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/PP107/2/5/1-278

[1871-1875]

Papers entitled ‘electro-motive forces’, comprising experimental notes and test results compiled by Charles Wheatstone, principally relating to the utility of employing combinations of elements in battery electrodes.
July 3rd 1871.

Charged 5 standard cells, A, B, C, D, E.

A gave 14 turns to reduce deflection in the B.
B - 14 -
C - 14 -
D - 14 -
E - 14 -

The thickness of the porous cup does not appear to affect the electromotive force when measured in this manner. C had a very thick cup, A a very thin one. The thickness of the cup affects the deflection with a constant resistance; thus A with 10 turns of the rheostat in circuit gave a deflection of 50°, while C only gave, because of its...
internal resistance, 37° deflection. As seen above both gave 14 turns as necessary to reduce the deflection of 115° to 60° with a different resistance at the commencement of the measure.

Arranged for a higher number of turns:
deflection from 35° to 30°

A gave 114 turns
B — 114 —
C — 114 —
D — 112 — upper denoted as porous cup.
E — 111 —

D and E have been in work during the rather lengthy trials to approximate 100 turns. 114 is the nearest to 100 I can obtain; and it is then.
July 5, 1871.

necessary to introduce resistance from the coils. Without the coils there
greatest number of turns available
for any 5° deviation is 50.

Circular wooden cell with diaphragm
In amalgam, copper was thinly deposited
on mercury, and also, but no so thickly,
on upper surface of blotting paper. The
cell only gave 89 turns against 114 of
the standard cell with porous cup.

The standard cells appear to work
very constantly until copper is deposited
on the porous cup; they then rapidly
fail. An old cup upon which copper,

Notes by Richard William Mellingford Higgs, chemist, describing the results of experiments to measure electromotive forces using different thickness of porous cup, 1871 Jul 3, page 3.
July 30th, 1871

has been deposited, and, as far as visible, been taken out with acid, when re-charged, receives a deposit of copper and jades much more quickly than a perfectly new cell, or one on which copper has not been deposited at all.

The copper deposited the other day upon the mercury in the circular wooden cell (in which four of any other had been placed formerly) to the mercury) has suddenly disappeared, owing to some action which has spun a red to the formation of a white crystalline jelly.

K/PP107/2/5/8
Notes by Richard William Mellingford Higgs, chemist, describing the results of experiments to measure electromotive forces using different thickness of porous cup, 1871 Jul 3, page 4.
Notes on experiments to answer the question 'Does Magnesium or Alumina reduce Copper without circuit'
(verso notes by Richard William Mellingford Higgs, chemist), [1871-1872], page 1.
Notes by Richard William Mellingford Higgs, chemist, (verso of notes on experiments to answer the question ‘Does Magnesium or Alumina reduce Copper without circuit’), [1871-1872], page 2.
Standard 70,
Dec 12th 1871

\[ aZ + \text{Sul. of } C + C = 70 \]

\[ aZ + \text{Sul. of } C + C \] gave at first 70 (45° 67° 40') after a few minutes 65 again 34. Great polarisation. Tried from 70° to 65° the standard gave 25 but the \[ aZ + \text{Sul. of } C + C \] cell gave such variable readings as prevented any calculation. From 30° to 35° the standard gave 103 and the \[ aZ + \text{Sul. of } C + C \] cell gave 103 and 102 for several trials, there being in this case considerable resistance.

Changed a new cell.

Obtained 70 for the first reading.
12/12/71

The needle fluctuated very much, giving very anomalous readings. The 

Volta cell (\(aZ + \text{col} \text{Ag} + c\))

to pieces. When reconstructed obtained 70. Two or three minutes later readings again varied.

I should consider 70 the most correct reading. The variations are evidence of unequal polarizations.

The porosity of the cell seems to have some effect—cells that admit most freely of the percolation of water seem to allow polarization to be more readily set up.
Dec 12, 1871. Standard 70

Compare

a So + sul Ac + Z with
a So + sul Zine + Z.

\[ \text{a So + sul Ac + Z} = 63 \]
\[ \text{a So + sul Zine + Z} = 64 \]

70:64 :: 100:91.4
\[ \text{So} = 194.4 \]
Dec 12. 1871.
Charge 6 standard elements and ascertain the cause of the difference of their electro-motive forces, if any.

