after birth. He has dissected and figured eight or nine of the more important stages, and shown the relative alteration of each part consecutively, commencing with the *Zœa* taken from the egg, and pursued the observations through the older forms to that of the adult *Carcinus*.

The paper is carefully illustrated by drawings made by the author.

XIX. "On the Electro-dynamic Qualities of Metals:—Effects of Magnetization on the Electric Conductivity of Nickel and of Iron." By Professor W. Thomson, F.R.S. Received June 18, 1857.

I have already communicated to the Royal Society a description of experiments by which I found that iron, when subjected to magnetic force, acquires an increase of resistance to the conduction of electricity along, and a diminution of resistance to the conduction of electricity across, the lines of magnetization*. By experiments more recently made, I have ascertained that the electric conductivity of nickel is similarly influenced by magnetism, but to a greater degree, and with a curious difference from iron in the relative magnitudes of the transverse and longitudinal effects.

In these experiments the effect of transverse magnetization was first tested on a little rectangular piece of nickel 1·2 inch long, ·52 of an inch broad, and ·12 thick, being the "keeper" of the nickel horse-shoe (§ 143) belonging to the Industrial Museum of Edinburgh, and put at my disposal for experimental purposes through the kindness of Dr. George Wilson. Exactly the method described in § 175 of my previous communication referred to above, was followed, and the result, readily found on the first trial, was as stated.

The effect of longitudinal magnetization on nickel was first found with some difficulty, by an arrangement with the horse-shoe itself, and magnetizing helix (§ 143), the former furnished with suitable electrodes for a powerful current through itself, and the system treated in all respects (including cooling by streams of cold water) as described in § 156, for a correspondiug experiment on iron. The

* See Phil. Trans. Bakerian Lecture, "On the Electro-dynamic Qualities of Metals," Feb. 27, 1856, § 146 of Part 4 and Part 5. In the present communication that paper will be referred to simply by the sectional (§) numbers.

result, determined by but a very slight indication, was, as stated above, that longitudinal magnetization augmented the resistance.

The magnetization of the small piece of metal between the poles of the Ruhmkorff electro-magnet being obviously much more intense than that of the larger piece under the influence merely of the smaller helix, I recurred to the plan of experiment (§ 175) by which the effect of transverse magnetization on the little rectangular piece of nickel was first tested, and I had an equal and similar piece of iron, and another of brass, all prepared to be tested, as well as the nickel, with either longitudinal or transverse magnetic force.

To each of the little rectangles of metal to be tested, a thin slip of copper (instead of lead, as in the experiment of § 175), of the same breadth (·52 of an inch), to serve as a reference conductor, was soldered longitudinally, and to the other end of the metal tested, a piece of copper to serve as an electrode, for the principal current, was soldered. The ends of a testing conductor, 6 feet of No. 18 copper wire, were soldered respectively to the last-mentioned end of the tested metal, and to a point in the reference-conductor found, so that the resistance between it and the junction of the reference-conductor with the tested conductor, should be about equal to the resistance in the latter.

A single element, consisting of four large double cells of Daniell's (§ 63), exposing in all 10 square feet of zinc surface to 17 square feet of copper, was used to send the testing current through the conducting system thus composed, by electrodes clamped to the ends of the principal conducting channel, just outside the points of attachment of the testing conductor.

The electro-magnet was excited by various battery arrangements, in different experiments, at best by 52 cells of Daniell's, each exposing 54 square inches of zinc surface to 90 square inches of copper, and arranged in a double battery* equivalent to one battery of 26 elements each of double surface. By accident, only a single battery of 26 elements was used in obtaining the numerical results stated below.

* This arrangement was found to give about the same strength of current through the coils of the electro-magnet, as a single battery of 52 of the same cells in series, and was therefore preferred as involving only half the amount of chemical action in each cell, and consequently maintaining its effect more constantly during many successive hours of use.

The nickel was first placed between the flat poles of the electro-magnet, with its length across the lines of force, and, one galvanometer electrode being kept soldered to the junction of the nickel and the copper reference-conductor, the other galvanometer electrode was applied to the testing conductor till the point (equipotential with that point of junction) which could be touched without giving any deflection of the needle, was found. A multiplying branch, 3 feet of No. 18 wire, was then soldered with its ends $\frac{3}{8}$ths of an inch on each side of this point, and, as soon as the solderings were cool, the corresponding point on this multiplying branch was found. The magnetizing current was after that sent in either direction through the coils of the electro-magnet, and it was found that the moveable galvanometer electrode had to be shifted over about $4\frac{1}{2}$ inches on the multiplying branch towards the end of the testing conductor connected with the nickel, that is to say, in such a direction as to indicate a *diminished resistance* in the nickel. When the same operations were gone through with the nickel placed longitudinally between the poles of the electro-magnet, the zero-point on the multiplying branch was shifted about 6 inches in the direction which indicated an *increased resistance* in the nickel.

