collision with material objects. In fact we find that in sheltered situations, such for instance as one or two inches above a wall opposite to the wind, the thermometer indicates a higher temperature than it does when exposed to the blast. The question, which is one of great interest for meteorological science, has hitherto been only partially discussed by us, and for its complete solution will require a careful estimate of the temperature of the earth's surface, of the effects of radiation, &c., and also a knowledge of the causes of gusts in different winds.

XXII. "On the Thermal Effects of Longitudinal Compression of Solids." By J. P. Joule, Esq., F.R.S.; and "On the Alterations of Temperature accompanying Changes of Pressure in Fluids." By Prof. W. Thomson, F.R.S. Received June 18, 1857.

In the further prosecution of the experiments of which an outline was given in the 'Proceedings' for January 29, 1857, the author has verified the theory of Professor Thomson, as applied to the thermal effects of laying weights on and taking them off metallic pillars and cylinders of vulcanized india-rubber. Heat is evolved by compression, and absorbed on removing the compressing force in every substance yet experimented on. In the case of metals, the results agree very closely with the formula in which *e*, the longitudinal expansion by heat under pressure, is considered the same as the expansion without pressure. It was observed, however, that all the experimental results were a little in excess of the theoretical, and it became therefore important to inquire whether the force of elasticity in metals is impaired by heat. In the first arrangements for this purpose, the actual expansion of the bars employed in the experiments was ascertained by a micrometric apparatus,—1st, when there was no tensile force, and 2nd, when a weight of 700 lbs. was hung to the extremity of the quarter-inch rods. The results, reliable to less than one-hundredth of their whole value, did not exhibit any notable effect of tensile force on the coefficient of expansion by heat. An experiment susceptible of greater delicacy

was now tried. Steel wire of $\frac{1}{90}$th of an inch in diameter was wound upon a rod of iron $\frac{1}{4}$ of an inch in diameter. This was heated to redness. Then, after plunging in cold water, the spiral was slipped off. The number of convolutions of the spiral was 420, and its weight 58 grains. Its length, when suspended from one end, was 6·35 inches, but on adding to the extremity a weight of 129 grains, it stretched without sensible set to 14·55 inches. The temperature of the spiral thus stretched was raised or lowered at pleasure by putting it in, or removing it out of an oven. After several experiments it was found that between the limits of temperature 84° and 280° Fahr., each degree Centigrade of rising temperature caused the spiral to lengthen as much as ·00337 of an inch, and that a contraction of equal amount took place with each degree Centigrade of descending temperature. Hence, as Mr. James Thomson has shown that the pulling out of a spiral is equivalent to twisting a wire, it follows that the force of torsion in steel wire is decreased ·00041 by each degree of temperature.

An equally decisive result was obtained with copper wire, of which an elastic spiral was formed by stretching out a piece of soft wire, and then rolling it on a rod $\frac{1}{4}$ of an inch in diameter. The spiral thus formed consisted of 235 turns of wire, $\frac{1}{40}$ of an inch in diameter, weighing altogether 230 grains. Unstretched, it measured 6·7 inches, but with a weight of 1251 grains attached to it, it stretched, without set, to 10·05 inches. Experiments made with it showed an elongation of ·00157 of an inch for each degree Centigrade of elevation of temperature, and an equal shortening on lowering the temperature. The diminution of the force of torsion was in this case ·00047 per degree Centigrade*.

* Since writing the above, I have become acquainted with M. Kupffer's researches on the influence of temperature on the elasticity of metals (*Compte-Rendu Annuel*, St. Petersburgh, 1856). He finds by his method of twisting and transverse oscillations, that the decrease of elasticity for steel and copper is ·000471 and ·000478. Very careful experiments recently made by Prof. Thomson, indicate a slight increase of expansibility by heat in wires placed under tension.—August 1. J. P. J.

Professor Thomson has obligingly furnished me with the following investigation :—

On the Alterations of Temperature accompanying Changes of Pressure in Fluids.

Let a mass of fluid, given at a temperature t and under a pressure p, be subjected to the following cycle of four operations in order.

(1) The fluid being protected against gain or loss of heat, let the pressure on it be increased from p to $p+\varpi$.

(2) Let heat be added, and the pressure of the fluid maintained constant at $p+\varpi$, till its temperature rises by dt.

(3) The fluid being again protected against gain or loss of heat, let its pressure be reduced from $p+\varpi$ to p.

(4) Let heat be abstracted, and the pressure maintained at p, till the temperature sinks to t again.

At the end of this cycle of operations, the fluid is again in the same physical condition as it was at the beginning, but, as is shown by the following considerations, a certain transformation of heat into work or the reverse has been effected by means of it.

In two of these four operations the fluid increases in bulk, and in the other two it contracts to an equal extent. If the pressure were uniform during them all, there would be neither gain nor loss of work; but inasmuch as the pressure is greater by ϖ during operation (2) than during operation (4), and rises during (1) by the same amount as it falls during (3), there will, on the whole, be an amount of work equal to $\varpi\, dv$, done by the fluid in expanding, over and above that which is spent on it by pressure from without while it is contracting, if dv denote a certain augmentation of volume which, when ϖ and dt are infinitely small, is infinitely nearly equal to the expansion of the fluid during operation (2), or its contraction during operation (4). Hence, considering the bulk of the fluid primitively operated on as unity, if we take

$$\frac{dv}{dt}=e,$$

to denote an average coefficient of expansion of the fluid under constant pressure of from p to $p+\varpi$, or simply its coefficient of

expansion at temperature t and pressure p, when we regard ϖ as infinitely small, we have an amount of work equal to

$$\varpi\, e\, dt$$

gained from the cycle. The case of a fluid such as water below $39^{\circ}\cdot 1$ Fahr., which contracts under constant pressure, with an elevation of temperature, is of course included by admitting negative values for e, and making the corresponding changes in statement.

