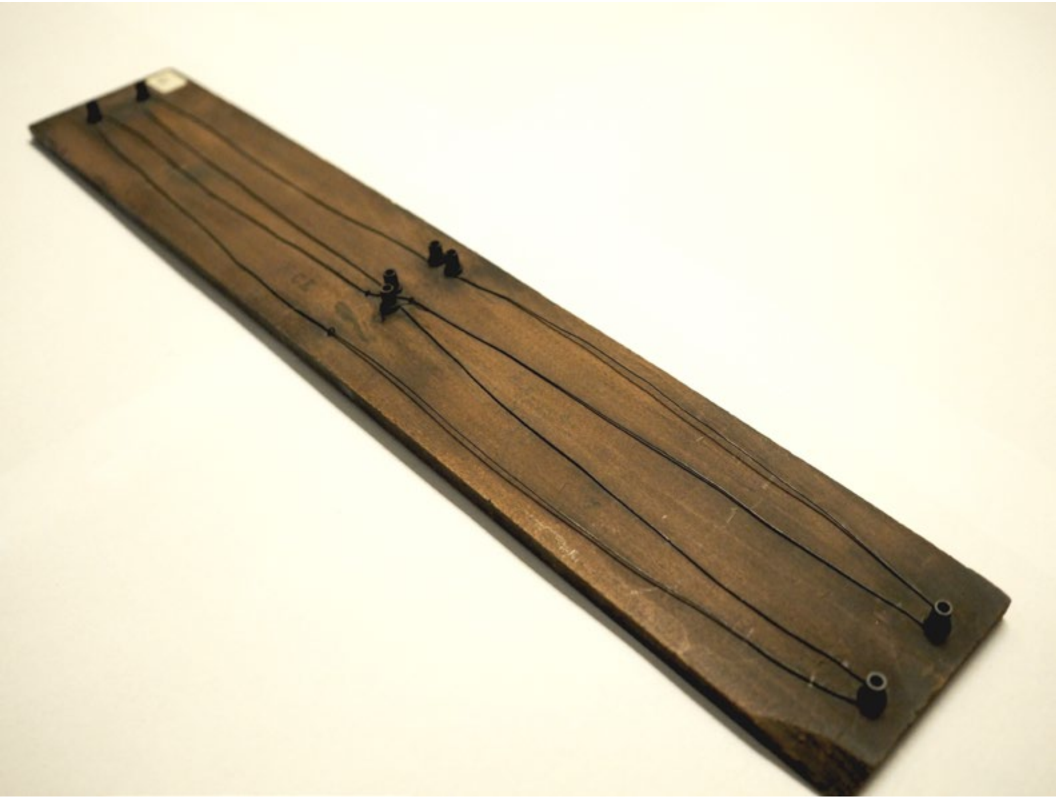
CATALOGUE ENTRY R7 | RESISTANCE

# CHARLES WHEATSTONE'S WHEATSTONE BRIDGE

## KING'S COLLEGE LONDON ARCHIVES. K/PP107/11/2/1



Of the many inventions that bear Charles Wheatstone's name, the Wheatstone Bridge is perhaps the best known. This is slightly ironic as it was in fact not devised by Wheatstone himself but by Samuel Hunter Christie.

Christie was interested in how the electrical and magnetic properties of a metal varied with mass and dimensions. He constructed a circuit to allow him to measure the electrical resistance (though he called it Magneto-electric induction) of wires of different thicknesses. In the 1833 lecture to the Royal Society in which he displayed the circuit, he called it the Diamond method, referring to the shape made by the wires.[1]

The diamond can be imagined as having two parts, the uppermost two wires (called 'legs') comprising one part, the lower two 'legs' the other. Across the middle of the circuit, joining these two parts is a bridging wire into which a galvanometer is connected. Galvanometers detect the flow of electricity. If the top part and the bottom part of the circuit are balanced (i.e. they have the same resistance) then no electricity will flow across the bridging wire and the galvanometer will stay at zero. If the two halves are unbalanced - if one part has a higher resistance than the other - then electricity will flow across the bridge and be detected by the galvanometer. Importantly, if you know the resistance of three of the 'legs' you can work out the resistance in an unknown fourth one.