A gave 70
B 70
C 70
D 70
E 69
F 70

E in took out the porous cell; washed it in sulphuric acid and in water; replaced the same amalgam, using the same solution of sulphate. Then obtained 70 as a constant reading.
Dec 12, 1871.

Opposed

(A) $aZ + \text{bul of } C + C$

(B) $aZ + \text{bul ac } + C$.

With considerable resistance in circuit, no deflection.

With only galvanometer in circuit a deflection of 10° after 5 minutes; but at first no deflection. The needle rises and falls. The deflection is not constant, being on alternate sides of zero.

Take B out of the circuit and apply a galvanometer to it. Does it show polarization? -- do the same of A.
The standard cell this morning gave 70 turns. Tried three cells.

\[ \text{Zn} + \text{Sul Ae} + C = \]

This combination gave a deflection of 50\(^\circ\) to the left of zero (same as standard). The needle is now gradually falling. It is still falling.

Noted our sulphuric acid — it contains small quantities of nitric acid or rather binoxide of nitrogen. That protuberance of paper.

The needle has reached 22\(^\circ\) and is still falling. 19\(^\circ\) has reached 19\(^\circ\). 10\(^\circ\) has fallen to 17\(^\circ\). 15\(^\circ\) has fallen to within 2\(^\circ\) of zero.
K/PP107/2/5/30
Notes by Richard William Mellingford Higgs, chemist, describing the readings from zinc amalgam, carbon sulphate and carbon, 1871 Dec 12, page 7.

Place a very weak solution of sulphate of copper with copper electrodes in circuit with a single standard cell and a galvanometer, and let it remain until all the copper is deposited and the needle comes to zero. The arrangement has been in circuit now for 14 days. On the first day the deflection was 60°. It is very nearly that now. The sulphate solution appears to deposit its copper, and the reducing agent set free to act upon the electrode attached to the + pole of the standard cell employed to decompose the solution. Thus as the copper of the solution is deposited, fresh copper is taken up from the + electrode. If the electrodes were of a non-oxidable metal, the needle would fade to zero.

Dr. Steinbeck, who lately obtained a government premium for a quick analysis of copper ores, effects the reduction of the metal from its sulphate by placing in the solution a plate of platinum and one of copper. The reduction takes place in 15 to 20 minutes. 18 analyses may be made per day by this method. The copper is deposited on the platinum as a deposit.

I would wish to make a remark that perhaps the same evidence as to the cause of variation in our standard cell. Last summer I took home a porous cell and an order cell. Measuring the electromotive force with my own zinc amalgam made at various times, the measure being taken upon a small Thomson's galv. and with resistance coils of 1000, I almost invariably obtained a constant standard. For several days past the experiment has been repeated; the results are still constant. The galv. is enclosed in a sheet iron box; and before each measure the adjusting magnet is regulated until the needle gives the same number of oscillations.
Dec. 27, 1871.

Triied various forms of small elements. The best results are obtained with a small glass cell, the amalgam and solution being separated by a diaphragm of plaster of paris. Still more steady results are obtained with a minute standard cell, the porous cup containing only a few grains of amalgam.

Owing to the diminished surface exposed to the fluid there is a greatly increased resistance, and it will be necessary to make the measure between 25° and 30°; if not lower.

Between 25° and 30° the
To prepare

Ni_2O_3 There will be required either metallic nickel to dissolve in the nitric.

CoO metallic cobalt oxide, in nitric. We have the sulphate only of nickel and cobalt cyanide of potassium. The nitric can be prepared from neither of these, and the cyanide can be obtained only from the nitrate, N. 17.
Calculations by Wheatstone on reverse of note outlining chemicals needs to be prepared for experiments, by Richard William Mellingford Higgs, chemist [1871-1872], page 2.
K/PP107/2/5/64
Notes probably by John Rymer Jones (1851-[1919]), chemist and electrical engineer, describing the results of tests on zinc amalgam using different cells, [1872-1875].
Osmium and its oxides: March 1st 1872.

Standard = 28.8 units (45° to 60°).

a) L + sulphuric acid + Osmum

Hydrochloric acid + Osmum oxides of Os # 61.5 units (45° to 60°). S. 213.5

O₂ O₃

Os₂O₃

Osmium ignited in a retort containing air first yields a white sublimated osmium oxide acid, and afterwards a blue sublimated (blue oxide of osmium). The sublimates were collected on platinum.