Since the fluid is restored to its primitive physical condition at the end of the cycle, the source from which the work thus gained is drawn, must be heat, and since the operations are each perfectly reversible, Carnot's principle must hold; that is to say, if θ denote the excess of temperature of the body while taking in heat above its temperature while giving out heat, and if μ denote "Carnot's function," the work gained, per unit of heat taken in at the higher temperature, must be equal to

$$\mu\,\theta.$$

But while the fluid is giving out heat, that is to say, during operation (4), its temperature is sinking from $t+dt$ to t, and may be regarded as being on the average $t+\frac{1}{2}dt$; and while it is taking in heat, that is, during operation (2), its temperature is rising from what it was at the end of operation (1) to a temperature higher by dt, or on the average exceeds by $\frac{1}{2}dt$, the temperature at the end of operation (1). The average temperature while heat is taken in consequently exceeds the average temperature while heat is given out, by just as much as the body rises in temperature during operation (1). If, therefore, this be denoted by θ, and if $\mathrm{K}\,dt$ denote tbe quantity of heat taken in during operation (2), the gain of work from heat in the whole cycle of operations must be equal to $\mu\,\theta\,\mathrm{K}\,dt$, and hence we have

$$\mu\,\theta\,.\,\mathrm{K}\,dt=\varpi\, e\, dt.$$

From this we find

$$\theta=\frac{e}{\mu\mathrm{K}}\varpi,$$

where, according to the notation that has been introduced, θ is the elevation of temperature consequent on a sudden augmentation of pressure from p to $p+\varpi$; e is the coefficient of expansion of the fluid, and K its capacity for heat, under constant pressure; and μ is Carnot's function, being, according to the absolute thermodynamic

scale of temperature, simply the reciprocal of the temperature, multiplied by the mechanical equivalent of the thermal unit. If then t denote the absolute temperature, which we have shown by experiment* agrees sensibly with temperature by the air-thermometer Cent. with 274° added, and if J denote the mechanical equivalent of the thermal unit Centigrade, we have

$$\theta=\frac{t\,e}{\mathrm{JK}}\varpi.$$

This expression agrees in reality, but is somewhat more convenient in form, than that first given, Dynamical Theory of Heat, § 49, Trans. R.S.E. 1851.

Thus for water, the value of K, the thermal capacity of a cubic foot under constant pressure, is 63·447, and e varies from 0 to about $\frac{1}{2200}$, for temperatures rising from that of maximum density to 50° Cent., and the elevation of temperature produced by an augmentation of pressure amounting to n times 2117 lbs. per square foot (that is to say, to n atmospheres), is

$$\frac{t\,e\times 2117}{1390\times 63\cdot 447}n.$$

For mercury, we have $\frac{t\,e\times 2117}{1390\times 28\cdot 68}n.$

If, as a rough estimate, we take

$$e=\frac{t-278}{46}\times\frac{1}{2200},$$

this becomes $\frac{t(t-278)}{420000}n.$

If, for instance, the temperature be 300° on the absolute scale (that is, 26° of the Centig. thermometer), we have

$$\frac{n}{636}$$

as the heating effect produced by the sudden compression of water at that temperature: so that ten atmospheres of pressure would give $\frac{1}{64}$ of a degree Cent., or about five divisions on the scale of the most sensitive of the ether thermometers we have as yet had constructed.

Thus if we take $\frac{1}{5500}$ as the value of e, this becomes

$$\frac{t}{103600}n;$$

* See Part II. of our Paper "On the Thermal Effects of Fluids in Motion," Philosophical Transactions, 1854.

and at temperature 26° Cent., the heating effect of ten atmospheres is found to be $\frac{1}{34}$ of a degree Cent.

TABLE giving the thermal effects of a pressure of ten atmospheres on water and mercury*.

Temperature.	Increase or decrease of temperature in water.	Increase of temperature in mercury.
0°	·005 decrease	·026
3°·95	·0	·0264
10°	·006 increase	·027
20°	·015 do.	·028
30°	·022 do.	·029
40°	·029 do.	·030
50°	·035 do.	·031
60°	·041 do.	·032
70°	·047 do.	·033
80°	·055 do.	·034
90°	·065 do.	·035
100°	·078 do.	·036

XXIII. "On the Phenomenon of Relief of the Image formed on the Ground Glass of the Camera Obscura." By A. CLAUDET, Esq., F.R.S. Received June 17, 1857.

(Abstract.)

The author having observed that the image formed on the ground glass of the camera obscura appears as much in relief as the natural object when seen with the two eyes, has endeavoured to discover the cause of that phenomenon, and his experiments and researches have disclosed the singular and unexpected fact, that although only one image *seems* depicted on the ground glass, still each eye perceives a different image; that in reality there exist on the ground glass two images, the one visible only to the right eye, and the other visible only to the left eye. That the image seen by the right eye is the representation of the object refracted by the left side of the lens, and the image seen by the left eye is the representation of the object refracted by the right side of the lens. Consequently these two images presenting two different perspectives, the

* Added August 1.