The Diamond method - though an interesting experiment - languished as a footnote in a paper about magnetism for ten years until 1843, when Charles Wheatstone (with his usual inventive pragmatism) saw the potential in it. In a lecture he delivered at the Royal Society (in which he fully cited Christie as the originator of the circuit) Wheatstone outlined several applications.[2] First, you could connect up far more useful things to the 'unknown' leg of the circuit than different bits of copper wire. You could connect it up to telegraph lines, submarine cables, electrical circuits, even entire telegraphic instruments and measure their resistance. This observation meant that, for the first time, telegraph engineers had a way to measure the electrical efficiency of their designs; an insight into how to hone and perfect their materials and apparatus. They could see the effect of impurities on the conductivity of copper wires, the extra capacitance effects of a thick insulation, or the resistance of a particular design of switch.

Moreover, it was suddenly possible to see the effects of other forces on telegraph equipment. For example, the same piece of cable could be tested at different temperatures or pressures to gauge the effect of the environment on it. The most important realisation - and perhaps the factor which best explains why it is Wheatstone who is remembered for his Bridge rather than Christie for his Diamond – Wheatstone pointed out that the galvanometer is not just as an instrument for measuring resistance. It can be used to measure any number of things including inductance, capacitance, impedance and frequency (including radio frequency). Wheatstone's observations led others to modify the Bridge and push it to new heights of usefulness. Indeed, William Thomson, gave his name to a modified form of the bridge, the Kelvin Bridge, which when hooked up to the incredibly sensitive mirror galvanometer, allowed him to continually monitor the electrical condition of the 1865 and 1866 Atlantic cables.[3]

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1. S. H. Christie, 'Bakerian Lecture: Experimental Determination of the laws of Magneto-electric Induction in different masses of the same metal, and its intensity in different metals', *Philosophical Transactions of the Royal Society of London*, vol. 123 (1833).

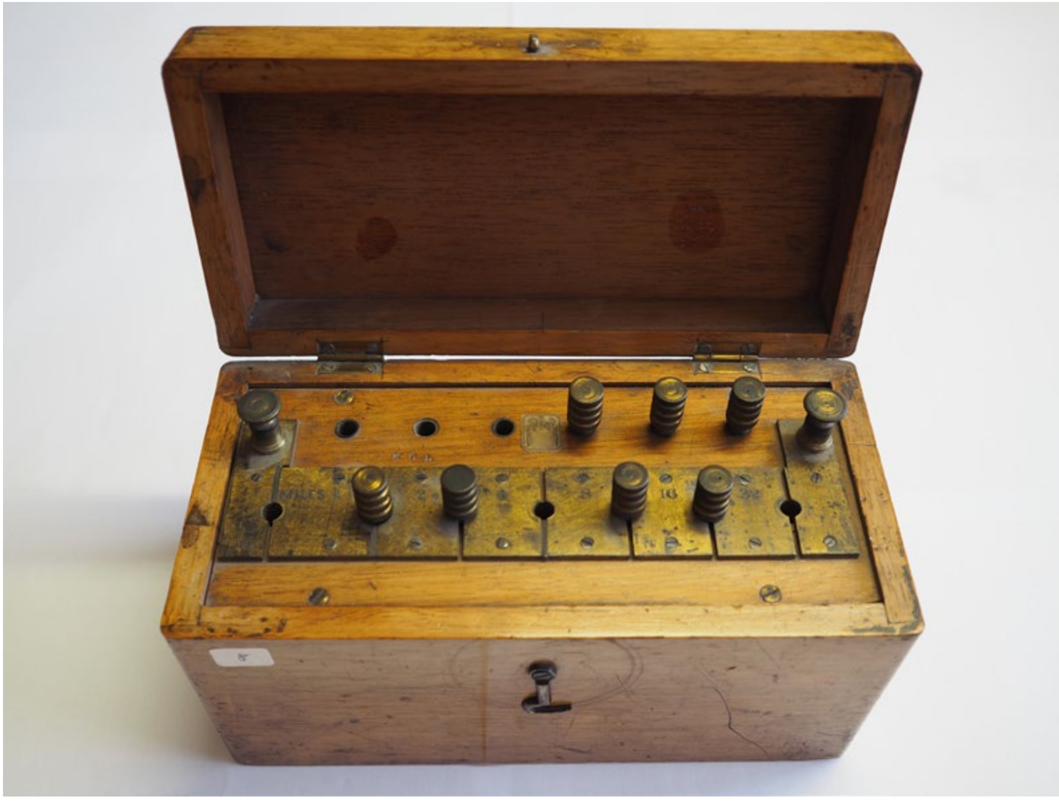
2. C. Wheatstone, 'Bakerian Lecture: An Account of Several New Instruments and Processes for Determining the Constant of a Voltaic circuit', *Philosophical Transactions of the Royal Society of London*, vol. 133 (1843).

