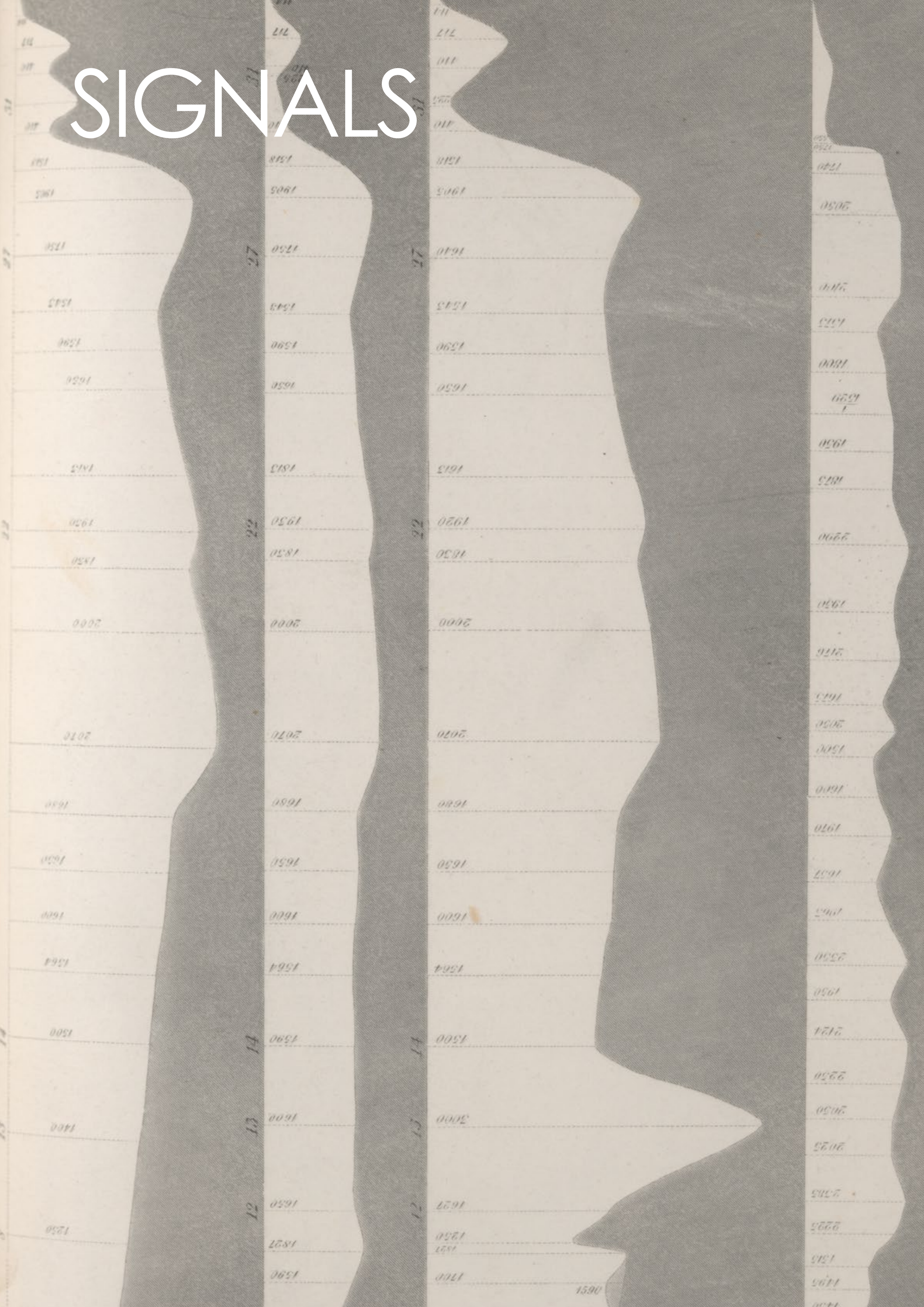
SIGNALS



from VICTORIANS DECODED: ART AND TELEGRAPHY

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BACK AND FRONT COVER:
James Tissot, *The Last Evening*, 1873 (details), The Guildhall Art Gallery, Corporation of London.