O₂O₃

Os₂O₃

Obtained from the bichloride of osmium and potassium as described by Ghelzin

Os₂ + sulphuric acid + bichloride of 

Osmium = 88.0 units (45° to 60°). S. 305.5

K/PP107/2/5/72

Notes probably by Richard William Higgs, chemist, measuring electromotive forces of ‘osmium and its oxides’ (with annotations by Wheatstone), 1872 Mar 1.
March 13th 1872.

Made some experiments at friend's house with electrometer. (Small quadrant, old form).

1 Standard cell gave 20° (read from a very perfectly graduated scale with a telescope).
2 . . . . 40.25°
3 . . . . 60°

Sodium + sulphate gave + same gave 23.25°
a S + sulphate copper + Cu gave 20°
S + sulphate copper + Cu gave 43°
March 18th, 1872.

Standard = 28.8 units (45° to 40°).

lead + dilute nitric acid + iron
= 5.1 units (45° to 40°). This does not become inverted until a long time has passed, when it behaves as lead + dilute nitric acid + iron.

Scraping the lead as soon as the needle comes to zero, a strong current obtains in the opposite direction = (lead + iron) = $2.0$ units (45° to 40°). Dioxide of iron is formed upon the iron plate.

Lead + $\frac{1}{2}$ Iron = \text{1137}
March 20th, 1872.

Standard = 28.8 units (45% 100).

a Z, a Z, a Z, a Z, a Z, a Z, a Z, a Z, a Z, a Z.

Cadmium gives exactly the correct measure with platinum
and with copper (as the negative metal) when nitric or when
sulphuric acid is employed.

I notice no permanent irregularity in the measure: occasionally
when nitric acid is employed there is a slight variation in
deflection, but never in electromotive force.

With and without rotating electrodes.

What is the measure of the Earth?
For the measure of Copper & Platinum?
Notes and diagram by Richard William Mellingford Higgs, chemist, on results contradicting those found in an experiment by Christian Friedrich Schönbein (1799-1868), German-Swiss chemist, 1872 Mar 23.
March 23, 1872.

The curious phenomenon observed this morning of the weak colouration of iodide of potassium would appear to be due to oxidation.

No metallic bath produces the colouration.

No reducing agent produces the colouration.

But the colouration is produced by:

- Boiling a small, divided spray of iodide of potassium in an Erlenmeyer flask.
- Boiling a small divided spray of iodide of potassium in a glass plate.
- Boiling a small divided spray of iodide of potassium in a vessel of water.
- By passing hydriodic acid through a jet of oxygen.
- By touching with a blow-pipe flame.
April 10th, 1872.

Johann Rudolf von Wagner, in his report on Technological Chemistry, published very recently in Germany, states that zirconium as a double salt may be reduced by aluminium; that aluminium reduces most of the metals (he does not state which metals); that magnesium may be substituted advantageously for potassium and sodium; that hydrogen under certain conditions reduces all metals.

His notes are very numerous; but as far as I can remember the reductions are not in the order of the electro-motive force.
June 7th 1872

The number of turns multiplied by 48 will give approximately the number of B. A. units.

Experiments with Standard cell. Wet (saturated) porous pat. Nephelometer, at first 10°, after half a minute 85°, when immersed 5 minutes 75°. The deflection continued steady. There had been up to this time 100 turns on the rheostat in each limb with the galvanometer and rheostat. This resistance was maintained in all the experiments in order to prevent alteration in the magnetic condition of the needles, which are very sensitive, once. Mr. Becker’s repairs to the galvanometer.

To reduce the deflection to 45° (from 75°) 2000 units were required. From 45° to 40° more turns are required than the length of the rheostat will permit. From 65° to 60°. Between these degrees a slight change in the resistance, produces a considerable and
2) June 9th 1872.

unwarranted variation in the resistance; more especially, with the rheostat; this variation is very apparent now that the magnifying power of the glasses of the telescope has been increased; with the New galvanometer (without the telescope) it is hardly noticeable. The variation is not always in the direction of the increase or decrease proceed by the above resistance, that is, not always inversely as the resistance. The maximum variation has been 200 degrees with one-tenth (about) turn of the rheostat; and 30 turns of the rheostat have been introduced into circuit, the deflection steadily increasing 1° during the addition. The needle then then allowed to remain went up ½° more (to 6°). Ten minutes after the deflection was 6°. On adding one turn of the rheostat the deflection fell to 63°, ultimately rising to 65°. After 5 minutes

K/PP107/2/5/112
3) the needle stood at 63°. After 5 minutes at 63½°. After 5 minutes 
64½° about. After 15 minutes 64°. 64° constant for 10 minutes.
One turn of the rheostat taken out of circuit reduced deflection 
to 62½°. After 5 minutes measured to 63° and then fell to 62°.