The piece of iron similarly tested, gave effects in the same direction in each case, and the results originally obtained for iron (§§ 146, 155, 161–177) were thus verified.

No effect whatever could be discovered when the piece of brass was similarly tried. It is much to be desired that experiments with highly increased power, and with a better kind of galvanometer, should be made, to discover whatever very small influence is really produced by magnetic force on the comparatively non-magnetic metals.

The shifting of the neutral point on the multiplying branch required to balance the effect produced by the longitudinal magnetization in the iron, was only from $1\frac{1}{2}$ to 2 inches. Three inches were required to balance the opposite effect of the transverse magnetization.

Hence, with the same magnetic force, the effect of longitudinal magnetization in increasing the resistance, is from three to four times as great in nickel as in iron; but the contrary effect of transverse magnetization is nearly the same in the two metals with the same magnetic force. It may be remarked, in connexion with this comparison, that nickel was found by Faraday to lose its magnetic inductive capacity much more rapidly with elevation of temperature, and that it must consequently, as I have shown, experience a greater cooling effect with demagnetization* than iron, at the temperature of the metals in the experiment. It will be very important to test the new property for each metal at those higher temperatures at which it is very rapidly losing its magnetic property, and to test it at atmospheric temperature for cobalt, which, as Faraday discovered, actually gains magnetic inductive capacity as its temperature is raised from ordinary atmospheric temperatures, and which, consequently, must experience a heating effect with demagnetization and a cooling effect with magnetization.

The actual amount of the effects of magnetization on conductivity demonstrated by the experiments which have been described, may be estimated with some approach to accuracy from the preceding data. Thus the value of an inch on the multiplying branch would be the same as that of $\frac{1}{36}\times\frac{3}{4}$, or $\frac{1}{48}$ of an inch on the portion of the main testing conductor between its ends. The whole resistance of this $\frac{3}{4}$ of an inch of the main testing conductor, assisted by the attached multiplying branch of 36 inches, is of course less in the ratio of 48 to 49, than that of any simple $\frac{3}{4}$ of an inch of the testing conductor; but in the actual circumstances there will be no loss of accuracy in neglecting so small a difference. Hence the effect of the transverse magnetization of the nickel was to diminish its resistance in the ratio of half the length of the testing conductor diminished by $\frac{4\frac{1}{2}}{48}$ of an inch, to that of the same increased by the same, that is to say, in the ratio of $11\frac{31}{32}$ to $12\frac{1}{32}$, or of 383 to 385. Hence it appears that the resistance of the nickel, when under the transverse magnetizing force, was less by $\frac{1}{192}$, and similarly, that the resistance, when under the longitudinal magnetizing force, was greater by $\frac{1}{144}$, than when freed from magnetic influence; and that the effects of the transverse and of the longitudinal magnetizing forces on the iron were to diminish its resistance and to increase its resistance by $\frac{1}{288}$ and $\frac{1}{500}$ respectively. The first effect which I succeeded in estimating (§ 155) amounted to only $\frac{1}{3000}$, being the increase of resistance in an iron wire when longitudinally

* See Nichol's Cyclopædia of Physical Science, article 'Thermo-magnetism.'

magnetized by a not very powerfully excited helix surrounding it. In the recent experiments the magnetizing force was (we may infer) far greater.

It is to be remarked that the results now brought forward do not afford ground for a quantitative comparison between the effects of the same degree of magnetism, on the resistance to electric conduction along and across the lines of magnetization, in either one metal or the other, in consequence of the oblong form of the specimens used in the experiment. It is probable that in each metal, but especially in the nickel of which the specific inductive capacity is less than that of iron, the transverse magnetization was more intense than the longitudinal magnetization, since the poles of the electro-magnet were brought closer for the former than for the latter.

I hope before long to be able to make a strict comparison between the two effects for iron at least, if not for nickel also; and to find for each metal something of the law of variation of the conductivity with magnetizing forces of different strengths.

XX. "On the Electric Conductivity of Commercial Copper of various kinds." By Professor W. Thomson, F.R.S.

Received June 17, 1857.