MARK MIODOWNIK

A BRIEF INTRODUCTION TO ELECTRICITY

This essay is intended as a primer for anyone unfamiliar with the basics of electricity, specifically: how it works, how it was employed to send messages along transatlantic telegraph cables, and its modern usage for sending information along wires such as from your phone to your headphones. This essay does not contain an historical account of the development of the understanding of electricity, electromagnetic theory as it is called, for an introduction to this a good source is *Electric Universe*.[1]

Every thing is made of atoms. There are 94 types of naturally occurring atoms, but they all share a common structure that comprises of a central nucleus containing positively charged particles called protons surrounded by negatively charged particles called electrons. Occasionally some of the electrons get free and start moving about. This movement of electrons is the basis of electricity. If you have ever rubbed a balloon on a woollen jumper and felt the build-up of charge you have successfully pulled electrons away from the nuclei of their atoms. Once free these electrons repel and want to get as far away from each other as possible. Hence if you hold the balloon up to your head you will feel the electrons jumping off the balloon onto your hair as they try to get away from each other. In an attempt to get further away they make your hair stand on end which is caused by the charge on each follicle repelling the others. Of course the electric charge ultimately wants to be reunited with positive charge and will flow or even jump through the air to do so. This is what happens during a thunder storm. Electric charge that has built up in cumulonimbus cloud as a result of certain climatic conditions, discharges through the air to the ground, and in doing so heats up the air to such high temperatures that it glows white hot, this is what lightning is. The sonic boom of the surrounding air rapidly expanding as it is heated, is the sound of thunder that accompanies lightning.

Storing electricity is difficult, as the balloon example shows; electrons once collected repel each other. They don't like to be compressed into a small space, and may discharge violently as in the case of thunder. The answer is to create a battery. Batteries produce electricity through chemistry by getting one type of atom to pull the electrons off another type of atom, this is called a chemical reaction. When iron rusts, the iron atoms are chemically reacting with oxygen to create iron oxide, thus creating a chemical bond between the oxygen and the iron atoms. This involves electrons moving from the iron atom to the oxygen atom. Chemical reactions like this that involve electron transfer do not require the two atoms to be physically next to each other, they can be separate and the reaction will still occur as long as there is a way that charges can travel between the atoms. This is the essence of a battery. In a battery the chemical reaction provides the energy for the electrons to flow down wires as long as the wire completes a circuit between the two materials. When a battery isn't being used, the two ends of a battery (the + and -) are not connected and cannot react so the energy remains stored. This potential energy of the electrons stored in the battery is called the voltage (Volt). In a simple disposable AA 1.5 Volt battery the chemical reaction is between zinc and manganese dioxide. In your mobile phone it is chemical reactions based on lithium that provide the electricity. Lithium is expensive but it is hard to beat for batteries because the reversibility of the chemical reactions involved means the battery is rechargeable, as well as being lightweight and with a high energy capacity. This means that it can provide lots of electrons. The flow of electrons, is an important characteristic of electricity and is called the current. You need a big enough current to deliver enough energy to do anything useful with electricity. For instance a light needs a constant flow of electrons to be able to keep giving out light, similarly your phone needs a constant current of electrons to keep transmitting data. If you need a large current you need a big battery, which is why car batteries are so big because the forces needed to turn the engine are large. The Victorians invented many types of batteries but the one used on the Transatlantic Telegraph Cable was called the Daniell cell. It harnesses the chemical reaction between zinc and copper compounds yielding 1 Volt. As you might guess if you want more current you join Daniell cells together to make a bigger battery, which is the origin of the word (as coined by Benjamin Franklin in analogy to a battery of cannon).

