# Extracts from the papers of Sir Charles Wheatstone

## WHEATSTONE 2: Material relating to experiments designed to measure electromotile forces and electric potential, [1834-1875]

## K/PP107/2/1

1834-1843

Observations upon electromotive force drafted by Charles Wheatstone, consisting of proposals for experiments to test the electro-motive force of combinations of electrode elements and electrolytes; the means for transforming weak currents; summary entitled 'new theory of voltaic decomposition', with sketches and diagrams.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph

2

King's College. June 27th 1843.

Resistance coils.

| | | |
|---|---|---|
| 50 feet | = | 45 turns |
| 50 | = | 44 |
| 100 | = | 97 |
| 200 | = | 191 |
| 400 | = | 361 |
| 800 | = | 639 |

Large Resistance Coils

× 500 yards = all the small resistance coils + 99 turns
= 1466 turns

The thermo-electric element of Bismuth and Copper the joints at 32° and 212° required 8 turns (exactly) to reduce the needle from 10° to 5° .. (Barometer stood at 29.71).

The standard voltaic element required 757 turns (= 500 yds − 800 ft − coils 99) to reduce the needle from 10° to 5°

The electromotive force of the thermo-electric element is therefore to that of the standard voltaic element as 1 : 94,6


* Built by ~~[illegible]~~ a very different proof has constrained this proportion to be as 1 : 95 See Cours de Physique

K/PP107/2/1/2
Notes on experiments undertaken at King's College London to determine electromotive force using resistance coils, 1843 Jun 27.

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K/PP107/2/1 - Papers relating to the development of the electric telegraph

5

In the electro-magnetic telegraph, the length of the wire being very considerable the resistance in it is much greater than that in other parts of the circuit. If we call the electromotive force 10, the resistance of the battery 2, and the resistance corresponding to the length of the wire 1000, we may illustrate the following conclusions.

1. The deviation of the needle will increase rapidly with the number of pairs. With one pair $A = \frac{100}{1000+2} = \frac{10}{1002}$. With ten pairs $A = \frac{100}{1000+20} = \frac{100}{1020}$. With 100 pairs $A = \frac{1000}{1200} = \frac{1000}{1000+200}$ With 1000 pairs $A = \frac{10000}{1000+2000} = \frac{10000}{3000}$. The limit of increase will be $\frac{E}{R'} = \frac{10}{2}$

2. Increasing the size of the plates will not materially increase the effect. With one pair having double surface $A = \frac{10\cancel{20}}{1000+\cancel{2}1} = \frac{10}{100\cancel{2}1}$. With ~~ten~~ pairs $A = \frac{100}{\cancel{1020}\ 1010}$. With 100 pairs $A = \frac{1000}{1100}$. With 1000 pairs $A = \frac{10000}{\cancel{2}000}$. Comparing these with the previous numbers it will be seen that the advantage is not considerable, but ~~it~~ the advantage of using large plates becomes more appreciable as the number of plates is increased.

3. If the diameter of the wire is increased while the size of the plates and the length of the wire remains the same, the proportionate advantages will be more felt as the number of plates is less. With one plate $A = \frac{10}{502}$. With 10 plates $A = \frac{100}{520}$

K/PP107/2/1/5

Notes on resistance in the electromagnetic telegraph including calculations, [1834-1843], page 1.

# The Papers of Charles Wheatstone

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with 100 pairs $A = \frac{1000}{700}$. with 1000 pairs $A = \frac{10000}{2500}$.

4. If the size of the plates and the diameter of the wire be simultaneously increased the force of the current will be increased in the same proportion. with 1 pair $A = \frac{10}{1000+2}$, the size of the plate and the diameter of the wire being doubled $A = \frac{10}{501}$; the force of the current is therefore double. with 100 pairs $A = \frac{1000}{1200}$; the size of the plates and the diameter of the wire being doubled $A = \frac{1000}{600}$.

5 If the number of pairs, and the length of the wire be increased in the same proportion, the force of the current will ~~current will~~ remain the same; for then the total resistance will increase in the same proportion as the electromotive force.

K/PP107/2/1/5

Notes on resistance in the electromagnetic telegraph including calculations, [1834-1843], page 2.

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Ent 5

King's College June 29th/40

In the following experiments two salts of copper were employed one was placed in one of the square cells and the other in a porous cylinder; copper electrodes were employed.

| | | |
|---|---|---|
| Sulphate .. | Per muriate .... | 56+ turns, point of the needle towards B. |
| Sulphate .. | Nitrate .... | 92+ towards A. |
| Nitrate .. | Per muriate .. | 160+. 156+. 140+ towards B. |
| Nitrate .. | Acetate ... | very slight towards B |
| Sulphate .. | Acetate .... | very imperceptible |

The per muriate was the most positive
— sulphate
— nitrate ..... most negative.

The figures indicate the number of turns required to reduce the needle from 10° to 5°.

| | | |
|---|---|---|
| Nitrate | Sulphate | 56 |
| Sulphate | Chloride | 92 |
| | | 130 |
| Nitrate | Chloride | 140 |

K/PP107/2/1/6

Notes on experiments to measure electromotive forces undertaken at King's College London, 1840 Jun 29.

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## K/PP107/2/1 - Papers relating to the development of the electric telegraph

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This revelation of a new physical power to man which recently dates beyond the commencement of the present century, is to exert a most important influence on the future destinies of his race. An energetic source of heat, of light, of chemical action and of mechanical power, already have economical applications of great value ~~results~~ been supplied from the development of its laws, which only require to be ~~known~~ understood and more determinately defined, to obtain from them these profitable results

K/PP107/2/1/7

Note describing the future potential of electromagnetic motors [quoted on page 85, Brian Bowers, 'Sir Charles Wheatstone FRS 1802-1875', HMSO Science Museum 1975, revised edition 2001], [1834-1843].

# The Papers of Charles Wheatstone

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In a voltaic series the effient current of electricity is furnished by the extreme elements alone, and if ~~the~~ it consists of 20 pairs there is $\frac{19}{20}$ ths of the electricity generated absolutely lost, that is, it is neutralized between the adjacent plates without doing any work. If this electricity could be set usefully to work without injuring the insulating power of the battery, a great advantage would be obtained

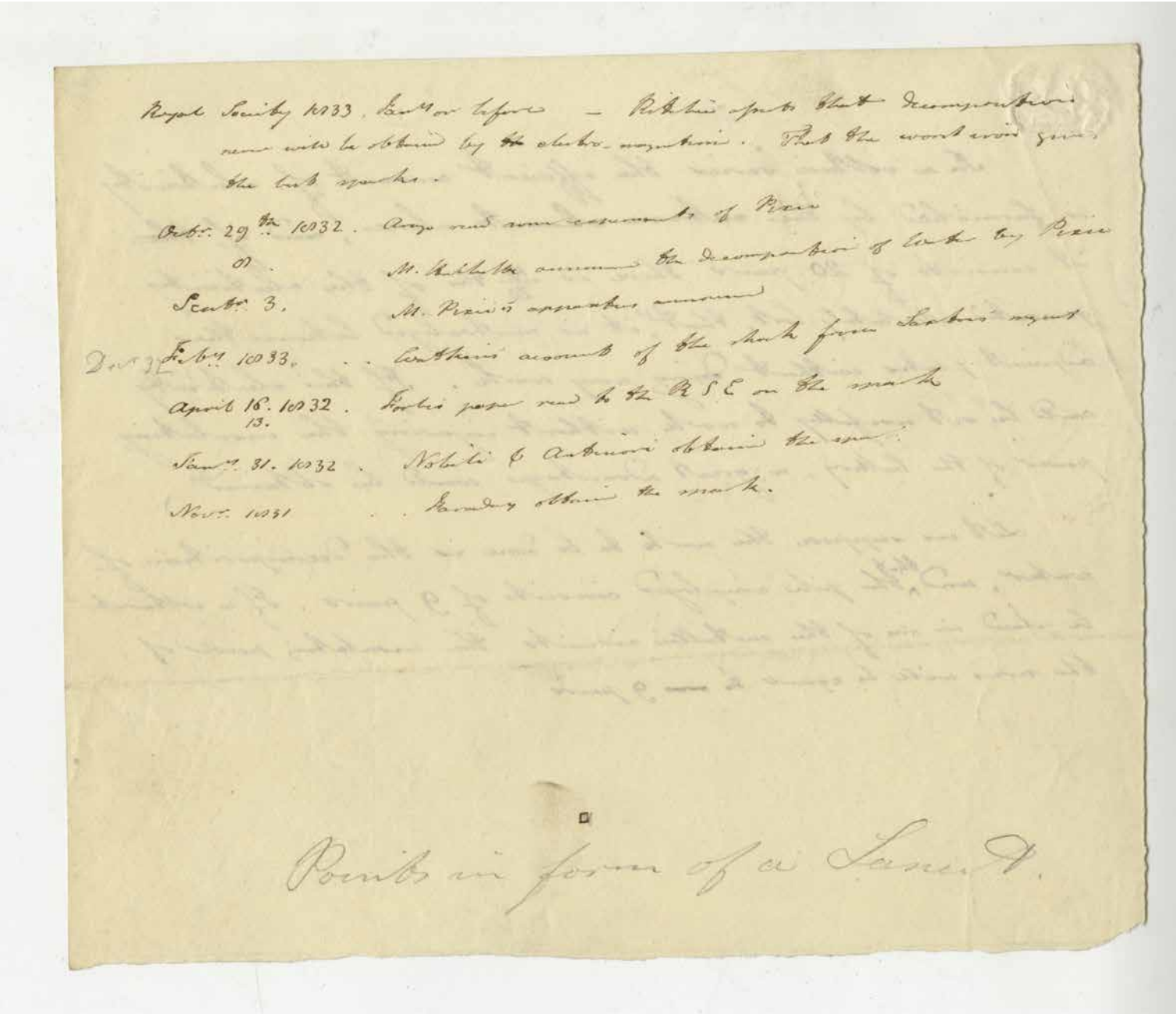
Let us suppose the work to be done is the decomposition of water, and that the pile employed consists of 9 pairs. If a voltameter be placed in one of the metallic circuits the insulating power of the series will be equal to ~~one~~ 9 pairs

