Theory of Heat," published in the Transactions of the Royal Society of Edinburgh for May 1854, and in the Philosophical Magazine for 1855, first half-year, the formula

$$\frac{H_t}{t} + \frac{H_{t'}}{t'} + \dots + \frac{H_{t^{(n-1)}}}{t^{(n-1)}} + \frac{H_{t^{(n)}}}{t^{(n)}} = 0$$

is given as an equivalent for

$$\Sigma \alpha_t = \Sigma \alpha_t (1 - e^{-\frac{1}{J} \int_T^t \mu dt}),$$

which was first published in the Proceedings of the Royal Society of Edinburgh for 1851, and Phil. Mag. 1852, first half-year. Tait had actually quoted the formula from my 1854 paper in § 176 of his book, and so left absolutely no foundation for Professor Clausius' objection to his saying "This is Thomson's expression &c.," quoted in his letter above.

As to the 'Good Words' article on Energy which appeared under our joint names, Professor Tait and I are equally responsible for its contents. I claim my full share of the "scientific patriotism" commended in that article, and cannot assent to Professor Clausius' giving all the credit of it to Professor Tait.

In compliance with the concluding sentence of Professor Tait's letter, I hope in the course of a few days to write out, and send to the Philosophical Magazine for publication, a short statement of the communication on Thermodynamic Motivity which I made *vivâ voce* to the Royal Society of Edinburgh on April 3rd, 1876.

LV. On *Thermodynamic Motivity*. By Sir W. THOMSON, F.R.S.*

AFTER having for some years felt with Professor Tait the want of a word "to express the Availability for work "of the heat in a given magazine, a term for that possession "the waste of which is called Dissipation"†, I suggested three years ago the word *Motivity* to supply this want, and made a verbal communication to the Royal Society of Edinburgh defining and illustrating the application of the word; but as the communication was not given in writing, only the title of the paper, "Thermodynamic Motivity," was published. In consequence of Professor Tait's letter to me, published in the present Number of the Philosophical Magazine, I now offer,

* Communicated by the Author.

† Tait's 'Thermodynamics,' first edition (1868), § 178: quoted also in Professor Tait's letter in the present Number of the Philosophical Magazine.

for publication in the Proceedings of the Royal Society of Edinburgh and in the Philosophical Magazine, the following short abstract of the substance of that communication.

In my paper on the Restoration of Energy from an Unequally Heated Space, published in the Philosophical Magazine in January 1853, I gave the following expression for the amount of "mechanical energy" derivable from a body, B, given with its different parts at different temperatures, by the equalization of the temperature throughout to one common temperature* T, by means of perfect thermodynamic engines,

$$W = J \iiint dx dy dz \int_T^t c dt (1 - \epsilon^{-\frac{1}{J} \int_T^t \mu dt}), \quad . \quad . \quad (1)$$

where t denotes the temperature of any point x, y, z of the body, c the thermal capacity of the body's substance at that point and that temperature, J Joule's equivalent, and μ Carnot's function of the temperature t .

Further on in the same paper a simplification is introduced thus:—

"Let the temperature of the body be measured according to an absolute scale, founded on the values of Carnot's function, and expressed by the following equation,

$$t = \frac{J}{\mu} - \alpha,$$

"where α is a constant which may have any value, but ought to have for its value the reciprocal of the expansibility of air,

* In the present article I suppose this temperature to be the given temperature of the medium in which B is placed; and thermodynamic engines to work with their recipient and rejectant organs respectively in connexion with some part of B at temperature t , and the endless surrounding matter at temperature T. In the original paper this supposition is introduced subordinately at the conclusion. The chief purpose of the paper was the solution of a more difficult problem, that of finding the value of T,—a kind of average temperature of B to fulfil the condition that the quantities of heat rejected and taken in by organs of the thermodynamic engines at temperature T are equal. The burden of the problem was the evaluation of this thermodynamic average; and I failed to remark that when the value which the solution gave for T is substituted in the formula of the text it reduces to $J \iiint dx dy dz \int_T^t c dt$, which was not instantly obvious from the analytical form of my solution, but which we immediately see must be the case by thinking of the physical meaning of the result; for the sum of the excesses of the heats taken in above those rejected by all the engines must, by the first law of thermodynamics, be equal to the work gained by the supposed process. This important simplification was first given by Professor Tait in his 'Thermodynamics' (first and second editions). It does not, however, affect the subordinate problem of the original paper, which is the main problem of this one.

“in order that the system of measuring temperature here adopted may agree approximately with that of the air-thermometer. Then we have

$$\epsilon^{-\frac{1}{J} \int_0^t \mu dt} = \frac{\alpha}{t + \alpha}, \quad . . . . . (2)$$

It was only to obtain agreement with the zero of the ordinary Centigrade scale of the air-thermometer that the α was needed; and in the joint paper by Joule and myself, published in the Transactions of the Royal Society (London) for June 1854, we agreed to drop it, and to define temperature simply as the reciprocal of Carnot's function, with a constant coefficient proper to the unit or degree of temperature adopted. Thus definitively, in equation (6) of § 5 of that paper, we took $t = \frac{J}{\mu}$, and have used this expression ever since as the expression for temperature on the arbitrarily assumed thermodynamic scale. With it we have

$$\epsilon^{-\frac{1}{J} \int_T^t \mu dt} = \frac{T}{t}; \quad . . . . . (3)$$

and by substitution (1) becomes

$$W = J \iiint dx dy dz \int_T^t c dt \left(1 - \frac{T}{t}\right). \quad . . . (4)$$