Once you have a battery you can reliably control electric signals down a wire to create a telegraph. But you need to be careful what wire you use, since not all materials conduct electricity. Some materials bind electrons very tightly to their atoms through atomic bonds leaving them unable to move through the materials; rocks, ceramics, plastics, woods, textiles are all examples of materials that do this, they are called non-conductors. Metals however, are held together by a type of bonding that allows some of the electrons to be free; it is these free electrons that allow metals to conduct electricity. It comes at a cost though, called resistance, which is due to the electrons bumping into atoms as they flow. This absorbs some of the strength of an electric signal. Iron conducts quite well, copper conducts better, and silver conducts electricity best of all metals. When trying to send a pulse of electric current across the Atlantic through a wire, it is obvious that engineers needed to minimise the resistance of the cable. Hence the ideal metal to use would have been silver. However the expense of this was too great. Copper is the next best conductor and although expensive, this is what was used. These days we still use copper, the wires that take electricity from the power station to your home and into your kettle are copper for the same reason. In fact it is very pure copper because the purity matters. Metals are made of crystals and so their atoms are arranged in a very regular order. Impurities disrupt this order and cause more interference to the current of electrons, hence the desire for purity.

In the Transatlantic Cable this subtlety was not understood by everyone involved, and so the resistance of that cable was not as small as it might have been. This is one of the reasons why the electrical signal quality was poor.

To protect the electricity from leaking out into the water, the cable needed to be coated with a material with a very high electrical resistance. Only a flexible material that was also an insulator would do – since it had to be wound into a cable. The material that was used was gutta-percha which is a plastic made from the latex of palaquium trees. Gutta-percha is an ideal material for undersea cables in many other ways too, it does not corrode in sea water and resists attack by marine animals and plants. However it only required one breach exposing the conducting copper to corrosive sea water to cause failure. To produce a 1600 mile cable and place it at the bottom of the sea without injuring the insulation thus was a considerable achievement, especially because gutta-percha could become brittle. Gutta-percha (unlike modern plastic insulators) reacts with oxygen in air making it brittle, and so leaving the cable in the air for any length of time increased the risks of failure.

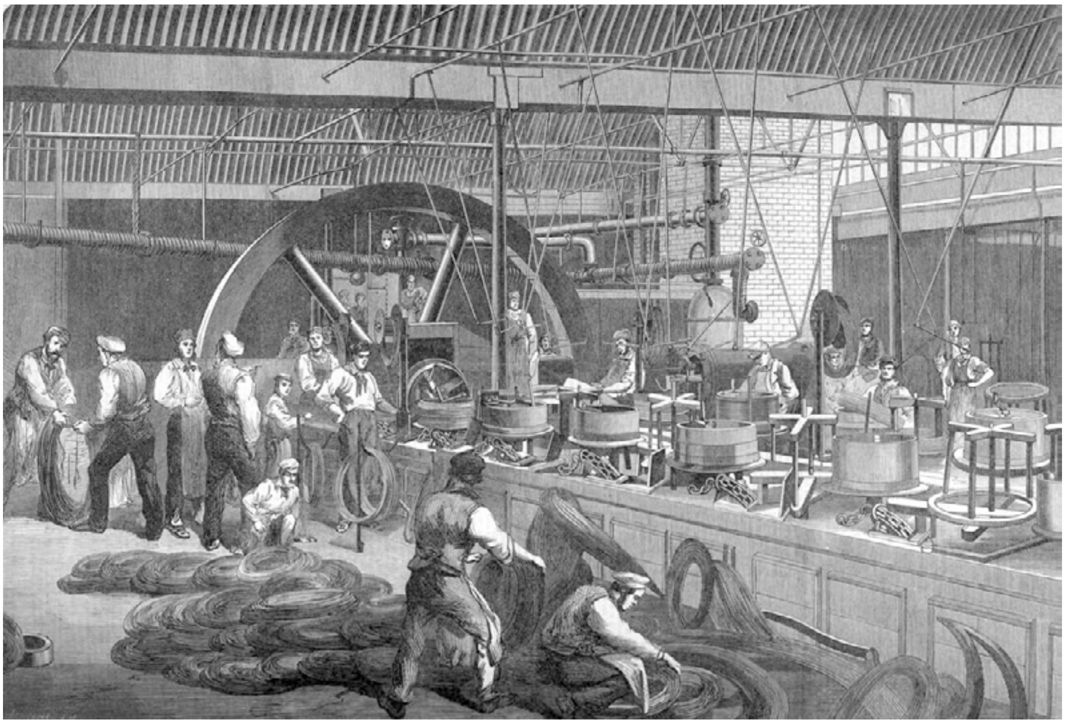
The electricity we use every day comes mostly from power stations, these are not giant batteries, but generate electricity on demand, using magnetic fields. This works because magnetism and electricity are connected: they are different aspects of the same phenomenon called electromagnetism. Thus when electricity flows, it generates a magnetic field around it, and likewise if you move a wire through a magnetic field it will generate electricity. This is called induction and is how a power station generates electricity. Induction affords the possibility of creating high voltage signals in a telegraph wire through the use of high magnetic fields. This method was used by Whitehouse to attempt to deal with the problems of the poor signal quality of the 1858 telegraph. The problem with using high voltage signal in wires is that the signals place the insulation under strain, and can break down its molecular structure. The rapid decline of the 1858 cable was blamed on such a breakdown of the gutta-percha due to high voltage signals. Induction also caused the electric signals to interact with the sea water making them weaker and harder to detect.