K/PP107/2/1/8

Notes describing the decomposition of water and on reverse a timeline of related events between 1831-1833, [1834-1843], page 1.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph



Royal Society 1833. Last or before – Ritchie states that decomposition
may not be obtained by the electro-magnetic. That the wire gives
the best spark.

Octr. 29th 1832. Arago read some extracts of Prevo
on. M. Ritchie answers the decomposition of water by Prevo

Septr. 3. M. Prevo's opinion answered

Dec 3 Febry 1833. . Ritchie's account of the shock from Saxton's report

April 16. 1832. Forbes paper read to the R S E on the spark
13.

Sept. 31. 1832. Nobili & Antinori obtain the spark

Nov. 1831 . Faraday obtains the spark.

Points in form of a Lance.

K/PP107/2/1/8
Notes describing the decomposition of water and on reverse a timeline of related events between 1831-1833, [1834-1843], page 2.

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

10

Electro-motive Force.

In voltaic arrangements, it is of the utmost consequence, if great intensity of action be required, that the single elements shall have great electromotive force. For in a circuit, of whatever number of elements it is composed, the resultant intensity of action may by an indefinite diminution of resistance approach more and more nearly to the electro-motive intensity of a single element, but never can reach it.

If the electro-motive intensity of Copper and Platinum be required to produce a certain decomposition (quantitative not quantitative); a pile of copper and platinum of however many elements it may consist will never do this because the independent resistance will always keep the intensity of the current below the proper degree; but a pile of a moderate number of Zinc & Platinum elements will be able to effect it.

~~The decomposability of a substance~~

Instead of saying as we now do that such substances are decomposable and such other non decomposable by voltaic electricity, it would be more correct to say that they are decomposable or non decomposable by ~~the~~ at below the intensity we can command by our ordinary voltaic arrangements, the elements of which usually have Zinc & Copper. Amalgamated Zinc & Platinum will effect this.

No advantage will be obtained if on increasing the electro-motive force of each element we increase the resistance in the same proportion, except that of requiring a less number of elements to produce the same effect. Thus an element represented by $\frac{2}{2}$ will produce double the effect of an element represented by $\frac{1}{1}$; but both, if the resistance in the all cases the same will have the same limit.

K/PP107/2/1/10

Notes describing methods of measuring electromotive forces, [1834-1843], page 1.

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

The maximum limit of the action of a pile of however many elements it may consist is that of a single element without any other resistance in the circuit; this is $\frac{E}{\frac{r}{s}} = \frac{sE}{r}$.

The maximum limit of a single element is that of the electro-motive force. Thus ten thousand elements of Copper & Silver, each a thousand square feet can never equal a single pair of Mercury and Platinum when the resistance are indefinitely reduced.

Hence the utter hopelessness of expecting to produce energetic decompositions with thermo-electric arrangements.

K/PP107/2/1/10

Notes describing methods of measuring electromotive forces, [1834-1843], page 2.

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

12

Means of multiplying the effects of very weak currents

Suppose we have a current which produces a permanent deviation of 5° towards A of Nellonis galvanometer. The needle being first at rest at 0° and one of the poles placed in the cup, connection must be made for an instant with the other cup, the needle will spring towards A and return with pole beyond 0° towards B; at the instant it is about to return from B touch the cups again and the magnitude of the oscillation will be increased, and repeat the same operation every time the needle is about to return from B. The oscillation may be thus increased until the needle strikes against the stop, and the number of oscillations required to attain this limit may be taken as the measure of the force.

To reduce the amplitude of the oscillation and bring the needle to rest, contact must be made at every instant the needle is at its extreme limit towards A; it requires fewer touches to reduce the oscillation of the needle than to increase them the same degree.

In the first case the current is made to act with the momentum of the needle, in the second case against it.

Currents which would produce deviation only of a fraction of a degree may be thus rendered very sensible; this method would be extremely applicable in some of the thermomagnetic experiments. ~~of the~~

K/PP107/2/1/12

Notes describing 'means of multiplying the effects of very weak currents', [1834-1843].

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

13

## Electromotive Forces.

Prepare a series of cells the metals of which are copper (perfectly clean) and amalgamated zinc. Charge the 1st with sulphate of copper, the 2d with nitrate of copper, the 3d with acetate of copper, the 4th with muriate of copper. Will the electro-motive forces in all the cells be precisely the same, or will they differ? If they differ will the comparative electro-motive forces have any relation to the order of affinity of the acids for the metals? If they differ, and two of the solutions be mixed together, will, as in the case of different salts of the same metals only the most (positive? negative?) be decomposed, or will both be decomposed together?

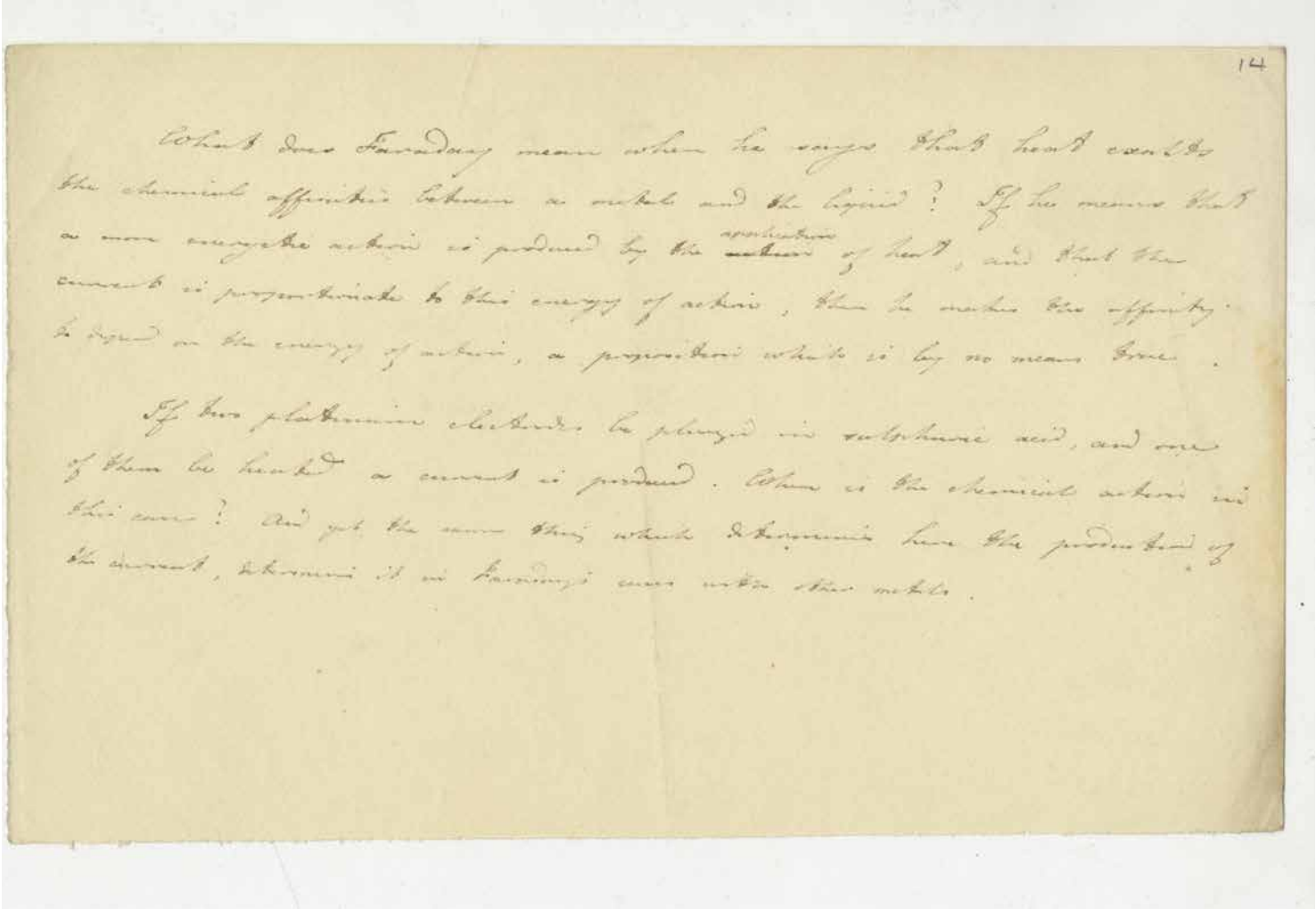
For Becquerel's experiment when the quantity of nitrate of silver is to that of nitrate of copper as 1:67 will the electro-motive force be the mean of the two or what?