In measuring the resistances of wires manufactured for submarine telegraphs, I was surprised to find differences between different specimens so great as most materially to affect their value in the electrical operations for which they are designed. It seemed at first that the process of twisting into wire-rope and covering with gutta-percha, to which some of the specimens had been subjected, must be looked to to find the explanation of these differences. After, however, a careful examination of copper-wire strands, some covered, some uncovered, some varnished with india-rubber, and some oxidized by ignition in a hot flame, it was ascertained that none of these circumstances produced any sensible influence on the whole resistance; and it was found that the wire-rope prepared for the Atlantic cable (No. 14 gauge, composed of seven No. 22 wires, and weighing altogether from 109 to 125 grains per foot) conducted about as well, on the average, as solid wire of the same mass: but, in the larger collection of specimens which thus came to be tested, still greater differences in conducting power were discovered than any previously observed. It appeared now certain that these differences were owing to different qualities of the copper wire itself, and it became important to find how wire of the best quality could be procured. Accordingly, samples of simple No. 22 wire, and of strand spun from it, distinguished according to the manufactories from which they were supplied, were next tested, and the following results were obtained :—

Table of relative conducting qualities of single No. 22 Copper wire, supplied from manufactories A, B, C, D.

	Resistances of equal lengths.	Weights of seven feet.	Resistances reduced to equal conducting masses and lengths.	Conducting power (reciprocals of resistances) of equal and similar masses.
A..	100	121·2 grs.	100	100
B..	100·2	125·8 „	104·0	96·05
C..	111·6	120·0 „	110·5	90·5
D..	197·6	111·7 „	182·0	54·9

The strands spun from wire of the same manufactories showed nearly the same relative qualities, with the exception of an inversion as regards the manufactories B and D, which I have been led to believe must have arisen from an accidental change of labels before the specimens came into my hands.

Two other samples chosen at random about ten days later, out of large stocks of wire supplied from each of the same four manufactories, were tested with different instruments, and exhibited, as nearly as could be estimated, the same relative qualities. It seems, therefore, that there is some degree of constancy in the quality of wire supplied from the same manufactory, while there is vast superiority in the produce of some manufactories over that of others. It has only to be remarked, that *a submarine telegraph constructed with copper wire of the quality of the manufactory* A *of only* $\frac{1}{21}$ *of an inch in diameter, covered with gutta-percha to a diameter of a quarter of an inch, would, with the same electrical power, and the same instruments, do more telegraphic work than one constructed with copper wire of the quality* D, *of* $\frac{1}{16}$ *of an inch diameter,* *covered with gutta-percha to a diameter of a third of an inch,* to show how important it is to shareholders in submarine telegraph companies that only the best copper wire should be admitted for their use. When the importance of the object is recognized, there can be little difficulty in finding how the best, or nearly the best, wire is to be uniformly obtained, seeing that all the specimens of two of the manufactories which have as yet been examined have proved to be of the best, or little short of the best quality, while those of the others have been found inferior in nearly constant proportion.

What is the cause of these differences in electrical quality is a question not only of much practical importance, but of high scientific interest. If chemical composition is to be looked to for the explanation, very slight deviations from perfect purity must be sufficient to produce great effects on the electric conductivity of copper; the following being the results of an assay by Messrs. Matthey and Johnson, made on one of the specimens of copper wire which I had found to be of low conducting power:—

Copper	99·75
Lead	·21
Iron	·03
Tin or antimony	·01
	100·00

The whole stock of wire from which the samples experimented on were taken, has been supplied by the different manufacturers as remarkably pure; and being found satisfactory in mechanical qualities, had never been suspected to present any want of uniformity as to value for telegraphic purposes, when I first discovered the difference in conductivity referred to above. That even the worst of them are superior in conducting power to some other qualities of commercial copper, although not superior to all ordinary copper wire, appears from the following set of comparisons which I have had made between specimens of the No. 22 A wire, ordinary copper wire purchased in Glasgow, fine sheet-copper used in blocks for calico-printers, and common sheet-copper.

Lengths of No. 22 A, weighing 17·3 grs. per foot, used as standards.	Conductors tested.	Their weights per foot.	Lengths resisting as much as standards if of equal conductivity.	Lengths found by experiment to resist as much as standards.	Conductivity referred to that of No. 22 A as 100.
inches.		grs.	inches.	inches.	
23·8	Ordinary No. 18 wire...............	57·5	79·0	73·6	93·2
7·5	Slip of fine sheet-copper	37·6	16·3	9·1	55·8
15·5	Slip of common sheet-copper ...	51·1	45·77	15·6	34·1

To test whether or not the mechanical quality of the metal as to hardness or temper had any influence on the electrical conducting power, the following comparison was made between a piece of soft No. 18 wire, and another piece of the same pulled out and hardened by weights applied up to breaking.

Soft No. 18 copper wire.	No. 18 copper wire, stretched to breaking.	Length found equivalent by experiment.
Weight per foot, 57·5 grs. Length used, 30·8 inches.	Weight per foot, 44·8 grs. Equivalent length, if of equal conductivity, 24·0 inches.	24·0 inches.

The result shows that the greatest degree of brittleness produced by tension does not alter the conductivity of the metal by as much as one half per cent. A similar experiment showed no more sensible effect on the conductivity of copper wire to be produced by hammering it flat. There are, no doubt, slight effects on the conductivity of metals, produced by every application and by the altered condition left after the withdrawal of excessive stress*; and I have already made a partial examination of these effects in copper, iron, and platinum wires, and found them to be in all cases so minute, that the present results as to copper wire are only what was to be expected.