These days our understanding of electrical signals and how they can be controlled and used to convey information is extensive and underpins every aspect of our lives. When you plug in your earphones and listen to your music on your computer or smart phone, the music is relayed to your earphones through insulated copper wires not too dissimilar from those used on the transatlantic cable. They seem trivial to us now, but oh how the protagonists of the cable would have marveled.

1. David Bodanis, *Electric Universe: How Electricity Switched on the Modern World* (London: Little, Brown 2005).

1866: THE YEAR COMMUNICATION CHANGED FOREVER

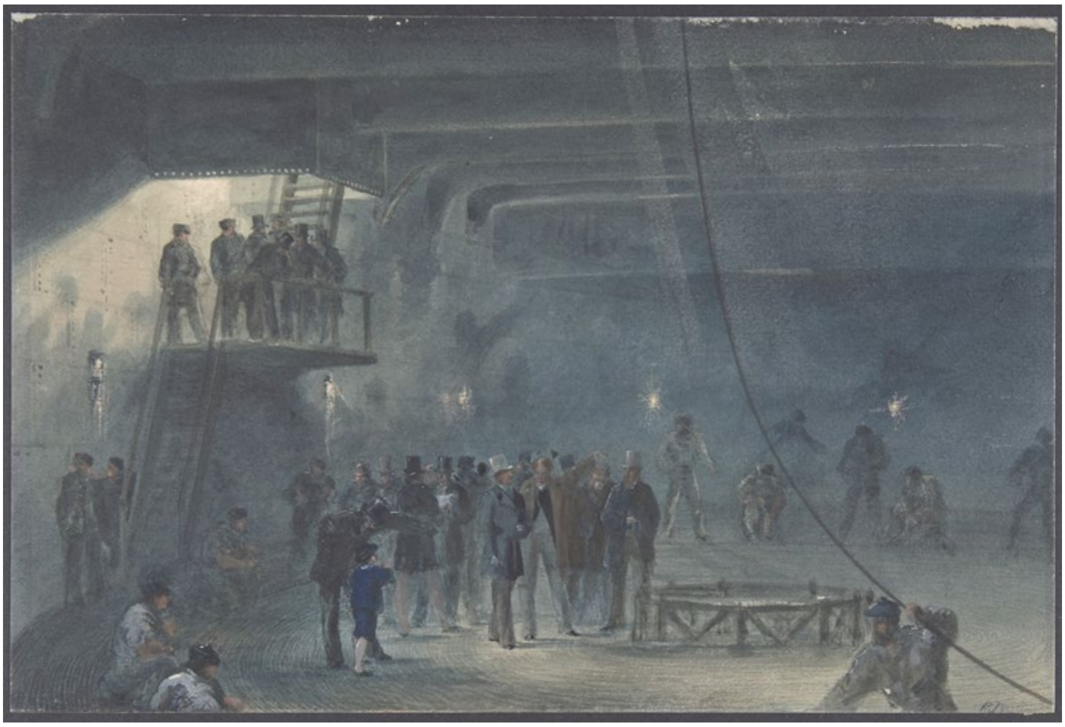
MARCH: CABLE CONSTRUCTION BEGINS



Making steel wire for the cable armouring at Greenwich, *Illustrated London News* (12 Dec, 1874), p.263. Wellcome Library, London.

The 2,300 miles of cable needed for the Atlantic telegraph was constructed in layers. A pure copper wire was coated in gutta-percha (a natural plastic). Seven strands of coated wire were then twisted together to form the core of the cable, which was wrapped in jute (hessian) and sealed with further layers of gutta-percha. The insulated core was armoured with steel wires: heavier ones for the shore end, where the cable could be damaged by anchors, and lighter for the safer deep-sea sections. A single mistake meant the failure of the whole cable, so it was electrically tested at each stage of the process.

MAY: CABLE LOADED ON BOARD THE SS GREAT EASTERN



Robert Charles Dudley, Coiling the Cable in the Large Tanks at the Works of the Telegraph Construction and Maintenance Company of Greenwich, 1865. Watercolour, www.metmuseum.org

The finished cable sections were so heavy that the Atlantic Telegraph Company chartered the largest ship of the day - Isambard Kingdom Brunel's *SS Great Eastern* - to carry them. They planned every move carefully to avoid kinks and breakages. The cable was threaded onto pulleys, passed over the water and carefully coiled into tanks on two decommissioned war ships, which ferried it to the *Great Eastern* anchored at Sheerness. It was fed out of their holds into three huge salt-water tanks on the *Great Eastern* and painstakingly coiled again for the onward journey to Ireland.

