result being that the mean thermal effect of applying and removing the pressure is lessened. The foregoing experiments do not afford sufficiently delicate tests to detect the excessively minute quantities of heat developed frictionally in the above manner.

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122. Professor THOMSON has pointed out that the dynamical theory of heat, with the modification of CARNOT'S principle introduced by himself and CLAUSIUS, show that "if

a spring be such that a slight elevation of temperature weakens it, and the full strength is recovered again with the primitive temperature, work done against that spring by bending or working in whatever way must cause a cooling effect." The quantity of cold expected was excessively small, yet I hoped to measure it by taking the mean of a large number of observations with the thermo-multiplier. I took a spiral of tempered steel wire $\frac{1}{9}$th of an inch thick, of which each convolution was $1\frac{1}{2}$ inch in diameter and one quarter of an inch distant from its neighbour. A thermo-electric junction was attached to one of the convolutions, and means were provided to compress or extend the spiral at pleasure without approaching it. In the case of a spiral stretched by a weight hung to it, the application of heat causes, as we have seen, a considerable elongation, in consequence of diminution of elasticity; but in the case of a spiral compressed by a weight laid on the top of it, the effect of the same cause is to diminish its length. Hence either the pulling out or the compression of the spiral must cause the absorption of heat, and the return of the spiral to its normal state must be accompanied by the evolution of heat.

123. The above thermal effects of bending a spring are evidently proportional to the square of the pressing or tensile force; for if these be increased, the elastic spring and the alteration of length by rise of temperature will be also proportionally increased.

124. Having arranged the thermo-multiplier so as to give one swing in 30″, I pursued the experiments as follows:—A weight of 7 lbs. was laid on the top of the spiral to compress it, and after 30″ had elapsed, the change in the position of the needle was noted. Then the weight was removed, and the needle observed after 30″ as before. One hundred such experiments were tried alternately. Afterwards I made another series of one hundred experiments, on the effect of stretching and removing the stretching force. The results are placed in the following Table, in which the signs + and − distinguish deflections indicating evolution and absorption of heat.

Deflection in minutes by compressing with 7 lbs.	Deflection on removal of compressing force.	Deflection in minutes by stretching with a force of 7 lbs.	Deflection on removing the tensile force.
−6	−2	0	−4
+1	+2	−4	−2
−1	−2	−8	−1
−1	0	−2	+1
0	+1	−3	+1
−4	+3	−3	−4
−6	−3	−4	0
+6	0	−2	+2
+2	+1	−6	−2
−1	0	+1	+2
0	+2	+1	−2
−3	−1	0	−3
−1	0	+1	−4
−4	0	0	−6
0	+6	−5	−1
−3	−1	−1	+4
0	0	−2	−1
−6	0	0	+3
−1	0	0	+5
−3	−1	+4	+3
−3	+5	−10	−1
−4	−2	−4	+7
+3	+5	−5	−3
+3	+3	−5	+4
−2	0	+4	+1
−1	+4	−5	−1
0	+5	+1	−1
0	+8	−6	+3
+4	0	−2	+1
−2	−1	0	+4
+2	+4	−3	+1
−1	+4	−3	+3
+2	+3	−2	+1
−1	+6	+4	+4
+2	+6	+2	+4
−2	+1	+6	+6
−5	−2	+3	+7
−2	+1	−6	−1
−1	+1	+2	−1
−3	−2	+2	+4
−4	−3	0	+1
−4	+2	−2	+1
−4	0	+2	+2
+1	+4	−1	0
0	+2	−2	+2
0	+6	−2	−2
−4	0	−1	0
0	+4	+1	+3
−7	−1	−1	+2
−6	+1	−1	+2
Mean...... −1·4	+1·38	−1·34	+0·88

125. The thermal value of 11° 6′ deflection being found to be 1°·63 Cent., the above deflections will indicate respectively ·00343 cold, ·00338 heat, ·00328 cold, and ·00215 heat, the average showing a quantitative thermal effect of 0°·00306. Using my own

coefficient for the diminution of the elastic force of steel by rise of temperature, I find for the theoretical result, in the case of compression,

$$H=\frac{283}{1390}\times\frac{7}{1}\times\frac{-1}{2379}\times\frac{1}{\cdot 11}\times\frac{1}{1\cdot 35}=-0^{\circ}\cdot 00403,$$

and in the case of extension,

$$H=\frac{283}{1390}\times\frac{-7}{1}\times\frac{1}{7500}\times\frac{1}{\cdot 11}\times\frac{1}{\cdot 428}=-0^{\circ}\cdot 00403,$$

the results being necessarily the same in both cases. The deficiency of the actual result is not great, and is on the side of the probable error, in consequence of the unavoidable loss of a portion of the thermal effect by conduction from the junction.

126. Thus even in the above delicate case is the formula of Professor THOMSON completely verified. The mathematical investigation of the thermo-elastic qualities of metals has enabled my illustrious friend to predict with certainty a whole class of highly interesting phenomena. To him especially do we owe the important advance which has been recently made to a new era in the history of science, when the famous philosophical system of BACON will be to a great extent superseded, and when, instead of arriving at discovery by induction from experiment, we shall obtain our largest accessions of new facts by reasoning deductively from fundamental principles.

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