To find whether or not there is any sensible loss of conducting power on the whole due to the spiral forms given to the individual wires when spun into a strand, it would be well worth while to compare very carefully the resistances of single wires with those of strands spun from exactly the same stock. This I have not yet had an opportunity of doing; but the following results show that any deficiency which the strand may present when accurately compared with

* See the Bakerian Lecture, "On the Electro-dynamic Qualities of Metals," §§ 104, 105 and 150, Philosophical Transactions for 1856.

solid wire, is nothing in comparison with the differences presented by different samples chosen at random from various stocks of solid wire and strand in the process of preparation for telegraphic purposes.

No. 16 Solid Wire. Pairs of samples in different states of preparation, each 1000 inches long.

Resistances*.			Weights per foot.	Specific resistances reduced to British absolute measure.
			grs.	
Not covered....	E_1 ·2036 E_2 ·1995	·2015	74·6	11,850,000
Once covered ..	F_1 ·2054 F_2 ·1999	·2026	77·55	12,410,000
Twice covered..	G_1 ·1963 G_2 ·1963	·1963	77·2	11,970,000
Thrice covered..	H_1 ·1893 H_2 ·1916	·1904	77·73	11,680,000
	Means....	·1977	76·78	11,980,000

No. 14 Gauge Strand (seven No. 22 wires twisted together). Pairs of samples in different states of preparation, each 1000 inches long.

Resistances.			Weight per foot.	Specific resistances reduced to British absolute measure.
			grs.	
Not covered....	K_1 ·1595 K_2 ·1634	·1614	115·82	14,750,000
Once covered..	L_1 ·1037 L_2 ·1043	·1040	109·37	8,964,000
Twice covered..	M_1 ·1426 M_2 ·1424	·1425	111·95	12,590,000
Thrice covered..	N_1 ·1092 N_2 ·1085	·1088	121·30	10,430,000
	Means....	·1297	114·61	11,680,000

* These resistances were measured, by means of a Joule's tangent galvanometer with a coil of 400 turns of fine wire, in terms of the resistance of a standard conductor as unity. The resistance of this standard has been determined for me in absolute measure through the kindness of Professor W. Weber, and has been found to be 20,055,000 German units $\left(\frac{\text{metre}}{\text{seconds}}\right)$, or 6,580,000 British units

The specific resistances of the specimens of copper wire from the manufactories A, B, C, D, of which a comparative statement is given in the first Table above, I have estimated in absolute measure by comparing each with F_2, of which the resistance in absolute measure is 6,580,000 × ·1999, or 1,316,000. The various results reduced to specific resistances per grain of mass per foot of length are collected in the following Table, and shown in order of quality in connexion with four determinations of specific conductivity by Weber .

Specific Conductivities of specimens of Copper expressed in British Absolute Measure.

Description of Metal.	Specific resistances.
Copper wire A No. 22	7,600,000
Wire of electrolytically precipitated copper : Weber (1)	7,924,000
Copper wire B No. 22	7,940,000
Ordinary No. 18 copper wire	8,100,000
Copper wire C No. 22	8,400,000
Weber's copper wire : Weber (2)............	8,778,000
No. 14 strand specimen, once covered	8,960,000
Kirchhoff's copper wire : Weber (3)	9,225,000
No. 14 strand specimen, thrice covered	10,400,000
Jacobi's copper wire: Weber (4)............	10,870,000
No. 16 wire specimen, thrice covered	11,700,000
Ditto, twice covered	11,970,000
Ditto, not covered........................	11,850,000
Ditto, once covered	12,410,000
No. 14 strand specimen, twice covered........	12,590,000
Slip of fine sheet-copper	13,600,000
Copper wire D No. 22	13,800,000
No. 14 strand specimen, not covered	14,750,000
Slip of common sheet-copper	22,300,000

$\left(\frac{\text{foot}}{\text{seconds}}\right)$. The numbers in the last column, headed "Specific resistances reduced to British measure," express the resistances of conductors composed of ten different qualities of metal, and each one foot long and weighing one grain. It is impossible to over-estimate the great practical value of this system of absolute measurement carried out by Weber into every department of electrical science, after its first introduction into the observations of terrestrial magnetism by Gauss. See "Messungen galvanischen Leitungswiderstände nach einem absoluten Maasse," Poggendorff's Annalen, March 1851. See also the author's articles entitled "On the Mechanical Theory of Electrolysis," and "Application of the Principle of Mechanical Effect to the Measurement of Electromotive Force, and of Galvanic Resistances in Absolute Units," Philosophical Magazine, December 1851.