Dry cell: 100 turns of rheostat in circuit with galvanometer, 
rheometer, etc. Deflection 90°. 500 units to bring needle to 65°.
After 5 minutes 65°. Introducing 3 turns of the rheostat reads the 
nneedle up 1°. It then begins to fall, and after 5 minutes stands 
at 65 ¼ new, rising to 66½°. Adding 30 turns does not alter deflection.
After 5 minutes adding 1 turn brings needle to 67°. After 5 minute 
65°. After 5 minutes 65°. 4 turns brought needle to 65½°.

After 5 minutes 69°.
June 7th 1872. Experiments with standard cell.

Nat. saturated cell: 1000 units, 15°. Resistance in circuit, 60° deflection steady for 10 minutes.

Nat. dry cell: 1000 units, resistance. For about 5 seconds no deflection whatever; then the needle gradually went up to 53°, and remained steady at 53°.

Cold dry cell: behaved nearly similarly, the same degree.
May 8th 73.

Standard Cell gave 109.6

turns of Rheostat to reduce
deflection of Galvanometer.

I then heated the Salt
in order to observe if any
alteration of temperature
affected the needle so as to
increase or reduce the
number of turns as the case
might be. I found that
at a temperature of about
98° inside the Salt Case,
it required in the 1st experiment
132 turns, and in the 2nd
trial 122 turns of Rheostat
to reduce deflection,
ordinary temp. 63°.

I tried to get a reading
from Standard Cell again
but from some cause the
needle would not remain
steady, but kept moving
about from one side to another
through a space of about 2°.
List of experiments to be tried and measurements to be taken, on reverse of envelope addressed to Wheatstone, 1873 May 9, page 1.
List of experiments to be tried and measurements to be taken, on reverse of envelope addressed to Wheatstone, 1873 May 9, page 2.
List outlining 'experiments to obtain a perfectly constant element of Amal Z [amalgam of zinc] + Sulp Cop [sulphate of copper] + Cop [copper]', 1873 May 10.
May 18th 73

Standard cell gave 104 turns of Rheostat to reduce galvanometer from 45° to 90°. Tried 3 times with same result.

Some further experiments with soda amalgam, with Cd in Sul. Cd.

Cell 1 required 57 turns of Rheostat to reduce deflection.

Cell 2. Would only deflect Galv. on the moment of contact up to 45° from whence it rapidly fell to 7° where it remained stationary. Cell 3 the same.
I tried the 1st Cell again to make sure that everything was in working order, and found that it was quite right, neither 2 nor 3 had any resistance in circuit. Found the porous pots of 2 and 3 very dirty after the Amalgam, but that of No. 1 almost as clean as when Amalgam was first put in.
May 17th, 1873

Before leaving yesterday, I left the two lead amalgam.
Cells that I had been experimenting upon, charged,
but with circuit open, all night, upon trying them
this morning I found a remarkable difference
in the effects of the two Cells.
The one containing all of Copper in outside Cell
showed a very weak current, only deflecting needle
as far as 30° on Gals from whence it gradually fell
toward zero.
Upon looking at the porous pot, I found it thickly covered inside with a coating of sulphate of lead, no copper being deposited on outside.

The cell containing acetate of copper on outside gave a good result, a permanent deflection of 60° on scale taking place, after bringing it to 175°. I took 3 readings from 64 to 100 on rheostat and back again, it remaining perfectly constant. This gives 36 turns to reduce deflection.

The porous pot of this cell was also coated with a
superficial film of metal, but not to nearly so great
an extent as the former; upon washing them and
putting a little dilute nitric acid in each pot, the
solution in the pot which had been in the Sul. of Cdp.
the solution showed a much stronger green colour, than the
one which had been in the Acetate, showing
that the former had absorbed a much larger quantity
of copper. The deposit in the latter pot, also was not
of such a black colour as the other, and laid more
regularly.
From this it follows that with Acetate of Copper in outside cell, a much better result can be obtained and the deflection remains constant.