3. M. Trainer, 'The Patents of William Thomson Lord Kelvin', *World Patent Information*, vol. 26, (Elsevier Ltd, 2004), http://tinyurl.com/hv4c2lk (consulted 4 September 2016).

CATALOGUE ENTRY R8 | RESISTANCE

# RESISTANCE BOX

KING'S COLLEGE LONDON ARCHIVES. K/PP107/11/1/19



The resistance box is an interesting object. It is interesting because, unlike its more famous lab-bench counterparts (for example, the Daniell cell or galvanometer), very little is known about its origins or originator. Wheatstone is certainly using a 'variable resistor' to control the known but variable 'leg' of his Wheatstone bridge in 1843, though we don't know what this looked like.[1] The 'variable resistor' appears again in Kelvin's 1858 patent drawing for the marine galvanometer but as a set of spools in an open box.[2] Neither appear to have been as sophisticated as the box in the exhibition. We can, however, use what we know about the box to determine its probable use.

It is built solidly from well-used light oak. A deep, hinged lid reveals a brass plate set across the top half of the upper surface. The plate is split into eight rectangles. The outer two rectangles sport positive and negative terminal screws respectively. Each of the six inner rectangles is separated from the next by a gap of a few millimetres with a round hole in the centre, in which sits a brass peg.

Inside the box beneath the holes are hand-wound resistors. Wire (probably of German Silver, 60% copper, 25% zinc, 15% nickel) of an exact length and mass is wrapped around a ceramic bobbin to give a known resistance.[3] Each of the resistors is connected to the next by a thin wire. When a peg is inserted into the hole above, it short-circuits the small connecting wire, and removes that resistor from the circuit. The idea of the instrument is that a piece of electrical equipment can be connected to the outer terminals and the pegs placed in the mileage holes to create any electrical resistance. In the lower, wooden half of the surface there are six holes in the wood to receive any unused pegs.

Resistance boxes were used for many different kinds of lab work as well as for activities of electrical and telegraphic engineers, however the construction of the box gives us some clues to its purpose and origin. The brass rectangles are marked 1, 2, 4, 8, 16 and 32 miles respectively, meaning that its purpose is to create resistances in miles rather than ohms. This suggests an application in telegraphy, rather than bench-based lab work. Submarine telegraphy is ruled out as a maximum of 63 miles resistance would be insufficient for most submarine systems. Certain possibilities are suggested.

The box could have been used to replicate 'real' conditions for the testing of prototype telegraphic equipment in the lab. Or it could be used to balance the resistance on the 'dummy' circuit used in Duplex telegraphy (where messages can be sent in both directions on a line simultaneously). However, the rugged, portable design (and well-used condition of the box) suggests it was carried around from place to place by engineers who needed to know about (a fairly limited number of) miles of resistance. In other words, fault finding.

When a line has a fault, engineers carry out a resistance check. The terminals of the resistance box are connected up to the variable resistance leg of a Wheatstone bridge. The faulty line is then connected up to the 'unknown' leg of the bridge. Pegs are placed in the holes of the resistance box until the resistance of the faulty wire and the resistance of the pegs are equal. Engineers can then be dispatched to the number of miles down the line as indicated by the resistance box and the fault repaired.

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1. C. Wheatstone, 'Bakerian Lecture: An Account of Several New Instruments and Processes for Determining the Constant of a Voltaic circuit', *Philosophical Transactions of the Royal Society of London*, vol. 133 (1843).

2. M. Trainer, 'The Patents of William Thomson Lord Kelvin', *World Patent Information*, vol. 26 (2004), http://documentslide.com/download/link/the-patents-of-william-thomson-lord-kelvin (accessed 22/08/2016).