7TH JULY: CABLE LAYING BEGINS

Robert Charles Dudley, *The Heights over Foilhummerum Bay, Valentia, the William Corey Heading Seawards, Laying the Shore-end of the Atlantic Telegraph Cable*, July 7th, 1866. Watercolour, www.metmuseum.org

The shore end of the cable was laid on 7 July at Valentia Island in Ireland, and SS Great Eastern, anchored off the coast, set sail on 13 July to begin laying it across the Atlantic. Signals were sent from the land end to the testing room on board, where an engineer was on watch 24-hours a day. If the signals faltered the ship could be stopped, and the cable hauled back and repaired. Unlike four previous attempts between 1857 and 1865, this time the weather was good and the expedition passed without incident.

27TH JULY: THE SHORE-END OF THE CABLE IS LANDED AT NEWFOUNDLAND

Robert Charles Dudley, *Landing at Newfoundland*, 1866. Oil on canvas, www.metmuseum.org

The *SS Great Eastern* arrived in Heart's Content, Newfoundland on 27 July. The end of the deep-sea section of the cable was carefully spliced to the heavily armoured shore-end of the cable. Waist high in water - and with much cheering - sailors and locals grabbed the cable and hauled it up the beach to the cable shed. Engineers worked through the night to make the link with London in time for the morning news. The project had finally succeeded.

AUGUST AND SEPTEMBER: RECOVERING THE LOST CABLE OF 1865

Testing the recovered 1865 cable on board the Great Eastern, *Illustrated London News* (13 Oct, 1866), p.365. Wellcome Library, London.

Two weeks later, the Great Eastern went in search of the 1865 cable, lost 600 miles from shore. Four ships grappled the sea bed two-and-a-half miles down for a month. On 1 September, on their 30th attempt, they hooked the lost cable and retrieved it. Signals were sent to Ireland and after a few tense seconds the line jumped into life to wild celebration on board. The last 600 miles of extra cable were then laid back to Newfoundland. SS Great Eastern returned having laid not one but two Atlantic cables.

