already found in my work 'Untersuchungen über den Magnetismus der Erde' (Christiania, 1819, with Atlas); whereof the two northern ones have a motion from west to east, the two southern ones in the contrary direction; and have attempted thereby in general to declare the cause of the known variations, as well of the system of declination as of that of inclination and of intensity.

As I am indebted for the greatest part of the materials to English observations, I have found it my duty to render my thanks to English science, and to express my hopes of future exertions towards the solution of this, in my thought, most interesting problem of the general physics of the globe.

Most respectfully,

CHRISTOPHER HANSTEEN.

Observatory in Christiania,
December 31, 1855.

II. THE BAKERIAN LECTURE.—"On the Electro-dynamic Properties of Metals." By Professor WILLIAM THOMSON, F.R.S.

The Lecturer gave an exposition of the substance of a paper presented by him to the Society under the above title.

The paper consists of five parts, namely:—1. On the Electric Convection of Heat; 2. On Thermo-electric Inversions; 3. On the Effects of Mechanical Strain and of Magnetization on the Thermo-electric Qualities of Metals; 4. On Methods for comparing and testing Galvanic Resistances, illustrated by Preliminary Experiments on the Effects of Tension and Magnetization on the Electric Conductivity of Metals; 5. On the Effects of Magnetization on the Electric Conductivity of Iron.

1. In the first part a full account of the experiments, of which the results were communicated to the Royal Society in April 1854*, is preceded by a short statement of the reasoning, founded on incontrovertible principles regarding the source of energy drawn upon by a thermo-electric current, which led the author to commence the experimental investigation with the certainty that the property looked for really existed whether he could find it or not. In confirmation of the extra-

* See Proceedings, May 4, 1854.

ordinary conclusion then announced,—that an electric current in an unequally heated conductor, if its *nominal direction* be from hot to cold through the metal, causes a cooling effect in iron, and a heating effect in copper,—the author describes new experiments which he has recently made, and which are as decisive in leading to the same conclusion as those by which he had first established it. He also describes experiments by which he had recently given an independent demonstration that brass has the same property as copper, and platinum the same quality as iron, with reference to electric convection of heat; results anticipated*, one as certain, and the other as highly probable, from the previous results regarding electric convection in copper and iron, and from the known thermo-electric relations between these metals and the others.

2. The phenomenon of thermo-electric inversion between metals, discovered by Cumming, forms the subject of the second part. A mode of experimenting is described, by which inversions may be readily detected when they exist between any two metals, and, when thermometers are available, the temperature of neutrality determined with precision. Various results of its application are mentioned, of which some are shown in the following Table:—

−14° Cent.	−12°·2	−1°·5	8°·2	36°	38°	44°	44°	47°
P_3 Brass	P_1 Cadmium	P_1 Silver	P_1 Zinc	P_2 Lead	P_2 Brass	P_2 Tin	Lead Brass	Silver Zinc

53°	64°	71°	72°	99°	121°	130°	162°·5	237°	280°
P_2 Double wire of Palladium, 11·31 grs., and Copper, 19·41 grs.	P_1 Copper	Silver Gold	Gold Zinc	P_1 Brass	P_1 Lead	P_1 Tin	Iron Cadmium	Iron Silver	Iron Copper

The number at the head of each column expresses the temperature Centigrade by mercurial thermometers, at which the two metals written below it are thermo-electrically neutral to one another; and the lower metal in each column is that which passes the other from *bismuth towards antimony as the temperature rises.* P_1, P_2, P_3 denote three particular specimens of platinum wire, used by the author as standards.

* See Proceedings, May 4, 1854; also "Dynamical Theory of Heat," Part VI. § 135; Transactions R.S.E., May 1854, p. 146.

It was also found that Aluminium must be neutral to either P_3, or Brass, or P_2, at some temperature between $-14°$ C. and 38° C.; that Brass becomes neutral to Copper at some high temperature, probably between 800° and 1400°; Copper to Silver, a little below the melting-point of silver; Nickel to Palladium, at some high temperature, perhaps about a low red heat; and P_3 to impure mercury (that had been used for amalgamating zinc plates), at a temperature between $-10°$ and 0°. Probably P_3 becomes neutral to pure mercury at some temperature below $-10°$ C.

3. In the third part, effects of mechanical strain, and of magnetization on the thermo-electric qualities of metals, are investigated. The author had previously communicated to the Royal Society* results he had obtained regarding the thermo-electric qualities of copper and of iron wires under longitudinal stress, namely, that the former exhibits a deviation towards bismuth, and the latter towards antimony, from the same metal in an unstrained state.

The only kind of stress applicable to a solid which has no directional attributes, is uniform pressure or traction in all directions. Hence it appeared probable to the author that a simple longitudinal stress would induce different thermo-electric qualities in different directions, in any homogeneous non-crystalline metal subjected to it. But he had found (see Proceedings, May 4, 1854) that the thermo-electric effect of longitudinal traction on a wire, either of iron or of copper, is sensible to tests he could readily command, and more so in the case of the former than in that of the latter. He therefore made experiments to test the difference of thermo-electric quality in different directions in a mass of iron under stress, and fully established the conclusion that the thermo-electric quality across lines of traction differs from the thermo-electric quality along lines of traction, as bars of bismuth differ from bars of antimony. The experiments he has already made nearly establish the conclusion that unstrained iron has intermediate thermo-electric quality between those of the two critical directions in iron under distorting stress.