Suppose now B to be surrounded by other matter all at a common temperature T. The work obtainable from the given distribution of temperature in B by means of perfect thermodynamic engines is expressed by the formula (4). If, then, there be no circumstances connected with the gravity, or elasticity, or capillary attraction, or electricity, or magnetism of B in virtue of which work can be obtained, that expressed by (4) is what I propose to call the whole Motivity of B in its actual circumstances. If, on the other hand, work is obtainable from B in virtue of some of these other causes, and if V denote its whole amount, then

$$\mathfrak{M} = V + W \quad . . . . . (5)$$

is what I call the whole Motivity of B in its actual circumstances according to this more comprehensive supposition.

We may imagine the whole Motivity of B developed in an infinite variety of ways. The one which is obvious from the formula (5) is first to keep every part of B unmoved, and to take all the work producible by perfect thermodynamic engines equalizing its temperature to T; and then keeping it rigorously at this temperature, to take all the work that can

be got from it elastically, cohesively, electrically, magnetically, and gravitationally, by letting it come to rest unstressed, dis-electrified, demagnetized, and in the lowest position to which it can descend. But instead of proceeding in this one definite way, any order of procedure whatever leading to the same final condition may be followed; and, provided nothing is done which cannot be undone (that is to say, in the technical language of thermodynamics, provided all the operations be reversible), the same whole quantity of work will be obtained in passing from the same initial condition to the same final condition, whatever may have been the order of procedure. Hence the *Motivity* is a function of the temperature, volume, figure, and proper independent variables for expressing the cohesive, the electric, and the magnetic condition of B, with the gravitational potential of B simply added (which, when the force of gravity is sensibly constant and in parallel lines, will be simply the product of the gravity of B into the height of its centre of gravity above its lowest position). So also is the *Energy* of a body B (as I first pointed out, for the case of B a fluid, in Part V. of my *Dynamical Theory of Heat*, in the Transactions of the Royal Society of Edinburgh for December 15, 1851, entitled, "On the Quantities of Mechanical Energy contained in a Fluid in Different States as to Temperature and Density"). Consideration of the *Energy* and the *Motivity*, as two functions of all the independent variables specifying the condition of B completely in respect to temperature, elasticity, capillary attraction, electricity, and magnetism, leads in the simplest and most direct way to demonstrations of the theorems regarding the thermodynamic properties of matter which I gave in Part III. of the *Dynamical Theory of Heat* (March 1851); in "Part VI. of *Dynamical Theory, Thermoelectric Currents*," (May 1, 1854); in a paper in the Proceedings for 1858 of the Royal Society of London, entitled, "On the Thermal Effect of Drawing out a Film of Liquid;" and in a communication to the Royal Society of Edinburgh (Proc. R. S. E. 1869-70), "On the Equilibrium of Vapour at the Curved Surface of a Liquid;" and in my article on the *Thermoelastic and Thermomagnetic Properties of Matter*, in the first number of the *Quarterly Journal of Mathematics* (April 1855); and in short articles in *Nichol's Cyclopædia*, under the titles "*Thermomagnetism, Thermoelectricity, and Pyroelectricity*," put together and republished with additions in the *Philosophical Magazine* for January 1878, under the title "*On the Thermoelastic, Thermomagnetic, and Pyroelectric Properties of Matter*."

It would be beyond the scope of the present article to enter

in detail into these applications, which were merely indicated in my communication to the Royal Society of Edinburgh of three years ago, as a very short and simple analytical method of setting forth the whole non-molecular theory of Thermodynamics.

University of Glasgow,
April 11, 1879.

LVI. *On the Transmission and Distribution of Energy by the Electric Current.* By C. WILLIAM SIEMENS, D.C.L., F.R.S.*

[Plate XII.]

IN the autumn of 1876, when standing below the Falls of Niagara, the first impression of wonderment at the imposing spectacle before my eyes was followed by a desire to appreciate the amount of force thus eternally spent without producing any other result than to raise the temperature of the St. Lawrence a fraction of a degree†, by the concussion of the water against the rocks upon which it falls.

The rapids below the fall present a favourable opportunity of gauging the sectional area and the velocity of the river; and from these data I calculated that the fall represents energy equivalent to nearly 17 million horse-power, to produce which by steam would require about 260 million tons of coal a year, or just about the entire amount of coal raised throughout the world.

If one fall represents such a loss of power, what must be the aggregate loss throughout the world from similar causes? and is it consistent with utilitarian principles that such stores of energy should go almost entirely to waste? But the difficulty arises, how such energy (occurring as it does for the most part in mountainous countries) is to be conducted to centres of industry and population.

Transmission by hydraulic arrangements or by compressed air would be very costly and wasteful for great distances; but it occurred to me that large amounts of energy, produced by means of the dynamo-electric current-generator, might be conveyed through a metallic conductor, such as a rod of copper fixed upon insulating supports. Such a conductor would no doubt be expensive; but, if once established, the cost of maintenance would be very small, and its power of

* Communicated by the Physical Society, having been read at the meeting on February 22.

† The vertical fall being 150 feet, the increase of temperature would be $\frac{1}{7} \frac{5}{7} \frac{0}{2} = \frac{1}{5}^{\circ}$ Fahrenheit nearly.