The standard zinc amalgam cell. 105 turns of Coerostat.

Cell mechanically sealed with par-aide of Teflo, with sulphate Copper outside, needle deflected to 30° on opposite side of scale.
2 Jan 1875

Galvanometrical needle made 17 oscillations per minute, reading pane 10°
Temp. of room 62° F.

Standard cell no. 1 = 100 times
" 202 = 99 "

Sodium amalgam + zinc amalgam in dilute sulphuric acid
All arranged in following manner

60 times of Wheatstone

Sodium amalgam + copper and sulphur:
Copper = 162 times
= 187 "
= 175 "
after a lapse of 10 minutes
= 186 times were required

The sodium amalgam used in these experiments was fluid.
K/PP107/2/5/191
Notes on experiments testing the use of different levels on resistance on electromotive force by John Rymer Jones (1851-[1919]), chemist and electrical engineer, 1875 Jan 11.
Notes and diagram on experiments testing the use of different levels on resistance on electromotive force by John Rymer Jones (1851-[1919]), 1875 Jan 11.
30 Jan 1875.

Gallbladder capsule made 17 oscillations per minute (25° C)
Comp. 38° F.

Standard Cell:
No 1 = 101 times
No 2 = 101

Notes:

These papers were made of brown paper.
Each pot consisted of three layers of paper.
They were saturated with dilute acid before using.

One measure at a time only was taken.

No 1 = 88 times
No 2 = 77
No 3 = 89

The pots were emptied of amalgam after each measure was taken.

On being refilled:

No 1 = 93
No 2 = 90
No 3 = 92

After being emptied and again refilled:

No 1 = 73
No 2 = 68
No 3 = 74

No 2 pot was found to have copper deposited on it.
15 May 1875

Two cells were arranged as below.

Two porous pots containing zinc amalgam were placed in two cells containing dilute sulphuric acid. The amalgam in each pot being connected by a tube twice bent at right angles filled with dilute acid. A wire was placed in the amalgam. One of the cells was heated to boiling point. A galvanometer in circuit. On closing the circuit a deflection of 4° took place. Current being from the hot cell to the cold one, declining almost immediately to 1°.
Notes on experiments testing the use of different porous pots in cells by John Rymer Jones (1851-[1919]), chemist and electrical engineer, 1875 Jan 15, page 3.
18 Jan 1875.

Galvanometer needle made 17 oscillations
per minute (300°)

Standard Cell 

\[ \begin{align*}
\text{No. 1} & = 103 \text{ cm} \\
\text{No. 2} & = 99 
\end{align*} \]

It is necessary that the surface of the zinc amalgam should be perfectly dry, as it was found in previous tests that when the surface of the amalgam was perfectly dry and a clean platinum wire plunged into the amalgam to close the circuit, the same number of turns were obtained. But when a few drops of dilute acid were poured on the surface of amalgam to moisten the platinum wire, Standard No. 1 required 6 more turns of Wheatstone, and Standard No. 2 required 13 more turns to deflect needle from 0°.
Notes on experiments testing the use of zinc amalgam and platinum in standard and gravitation cells by John Rymer Jones (1851-[1919]), chemist and electrical engineer, 1875 Jan 18, page 2.
Notes on experiments testing the use of zinc amalgam and platinum in standard and gravitation cells by John Rymer Jones (1851-[1919]), chemist and electrical engineer, 1875 Jan 18, page 3.
Experiment with wet and dry porous pot and amalgam.

Standard cell, with copper plate and sulphate of copper solution cold, porous pot with zinc amalgam heated to 100°C. placed in copper solution. After one deflection of needle for 2 or 3 seconds the needle was rapidly deflected.

\[93\] times
\[92\]
\[91\]
\[90\]
\[99\]

Cold and dry porous pot and zinc amalgam, placed in cold copper solution

No deflection of needle after remaining 5 minutes.

Removed amalgam, rinsed pot with a few drops of dilute sulphate amalgam, rapid deflections took place.

\[77\] times
\[87\] times (the porous pot was heated)
\[86\] times (to work the amalgam slowly)
\[85\] times (to work the amalgam slowly)
Notes on experiments testing the use of zinc and copper in gravitation cells by John Rymer Jones (1851-1919), chemist and electrical engineer, 1875 Feb 22.