K/PP107/2/1/13

Notes describing methods of measuring electromotive forces, [1834-1843].

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph



14

What does Faraday mean when he says that heat exalts the chemical affinities between a metal and the liquid? If he means that a more energetic action is produced by the ~~action~~ conductive of heat, and that the current is proportionate to this energy of action, then he makes the affinity to depend on the energy of action, a proposition which is by no means true.

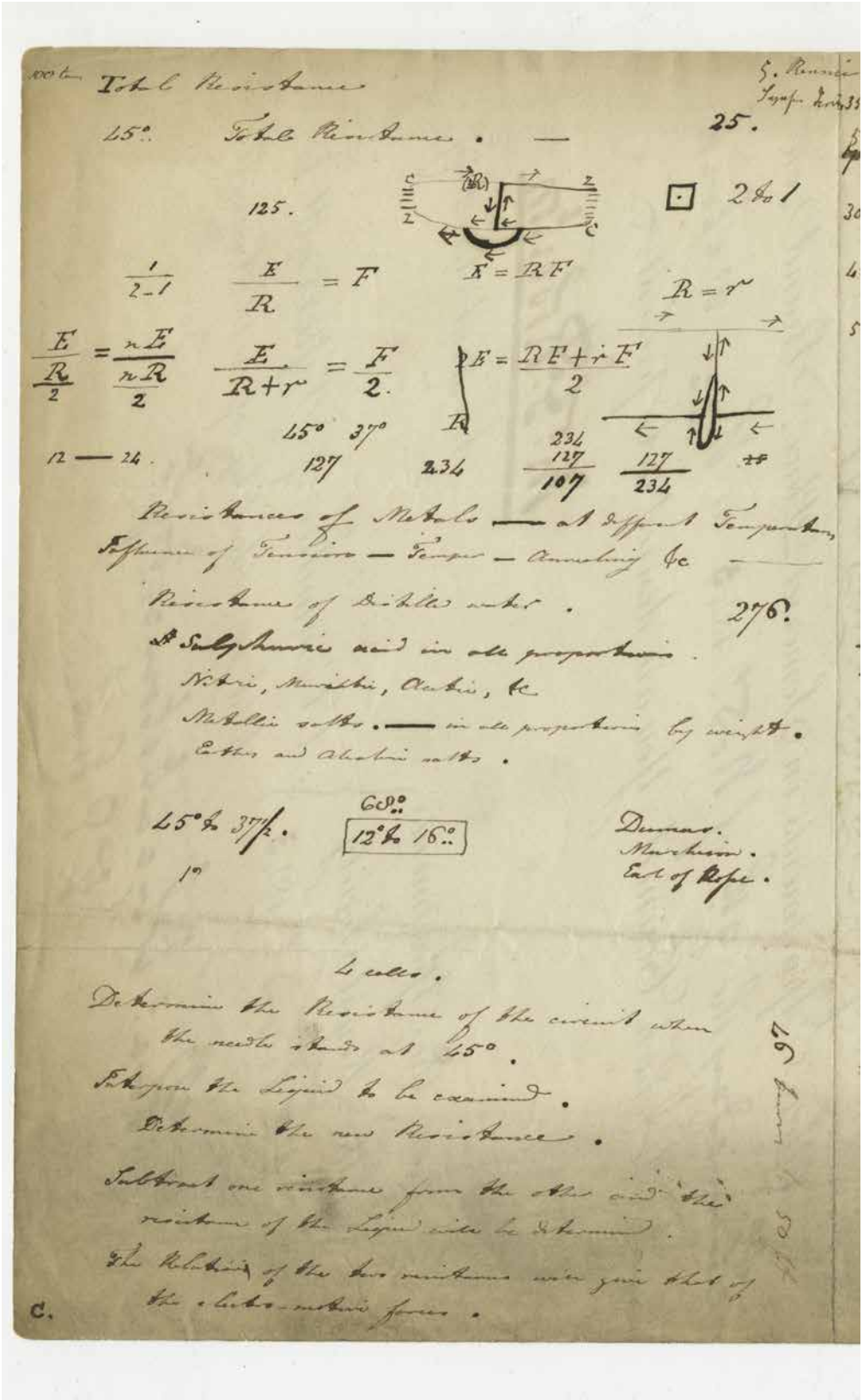
If two platinum electrodes be plunged in sulphuric acid, and one of them be heated a current is produced. Where is the chemical action in this case? And yet the same thing which determines here the production of the current, determines it in bringing zinc into other metals.

K/PP107/2/1/14

Notes examining the question 'What does Faraday mean when he says that heat exalts the chemical affinities between a metal and the liquid?', [1834-1843].

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph



Total Resistance

45°. Total Resistance. — 25.

125.

2 to 1

$\frac{1}{2-1}$ $\frac{E}{R} = F$ $E = RF$ $R = r$

$\frac{E}{\frac{R}{2}} = \frac{nE}{\frac{nR}{2}}$ $\frac{E}{R+r} = \frac{F}{2}$ $E = \frac{RF + rF}{2}$

45° 37°

12 — 24. 127 234 $\frac{234}{127}$ 107 $\frac{127}{234}$

Resistances of Metals — at different Temperatures,
Influence of Tension — Temper — Annealing &c —

Resistance of distilled water. 276.

Sulphuric acid in all proportions.
Nitric, Muriatic, Acetic, &c
Metallic salts. — in all proportions by weight.
Earthy and Alkaline salts.

45° to 37½. 60°. 12° to 16°. Dumas. Marchand. Earl of Rosse.

1°

4 cells.

Determine the Resistance of the circuit when the needle stands at 45°.

Take you the Liquid to be examined.

Determine the new Resistance.

Subtract one resistance from the other and the resistance of the Liquid will be determined.

The relating of the two resistances will give that of the electro-motive force.