A NEW ERA OF GLOBAL COMMUNICATION BEGINS

News from around the world in the Central Telegraph Office Instrument Gallery, *Illustrated London News* (12 Dec 1874), p.568. Wellcome Library, London.

By the 1870s transatlantic telegraphy was well-established. At an astounding eight words per minute the latest news criss-crossed the Atlantic bringing bulletins about reform riots in Hyde Park, war between Prussia and Italy, Napoleon arming his fleet, stocks, shares and bank rates. It brought news of Florence Nightingale, fabric prices in Calcutta, Fenian plots and attempts to assassinate the Czar alongside tips for Goodwood and the Derby. The Atlantic telegraph touched every part of life and brought the 'old world' of Europe into instantaneous contact with the 'new world' of the Americas.

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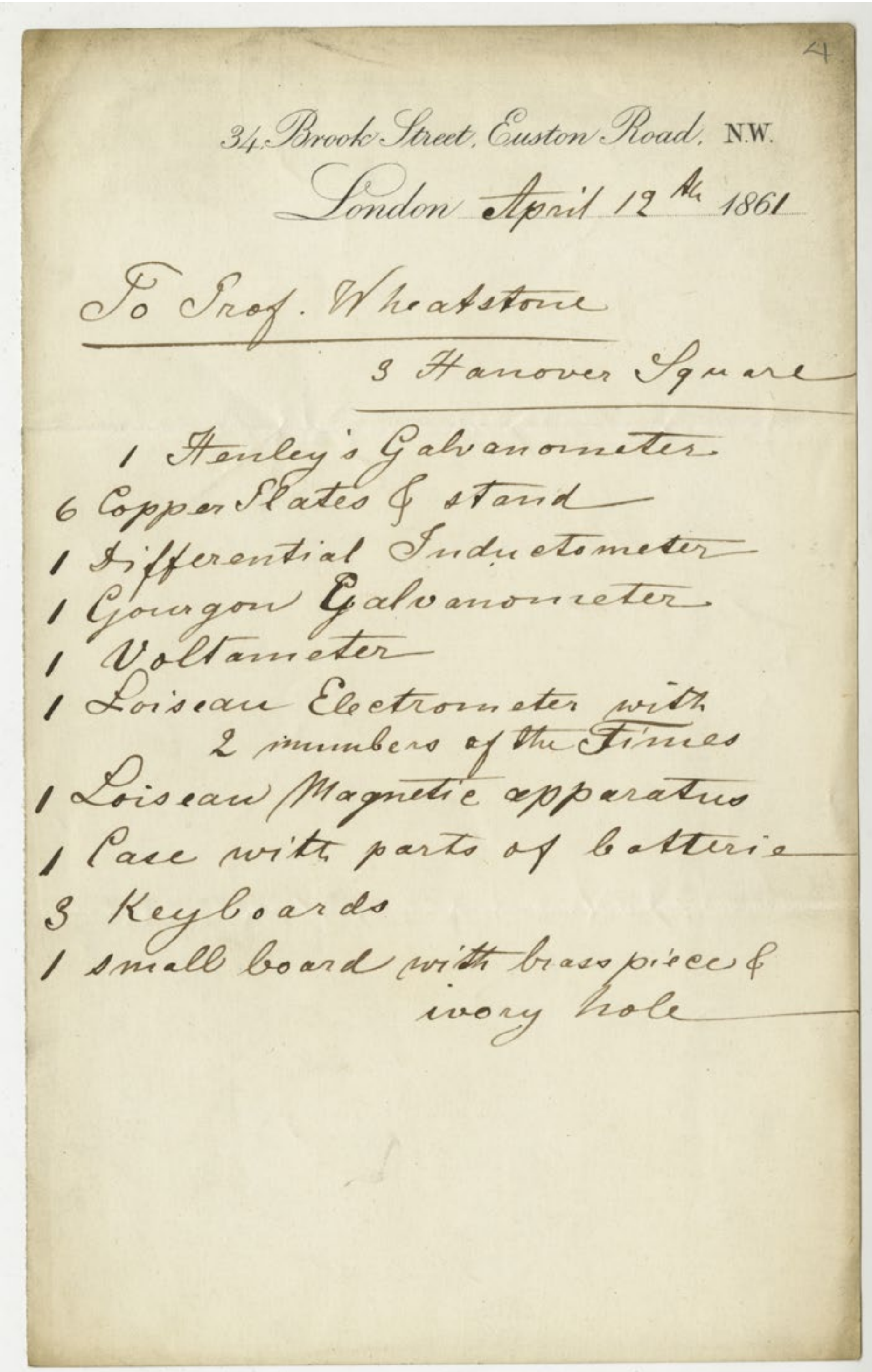
CATALOGUE ENTRY S2 | SIGNALS