3. Anon., *Laboratory Instruments and Measurements: Book 14* (New York: The Electrical Engineer Institute of Correspondence, 1904).

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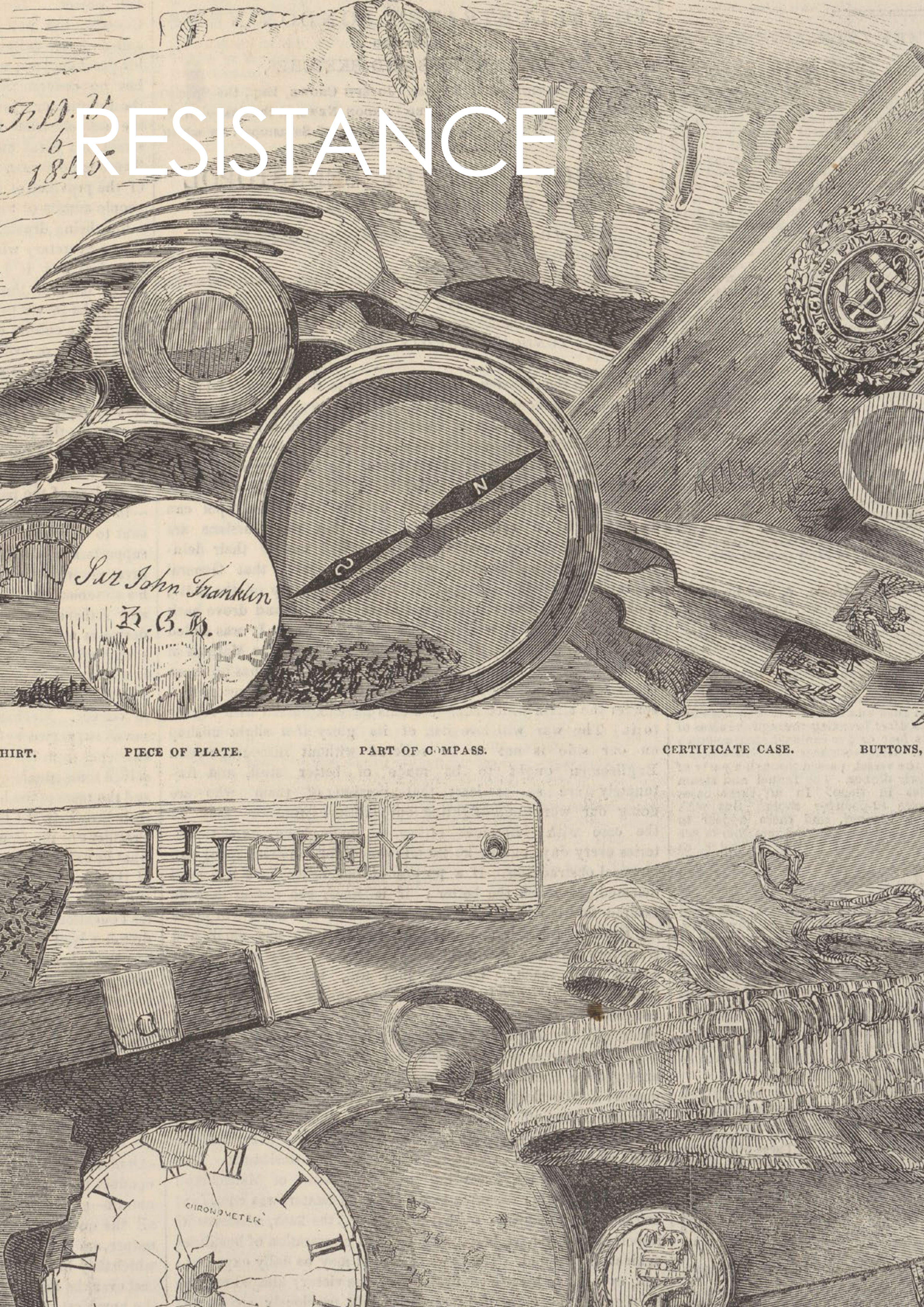
Sir John Franklin
K.C.H.
HICKEY
CHRONOMETER
HIRT.
PIECE OF PLATE.
PART OF COMPASS.
CERTIFICATE CASE.
BUTTONS,

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