The experiments of Magnus show that wires hardened by wire-drawing have different thermo-electric qualities lengthwise from wires of the same substance softened by annealing. The author has veri-

* April 1854. See Proceedings, May 4, 1854.

fied, that in copper, iron, and tin, simple traction, leaving permanent elongation, leaves also a thermo-electric effect, the same as Magnus had found by wire-drawing, which is a composite application of longitudinal traction and lateral compression; and that in a variety of metals, namely, iron, copper, brass, tin, platinum, permanent lateral compression (by hammering) leaves still the same thermo-electric effect, as Magnus had found by wire-drawing. In cadmium, not examined by Magnus, and lead, which had not a given result, the experiments now adduced show a thermo-electric effect of hammering, the same as in all the other metals except iron. Zinc wire was also tested, and found to exhibit the same effect as copper, though Magnus had found a reverse quality as due to wire-drawing. The discrepance in this case is probably due to the peculiar effect of annealing on zinc wire, making it brittle and crystalline, which might give a different condition, as the "annealed" in Magnus's experiment, and the "unhammered" in the experiment now adduced. Setting aside this case, the author concludes that generally the effect of permanent lateral compression is the same as that of permanent longitudinal extension, or of hardening by wire-drawing, upon the thermo-electric quality of a wire placed longitudinally in an electric circuit; that in iron it is a deviation from the constrained metal towards bismuth, and that in all the other metals mentioned it is a deviation towards antimony; and that in copper and iron it is the reverse of the effect experienced by the same metal while under the stress that caused the strain. Since no kind of strain, except uniform condensation or dilatation in all directions, is free from the directional attribute, it appeared probable to the author that the thermo-electric effects remaining in a metal left with a longitudinal strain, retained after the stress that caused it is removed, must be different in different directions. He therefore experimented on iron hardened by longitudinal compression, and found that it deviates from soft iron towards antimony, or in the contrary way to iron hardened by longitudinal traction. From this, and from the results quoted above, it follows that in iron hardened by compression in one direction, the thermo-electric qualities in this direction differ from those in lines perpendicular to it, as antimony differs from bismuth; that the reverse statement applies to iron hardened by traction in one direction; and that these differing thermo-electric qualities have in each case the thermo-electric quality of soft iron intermediate between them.

These various results show that the character of the effect in each case is decided by *distorting stress* or by *distortion*, and leave entirely open, and only to be answered by further experiments, the questions: what is the thermo-electric effect of pressure or traction, applied uniformly in all directions to a metal? and what is the thermo-electric effect of a permanent condensation or dilatation remaining in the metal, when freed from the force by which that condensation or dilatation was produced?

Experiments are also described, by which the author found that in soft iron under magnetic force, and in that retaining magnetism, when removed from the magnetizing force, directions along the lines of magnetization deviate thermo-electrically towards antimony; and that directions perpendicularly across the lines of magnetization in soft iron, deviate towards bismuth, from the unmagnetized metal. He illustrates this conclusion by an experiment on a riband of iron, magnetized nearly at an angle of 45° to its length, and heated along one edge while the other is kept cool. When the two ends, kept at the same temperature, are put in communication with the electrodes of a galvanometer, a powerful current is indicated, in such a direction, that if pursued along a rectangular zigzag from edge to edge through the band, the course is always *from across to along the lines of magnetization through the hot edge, and from along to across the lines of magnetization through the cold edge.*

4. In this part of the communication, attempts made by the author to find the effects of various influences on electric conductivities of metals are described. One of these, with a very unsatisfactory method for testing resistances, led to the conclusion that longitudinal magnetization diminishes the conducting quality of iron wire. The general plan for testing resistances, which he subsequently adopted as the best he could find, and which has proved very satisfactory, is next explained; and as an illustration, a single experiment on the relative effect of an equal longitudinal extension on the resistances of iron and copper wires is described. The conclusion established by this experiment is, that both by extension with the tractive force still in operation, and by permanent extension retained after a cessation of stress, the conductivity of the substance is more diminished

in iron than in copper ; or else that it is more increased in copper than in iron, or increased in copper while diminished in iron, if it is not in each metal diminished, as the author is led by a partial investigation of the absolute effect in each metal to believe.

5. The result previously arrived at regarding the effect of longitudinal magnetization on the conductivity of iron is confirmed ; and an experiment that would have been found impracticable by the less satisfactory method, proves the same conclusion for magnetized steel wire, with the magnetizing influence away. Two very different experiments show further, that the electric conductivity of magnetized iron is greater across than along the lines of magnetization. A last experiment, showing that iron gains in conducting power by magnetization across the lines of the electric current, leads to the conclusion that there is a direction inclined obliquely to the lines of magnetization, along which the conductivity of magnetized iron would remain unchanged on a cessation of the magnetizing force.