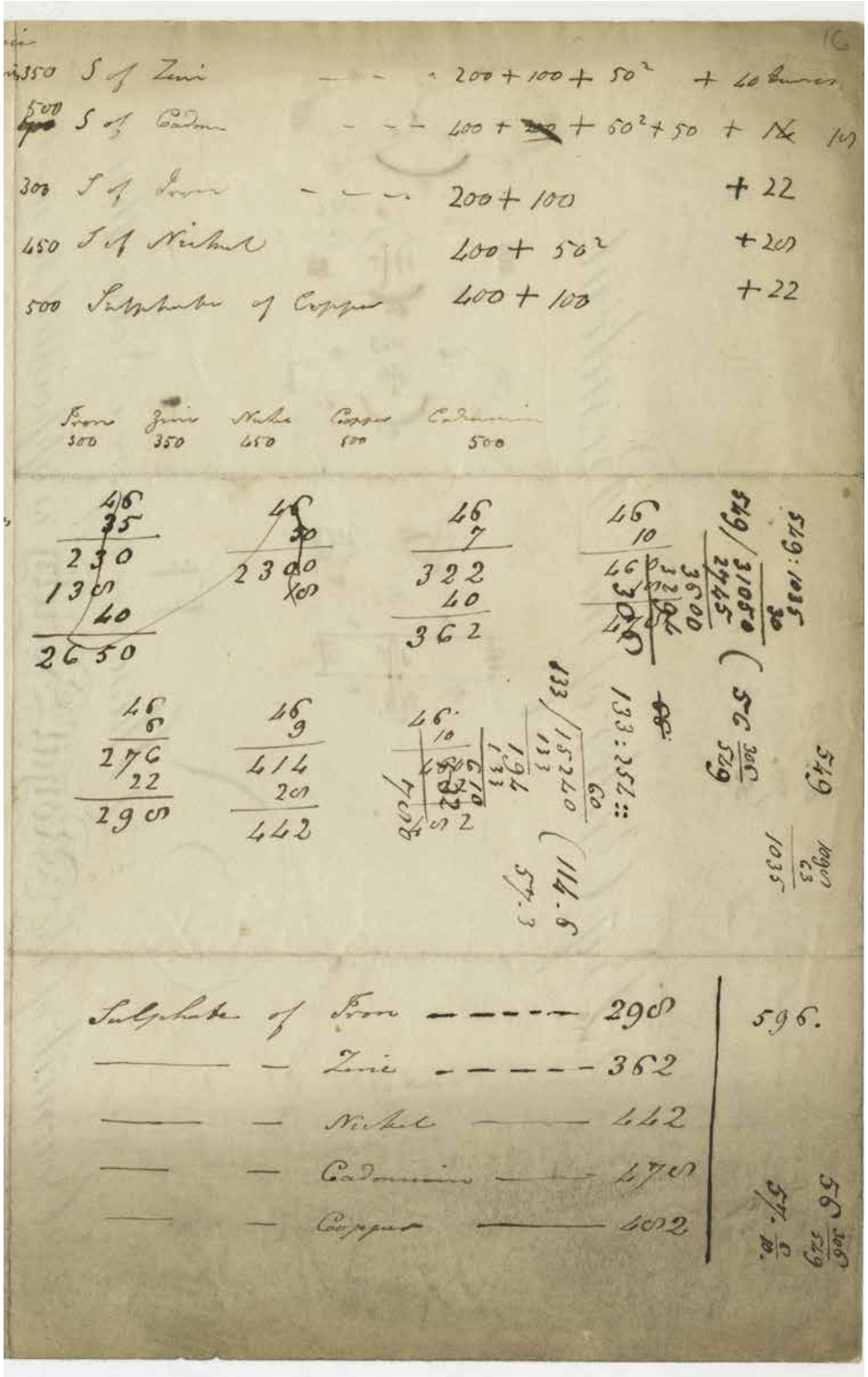
C.

K/PP107/2/1/16

Notes, formulas and calculations relating to the measurement of resistance on reverse of a letter from the Royal Society including Wheatstone's rough diagrams, [1843], page 1.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph



K/PP107/2/1/16

Notes, formulas and calculations relating to the measurement of resistance on reverse of a letter from the Royal Society including Wheatstone's rough diagrams, [1843], page 2.

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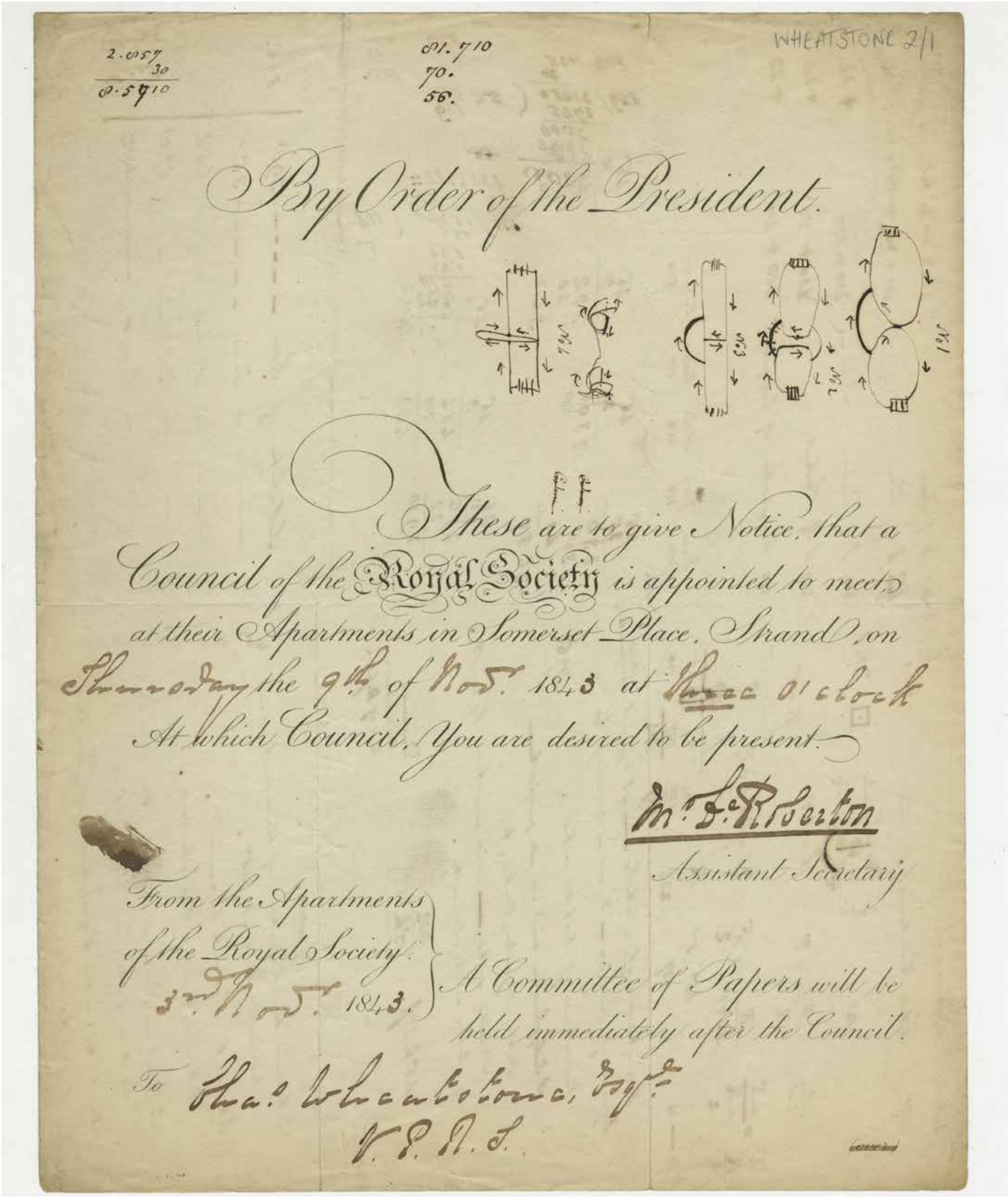
K/PP107/2/1 - Papers relating to the development of the electric telegraph



2.057
30
8.5710

81.710
70.
56.

WHEATSTONE 2/1

By Order of the President.

These are to give Notice, that a Council of the Royal Society is appointed to meet at their Apartments in Somerset Place, Strand, on Thursday the 9th of Nov.r 1843 at three o'clock At which Council, You are desired to be present.

Wm. H. Roberton
Assistant Secretary

From the Apartments of the Royal Society 3rd Nov.r 1843.

A Committee of Papers will be held immediately after the Council.

To Chas. Wheatstone, Esq.re
V. P. R. S.

K/PP107/2/1/16

Notes, formulas and calculations relating to the measurement of resistance on reverse of a letter from the Royal Society including Wheatstone's rough diagrams, [1843], page 3.

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

20

Sept 9th /43

$$\frac{E}{R+r} = \frac{E}{\frac{R}{2}+r+\lambda} \quad \because \cancel{R=2\lambda} \qquad \lambda = \frac{R}{2}, \quad R = 2\lambda$$

$\frac{E}{R}$ = a cell of the standard battery ... $\lambda = 7$ turns $R = 14$ turns

—

$$\frac{E}{R+r} = \frac{2E}{2R+r+\lambda} \quad \because r = l$$

$r$ = 100 ft + 7 turns + gals + appendages

$\lambda$ = 120 turns.

100 ft = 95 turns

gals + appendages = 7 turns

Sept 12.

A Copper wire 2 feet weighed $20\frac{24}{100}$ grs or 21 grs. 1 ft 10.5

B do do 64 9/10 grs or 65 grs. 1 f 32.5

2 feet of A was about equal to 1/10 th of a turn of the Regulator or 15 feet = 1 turn.

$\frac{21}{200}$ ths of a foot of A is equal in resistance to 1 foot of the standard

$R = 2\lambda = 2134$ standard units.

2 ft weighed 21 grs 10½ grs

1 foot was 100 grs

$\frac{1}{10.5} : \frac{1}{100} :: 1 : \frac{10.5}{100}$

$200 : 21 :: 1$

$21 : 100$

$21)\,200\,(9.50$, $189$, $110$, $105$

$100)\,10.5\,(0.105$, $10.0$, $500$

$\frac{76}{25}$ $\frac{6050}{10260}$

$300$ $109440$

$304$

$3420$, $32$

$9.5$, $07$

$76.0$

$50)\,1500\,(32$, $150$, $100$

K/PP107/2/1/20

Notes, formula and calculations relating to the measurement of resistance, 1843 Sep 9.

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

23

Experiments to be made with Faraday's circuit with Iodide of Potassium and Sulphuric acid.

Exp 1. Measure the electromotive force with the Iodide alone.

Exp 2. Measure the electro-motive force of the sulphuric acid alone.

Exp 3. Measure the difference of the electro-motive force

Exp. 4. Measure their sums.

Platinum, Nitrate of Platinum, Amalgam of Zinc per 10 lb Sum of expts between 45° & 50°

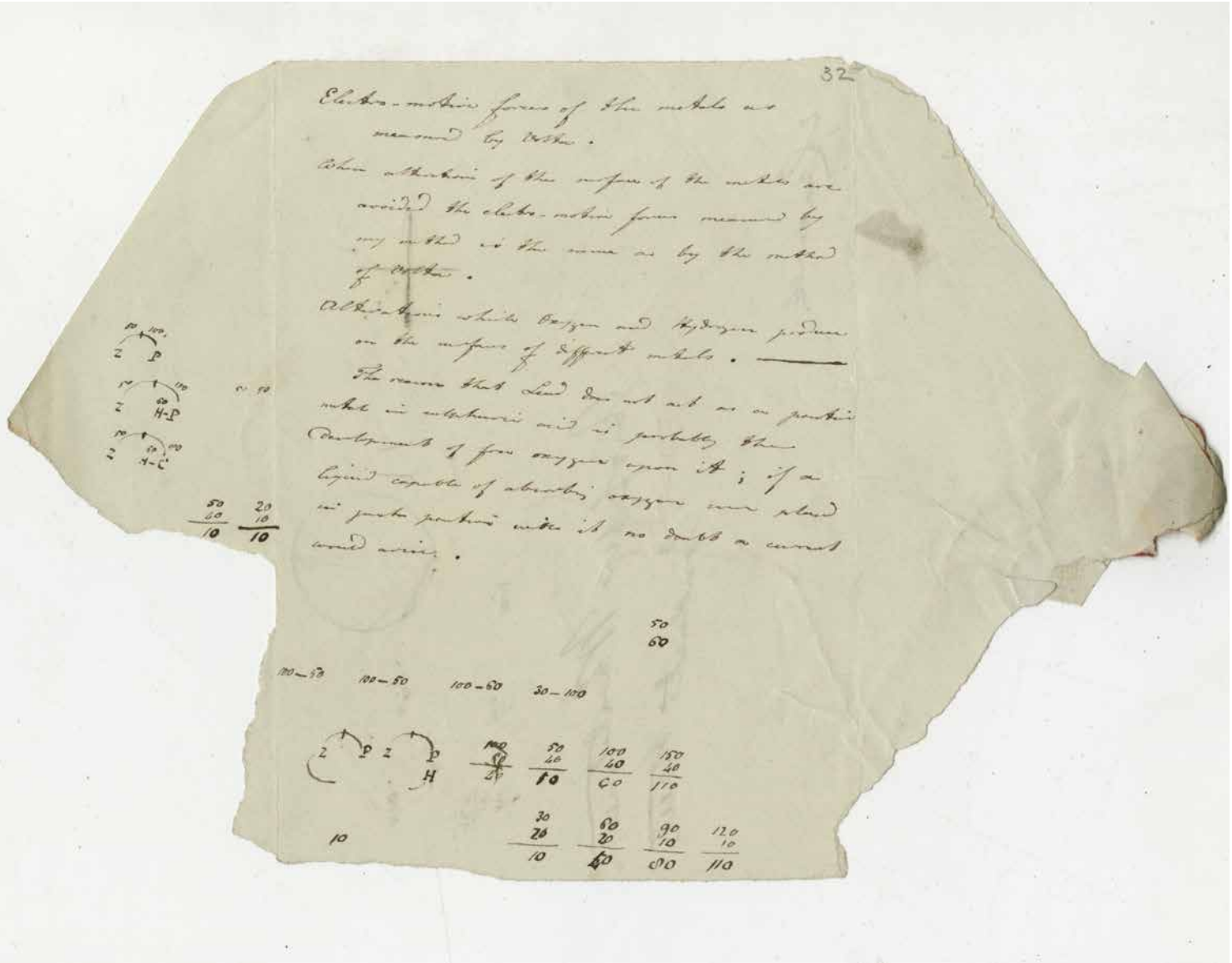
Copper, Sulphate of Copper, Amalgam of Zinc — 6 lb Sum

K/PP107/2/1/23

Notes on experiments 'to be made with Faraday's circuit with Iodide of Potassium and Sulphuric acid', [1834-1843].

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph



32

Electro-motive forces of the metals as measured by Volta.

When oxidation of the surface of the metals are avoided the electro-motive force measured by any method is the same as by the method of Volta.

Oxidation which Oxygen and Hydrogen produce on the surface of different metals. ——

The reason that Lead does not act as a positive metal in substance and is probably the Development of free oxygen upon it; if a liquid capable of absorbing oxygen were placed in positive position with it no doubt a current would arise.

K/PP107/2/1/32

Notes on 'Electro-motive forces of the metals as measured by volta' on reverse of envelope from the social reformer Edwin Chadwick (1800-1890), [1834-1843], page 1.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph

K/PP107/2/1/32

Notes on 'Electro-motive forces of the metals as measured by volta' on reverse of envelope from the social reformer Edwin Chadwick (1800-1890), [1834-1843], page 2.

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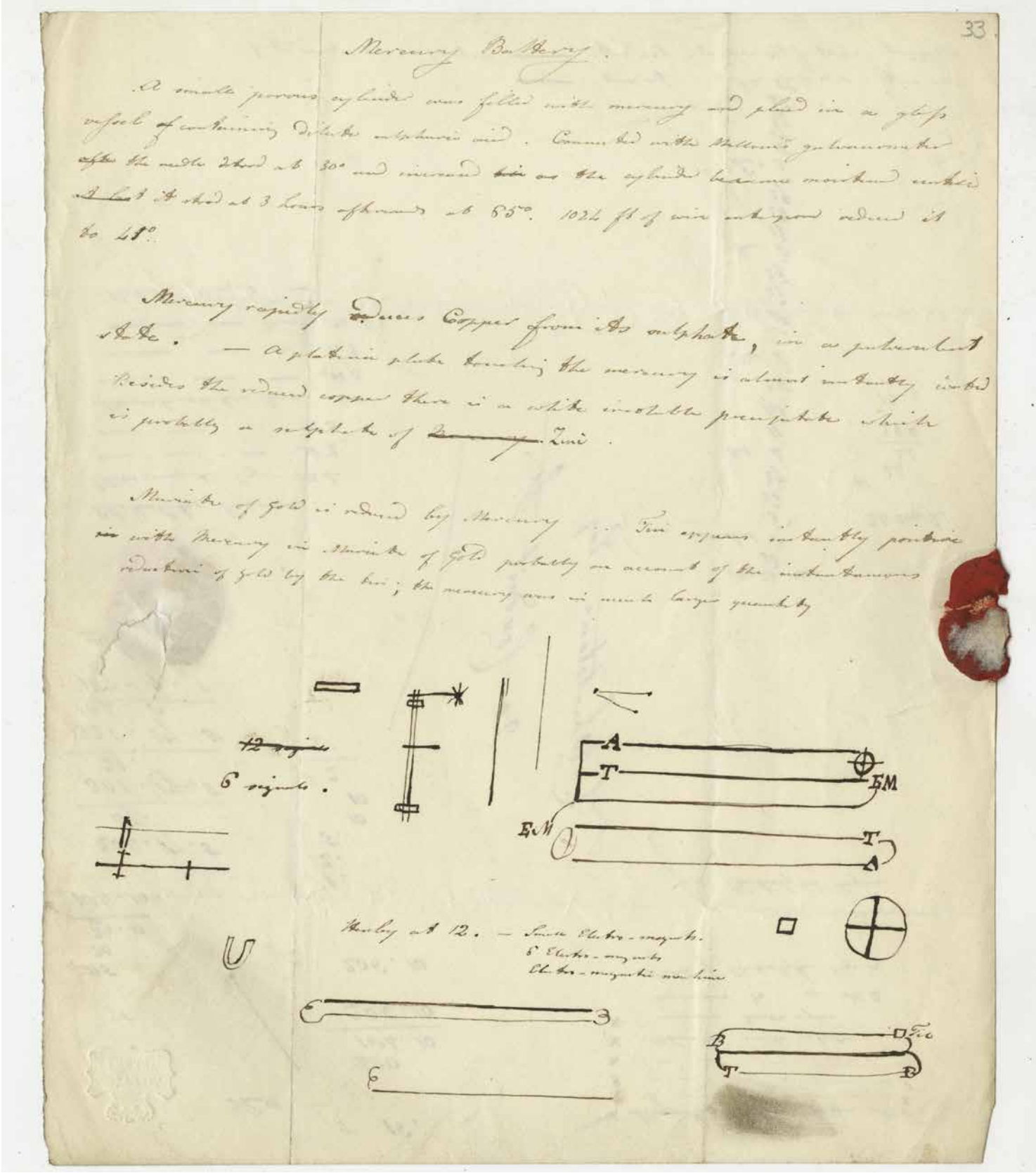


33

Mercury Battery.

A small porous cylinder was filled with mercury and placed in a glass vessel containing dilute sulphuric acid. Connected with Daniell's galvanometer the needle stood at 30° and increased ~~till~~ as the cylinder became moistened until ~~it had~~ it stood at 3 hours afterwards at 65°. 102 ft of wire interposed reduced it to 28°.

Mercury rapidly ~~reduces~~ Copper from its sulphate, in a galvanic state. — A platinum plate touching the mercury is almost instantly incrusted. Besides the reduced copper there is a white insoluble precipitate which is probably a sulphate of ~~Mercury~~ Zinc.

Muriate of Gold is reduced by Mercury ... Tin appears instantly positive with Mercury in Muriate of Gold probably on account of the instantaneous reduction of Gold by the tin; the mercury was in much larger quantity

~~12 rings~~
6 rings.

A
T
EM
EM
T
A

Battery at 12. — Simple Electro-magnets.
6 Electro-magnets
Electro-magnets non-linear

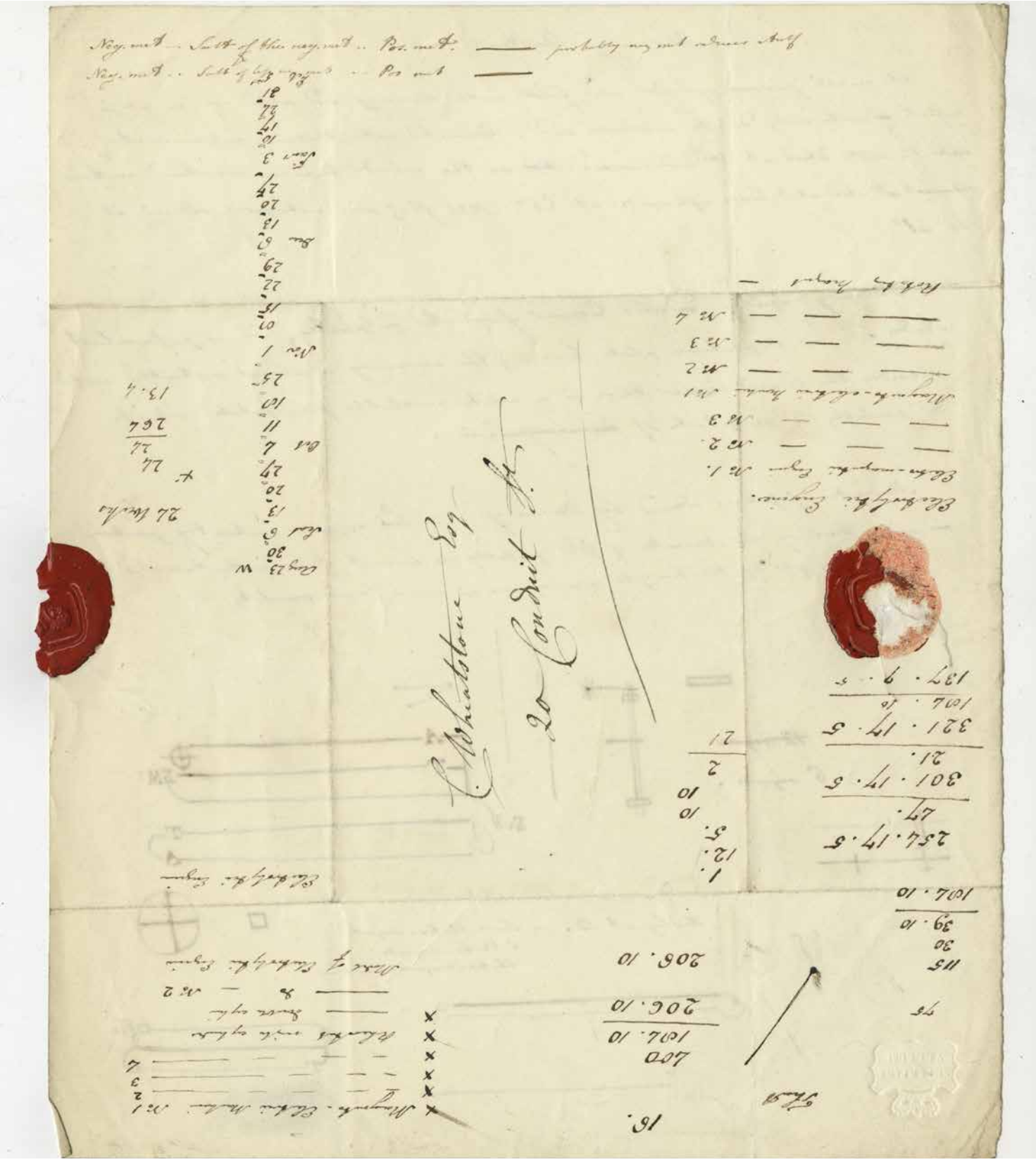
E
B
6

B
T
Fig.
B

K/PP107/2/1/33
Notes and sketch diagrams describing how to make a mercury battery, written on the back of an envelope, [1834-1843], page 1.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph



K/PP107/2/1/33

Notes and sketch diagrams describing how to make a mercury battery, written on the back of an envelope, [1834-1843], page 2.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph

31. 36

Sept 3d. 1841

12 square cells charged upwards of 12 hours.

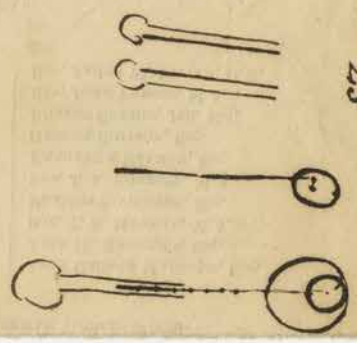
Current passed through 2 reels of 500 yards each ... needle deviated — 30½°

Differential connexion between the battery and galvanometer, a reel of 500 yards in each wire ... nearly neutralized ... the needle deviated ... 2½

One wire unappropriated — 31°

The four wires with the reels placed so as to form a single circuit ~~with~~ of double metal — 51°

$R = 51°$ $2R = 30½$ $3R = 31°$



43

K/PP107/2/1/36

Notes and sketch diagrams on an experiment using a twelve cell battery, 1841 Sep 3.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph

37

The resistance of a ~~wire~~ conductor of any form, prismatic conical be regular or irregular, is inversely as the weight, when the length and material of which it is composed remain the same; or $R = \frac{1}{W}$. Therefore the resistance of any shaped conductor is equivalent to the resistance of a cylinder of the same weight. This rule may be useful in determining the conductibilities of liquids notwithstanding the irregularities of the bores of the tubes which contain them.

K/PP107/2/1/37
Notes on measuring the resistance of a conductor, [1834-1843].

# The Papers of Charles Wheatstone

K/PP107/2/1 - Papers relating to the development of the electric telegraph

38

Faraday has proved the simple and remarkable law that the same quantity of electricity is required to effect the decomposition of an atom (definite proportions) of any substance. The law of Ohm ~~proves~~ shows that the quantity of electricity is diminished as the resistance of the body to be decomposed, (they not in the same proportion because the other resistances must be taken into consideration. It is a necessary consequence ~~from~~ of these two laws that the decomposability of substances, must be in reversion to their conducting powers, or more properly to their resistances to the passage of electricity. This is the law which Faraday has ascertained from direct experiment, by which he found that ~~the~~ electrolytes are the best conductors.

It has been observed, particularly by Becquerel in a recent paper of his, that those elements which are combined with the greatest energy, are also those which are most readily decomposed by the current, and that those elements which are combined in virtue of weak affinities, are also those which the least obey the decomposing action of dynamic electricity; and that it hence appears that all compound bodies separate under the influence of a current, in proportion to the affinity which unites their elements. If this be generally true it follows that the force of affinity, and the resistance to the passage of electricity correspond with each other, or in other words that the force of affinity is inversely as the conducting power.

K/PP107/2/1/38

Notes describing the law of electrolysis proposed in 1834 by Michael Faraday (1791-1867), natural philosopher, [1834-1843], page 1.

# The Papers of Charles Wheatstone

## K/PP107/2/1 - Papers relating to the development of the electric telegraph

It would be a most instructive series of experiments to ascertain the resistances of different substances by the aid of a constant battery; the quantity of elements decomposed in the same time by a constant current would be the best ~~a~~ measure of the resistance.

It having been proved that liquids become better conductors in proportion as their temperature is higher, the decomposition of a substance would be much facilitated by exalting the temperature. If the resistance of the substance to be decomposed is much greater than the resistance of the battery; far greater effects of decomposition would be produced by elevating the temperature of the liquid to be decomposed that by raising the temperature of the liquid of the battery. Thus if a battery consists of 10 pairs of plates ~~and~~ the resistance ~~tow~~ each cell be represented by 2 ~~cells~~ while the resistance of the decomposing substance be 1000; if ~~from~~ the temperature of the liquids in the cells be elevated to double, the force of the current will be $= \frac{10}{101}$, but if the temperature of the decomposing liquid be raised to the same degree the force of the current will be $= \frac{100}{520}$. Both being raised, the current will be $= \frac{100}{510}$, the additional current in this case is so small that it would not be worth while raising the temperature of the whole battery. Raising the temperature of the decomposing liquid will be unquestionably the most efficient means of increasing the electrolytic action.

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Notes describing the law of electrolysis proposed in 1834 by Michael Faraday (1791-1867), natural philosopher, [1834-1843], page 2.

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## Electro-motive Force.

If two elements having different electro-motive forces be interposed in the same circuit it is evident that the resistance of the entire circuit will remain the same whether the elements concur with or oppose each other; but the resultant electromotive force will in the first case be as the sum of the components, and in the second case as their difference.

The comparative electromotive forces of the two elements may be easily ascertained from these two experiments; the ~~strength with~~ observed intensities being $a$ & $b$, and the single electro-motive forces $x$ and $y$.

$$x = \frac{a+b}{2} \qquad y = \frac{a-b}{2}$$

$$x+y = 2a$$
$$x-y = 2b$$

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Notes describing different electromotive forces, [1834-1843].

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New Theory of Voltaic Decomposition.

When a salt is dissolved in water the positive metal takes the oxygen from the base and the oxide thus formed combines with the disengaged acid: If the base be not capable of decomposing water it is precipitated (sulphate of copper); but if it be so it combines with the oxygen of the water and hydrogen is evolved. (Sulphate of soda).

An acid dissolved in water may be considered as it is by many chemists a salt of water, and water may therefore be regarded ~~in the~~ as similar to a metallic oxide. When sulphuric acid is employed the positive metals takes the oxygen of the water, and then unites with the sulphuric acid while the hydrogen is liberated.

This hypothesis is much simpler than Daniell's and leads to precisely the same results. Both are in opposition to that which makes the decomposition of water the primary result.

The voltaic circuit makes the positive metal much more positive than the base and ~~thus~~ the force deprives it of its oxygen.

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Notes describing a 'New Theory of Voltaic Decomposition', [1834-1843].

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Measures of Electro-motive forces

| | | | |
|---|---|---|---|
| Cast amalgamated zinc | Platinum | Dilute Sulph acid | 39 |
| Distilled zinc | Platinum | Dilute Sulph acid | 37 |
| Do | Carbon | Do | 23 |
| Distilled zinc | Platinum | Do | 29 |
| Do clean | Do | Do | 34 |
| Impure Mercury | Do | Do | 33 |
| Do | Do | Do | 33 |
| Do | Do | Sulph of Copper sat. sol | 66 |
| Do | Do | Do after 3 hours | 59 |
| Do | Do | after 2 hours more | 59 or 60 |
| Do | Do | after 10 hours more | 59 or 60 |

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List of measurements of electromotive forces in different elements, [1834-1843].

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## Solubility of Metallic Salts.

The best dissolvent of lead is nitric acid; but when sulphuric acid is added to the latter, it dissolves, as it were, no lead: hydrochloric acid also diminishes the dissolving power of nitric acid; this depends on the combinations formed in both cases being very little soluble.

Plumbic acid dissolves in caustic soda.

According to the experiments of Guyton Morveau, plumbic oxide is soluble in pure water, but insoluble in water which contains the least trace of salt. If distilled water be poured into a leaden vessel, and be left in it some time, the lead is attacked and the water acquires the property of exerting a feeble alkaline action upon (turmeric rouge) paper &c. Spring water on the contrary, which contains salts does not dissolve lead.

Eleven parts of potash and thirteen parts of soda dissolve one of plumbic acid. A solution of plumbic carbonate is colourless. Milk of lime, boiled with plumbic oxide, dissolves a small portion.

Hydrochloric acid does not dissolve metallic lead, and scarcely attacks it when it is boiled with it.

Sulphate of lead is insoluble in water. Sulphuric acid exerts a little a dissolving action upon lead, that it may not only be boiled in a concentrated state with lead, without the latter being much attacked, but it even deprives nitric acid in a great part of its dissolving action, so far that a mixture of the two concentrated acids, put in digestion with lead scarcely stops the metal.

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Notes describing the 'Solubility of Metallic Salts', [1834-1843], page 1.

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According to the experiments of Bischoff, 1 part of nitrate of lead dissolves at the temperature of 12° in 172 parts of nitric acid, in 959 parts of nitrate of ammonia and 47 parts of acetate of ammonia.

Nitrate of lead dissolves in 7½ parts of cold water and in a much less quantity of boiling water.

Lead dissolves in acetic acid

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Notes describing the 'Solubility of Metallic Salts', [1834-1843], page 2.

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Assuming that the quantity of electricity evolved is in exact proportion to the quantity of zinc dissolved, the augmentation of power by acting more energetically on the zinc, or by bringing the plates closer together, or increasing the quantity of negative surface exposed to the fluid, can be effective, not by creating additional power, but merely by increasing the rapidity of the decomposition i.e. by producing the effect in less time. It would be satisfactory to measure the time a certain quantity of zinc requires for its dissolution under different circumstances; I have no doubt that the intensity of the electric current produced will be found exactly in the inverse proportion to the duration of the action.

Exps. The time to dissolve n grains of zinc in a saturated solution of sulphate of copper. Do, when an equal surface of copper is opposed, twice, three times &c.

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Notes describing a hypothesis on the decomposition of elements and possible related experiments, [1834-1843], page 1.

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If sulphate of copper acts more energetically on zinc in a battery than sulphuric acid does it may be explained in the following way. —— Sulphuric acid would in a given time combine with ~~dissolve~~ n grains of copper, and in the same time with m grains of zinc; when both are in presence of the solution the intensity of the action may be as proportional to the difference of the two effects. (This cannot be true, for if it were, increasing the quantity of copper would diminish the action.)

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1 The experiments of Marianini, Rogers & Daniell, seem to prove that the force of a current is increased by heating the battery; now is this increase of effect owing to the exaltation of the electromotive power, or to the diminution of the resistance of the conducting liquid. This question admits of an easy answer; in accordance with the law of Ohm, if it is the electro-motive power which is exalted, the force of the current should be increased in the same proportion whether a short or a very long wire join the poles of the electrometer, that is if the power be doubled in the first case it will be doubled in the second; but if the effect is due to the diminution of the resistance, then the augmentation of the strength of the current will be less in proportion to the length of the connecting wire.

It also follows from the same law that if the heating effect and the diameter of the connecting wire increase together, the current should increase in the same proportion; if however the heating effect increases while the diameter of the wire remains the same, the strength of the current will increase in less proportion than the heating effect, and the difference between the force of the current and the heating power will be greater as the length of the wire increases.

It equally follows that increasing the number of pairs, when the wire is very short no difference of effect on the needle will be observed beyond that caused by one pair of plates; but a difference will become sensible in proportion to the length of the wire.

~~It~~ In fine, augmenting the temperature of the liquid produces precisely the same effect as increasing the size of the plates. It is easy therefore to see that however the magnetic effects might be augmented, by the application of heat, we cannot expect to increase the chemical effects of a pile in any very eminent degree by this means, for the size of plates is of very little consequence when great resistances are to be overcome except the diameter of the connecting wire is increased in proportion.

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Description of experiments by Stefano Giovanni Marianini (1790-1866), Italian physicist, William Barton Rogers (1804-1882), American physicist, and John Frederic Daniell (1790-1845), Professor of Chemistry at King's College London, proving that the force of a current is increased by heating the battery, written on the back of an envelope, [1838], page 1.

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Description of experiments by Stefano Giovanni Marianini (1790-1866), Italian physicist, William Barton Rogers (1804-1882), American physicist, and John Frederic Daniell (1790-1845), Professor of Chemistry at King's College London, proving that the force of a current is increased by heating the battery, written on the back of an envelope, [1838], page 1.

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Experiments to be tried.

June 1840.

1 Ascertain the electromotive force of amalgam of potassium, 1st with sulphate of copper and copper. 2d with muriate of platina, and platina.

2. Ascertain the electromotive force of iron, employing successively sulphate, acetate and nitrate of iron with amalgam of Zinc.

3. Increase the power acting on the needle by presenting a magnet to it. Observe the number of coils necessary to reduce 40 to 35°. Coils they be proportionate to the intensity?

4. Ascertain the electromotive force of copper, sulphate of copper and amalgam of Zinc, at the temperatures of 0° and 212°.

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List of electromotive force experiments to be tried, 1840 Jun.

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Variability of the Electro-motive force.

I For some voltaic combinations the electro-motive-force changes with the energy of the current.
But as the measures of the different combinations are made when the currents have the same degree of energy, this does not prevent the electro-motive force from being properly ascertained.
It may be ascertained whether a combination is thus affected by making two different measures, the effects indicated by the electrometer in the two cases having a known proportion to each other.

II. In other voltaic combinations the electro-motive force changes with the duration of the action.
This is easily ascertained by the measuring apparatus.

III. And in other combinations again the electro-motive force may change while the energy remains constant, the nature of the elements of the voltaic combination alone varying.

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Notes on the variability of electromotive force, [1834-1843].

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Phenomena of the Electrical Current.

24) According to what has been proved in No 12, the strength of the electrical current in a prismatic body for each point thereof in general will be expressed by the following equation

$$S = \omega x \frac{du}{dx},$$

in which S indicates the strength of the current and u the electroscopic power at the point of the circuit, the abscissa of which is x, ω represents the section of the prismatic body, and x ~~the~~ its conducting power at the same point. In order now to connect this equation with the ascertained general equation in No 10 for each circuit compounded of a chosen number of parts, we write it thus:

$$S = x\omega \frac{du}{dy} \cdot \frac{dy}{dx},$$

and place for $\frac{du}{dy}$ the value deduced from that general equation $\frac{A}{L}$, and for $\frac{dy}{dx}$ the value $\frac{1}{x\omega}$ easily to be inferred from the same number, both which values are good for every point existing between two existing points, then we very simply obtain

$$S = \frac{A}{L}$$

in which L signifies the entire reduced length of the circuit, and A the sum of all its tensions. By means of this equation is obtained the strength of the electrical current of a galvanic circuit compounded of ever so many prismatic parts, which has assumed its permanent condition, ~~undergoes no influence~~ is unaffected by the influence of the surrounding air, and whose single sections possess the same electroscopic power in all its points, in which exactly the most frequently

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Notes describing phenomena observed in electric currents, [1834-1843], page 1.

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occurring cases are contained, on which account we have most carefully analysed this result.

Because A represents the sum of all the tensions occurring in the circuit, and L the sum of the reduced lengths of all the single parts, the following general properties of the galvanic circuit, concerning the electrical current, are immediately yielded by the ascertained equation:

I. The electrical current is at all points of a galvanic circuit ~~the~~ equal strength throughout, and independent of the value of the constant c, which, as we have seen, fixes the strength of the ~~current~~ electroscopic power at a determined point. In the open circuit ~~the~~ all current entirely ceases, for in this case the reduced length L assumes an infinitely great value.

II. The strength of the current in a galvanic circuit remains unchanged, when the sum of all its tensions and its entire reduced length, either not at all or in the same proportion changed; but it rises, the reduced length remaining the same, in proportion as the sum of the tensions increases, and the sum of the tensions remaining the same, when the reduced length of the circuit decreases. From this general law we will deduce the following in particular.

III. A difference in the arrangement and distribution of the single exciting points through a transposition of the parts of which the circuit consists, has no influence on the strength of the current, if only the sum of all the tensions remains the same. Thus, for example, a circuit formed according to the order of Copper, ~~Zinc~~, Silver, Lead, Zinc and a liquid will remain unchanged, if even Silver and Lead exchange their places with each other, because, according to the laws

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of tension observed with metals the single tensions may indeed be changed by this variation but not their sum.

2) The strength of the galvanic current remains the same, when even a part of the circuit is removed from it and another primatic conductor is placed at that point, only both must have the same reduced length and the sum of the tensions must in both cases remain the same. Conversely, if the current of a circuit is not changed by exchanging a part thereof for a foreign primatic conductor, and we can be convinced that the sum of the tensions has remained the same, the reduced lengths of both are equal to another exchanged conductor.

3) If we represent to ourselves a galvanic circuit always of an equal number of parts, of the same materials and formed in the same order, so that the single tensions may be considered as invariables, the strength of the current of this circuit increases, while the length of its parts remain unchanged, in the same proportion in which the resistance of all its parts increase in the same manner, and while the resistances are unaltered in the same proportion in which the length of all its parts equally increase. When the reduced length of ~~the reduced~~ a part of the circuit far exceeds that of the other parts, the strength of the current depends principally on the dimensions of this single part, and the law here expressed will assume a much more simple form, when when take into consideration in the comparison merely this single part.

The consequence stated in II.2 affords a convenient means to determine the conducting power of various bodies. Let us imagine, for instance two primatic bodies the length of which may be $l$ and $l'$, their resistances $w$ and $w'$ and their conducting powers $x$ and $x'$, and that both bodies possess the property, of not changing the current of a galvanic circuit, when it forms alternately a part thereof, and leave both the single tensions of the circuit unchanged, then

$$\frac{l}{xw} = \frac{l'}{x'w'}$$

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therefore

$$x : x' = \frac{l}{\omega} : \frac{l'}{\omega'}$$

the conducting power of both bodies are therefore in exact proportion to their lengths and inversely as their sections. Should this relation be used to determine the conducting powers of various bodies, and prismatic bodies of the same section be chosen for the experiments, which is already required without this for great accuracy, their lengths will exactly inform us of their relative conducting powers.

25) We have in the preceding number deduced the strength of the current from the general equation given in No 10.

$$u = \frac{A}{L} y - O + c$$

and found that it is expressed by the coefficient $\frac{A}{L}$ belonging to $y$. To discover the value $\frac{A}{L}$ the exact knowledge of all single parts of the circuit and their opposite tensions is in general requisite, but our general equation indicates to us a means to draw this value from the nature of any single part of the active circuit, which we will not ~~omitted~~ pass over since it will render us good service hereafter. Let us imagine, for instance in the above equation $y$ increased by a given magnitude $\Delta y$, and indicate by $\Delta O$ the corresponding change of $O$, and by $\Delta u$ that of $u$, it follows from that equation that

$$\Delta u = \frac{A}{L} \Delta O - \Delta O$$

and hence we find

$$\frac{A}{L} = \frac{\Delta u + \Delta O}{\Delta y}$$

we find therefore the strength of the electrical current, when we add to the difference of the electroscopic powers at any two points of the circuit the sum of all the tensions lying between these points, and divide this sum by the stretched length of the parts of the circuit, which lie between the same points.

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Notes describing phenomena observed in electric currents, [1834-1843], page 4.