SIR CHARLES WHEATSTONE'S NOTES



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34, Brook Street, Euston Road, N.W.

London April 12th 1861

To Prof. Wheatstone

3 Hanover Square

1 Henley's Galvanometer
6 Copper Plates & stand
1 Differential Inductometer
1 Gourgon Galvanometer
1 Voltameter
1 Loiseau Electrometer with
2 numbers of the Times
1 Loiseau Magnetic apparatus
1 Case with parts of batteries
3 Keyboards
1 small board with brass piece &
ivory hole

The handwritten notes, pamphlets and (the majority of) books within this exhibition are taken from the Wheatstone Collection housed at King's College, London. They span the period of Charles Wheatstone's life from 1832, when he was appointed as the first Professor of Natural Philosophy to his death in 1875. The Foyle Special Collection at the Maughan Library houses Professor Wheatstone's personal library; the books, pamphlets and papers he collected, read and wrote over an active research career spanning five decades. There are many interesting specimens, including autographed volumes, personal gifts and several entirely unique items. Many are annotated or contain personal dedications from the author. The library reflects Wheatstone's many and varied interests, just a few of which are represented in the exhibition.

The other items on display are drawn from the half of the collection housed at the King's College, London, Strand-site Archive. These comprise Sir Charles' personal notes collected from his office at the time of his death and curated by the Physics department until the 1970s. The collection is best described as eclectic. There are his lecture notes on electromagnetism and optics (though he was famously shy of public speaking).[1] There are shopping lists of materials to buy to experiment with. There are sketches and diagrams of machines, both built and unbuilt. There are records of experiments, some successful, some of which are so obviously unsuccessful as to have been abandoned half way through. In short, the notes are a treasure trove, a window into the life of a Victorian inventor and academic. From this eclectic collection we selected just a handful of illustrative pieces to feature in the exhibition.

Distance
In the Distance case we selected a Letter from physicist James Clerk Maxwell to Sir Charles Wheatstone to represent the communication and collaboration between engineers and physicists which were key to telegraphic projects. We also selected a chart from Wheatstone's reference library and some of his notes on from meteorology, oceanography, mechanical properties of natural materials and battery design to demonstrate how the Atlantic telegraph cut across many different specialisms and brought together diverse research interests.

Transmission
For the theme of transmission we selected notes and pamphlets which would complement or illustrate the machines on display. For example, to accompany the galvanometer we chose an 1858 Elliot Brothers' sales pamphlet, released when they were awarded the sole contract to build and distribute Sir William Thomson's Patent Graded galvanometer. We also included some of Wheatstone's sketches for what eventually became the Alphabetical Telegraph to display alongside the exhibition's example of the final, commercially produced machine. Telegraphic engineers were constantly rethinking and redesigning the telegraph

for different uses. Also on display are Wheatstone's sketches for different telegraphic circuits and sending apparatus, including what became his famous Five Needle Telegraph.

Coding

Charles Wheatstone was fascinated by ciphers and coding. He worked on many cipher systems including the 'Playfair Cipher'. Playfair was a favourite of the military as it encrypted pairs of letters at a time and took a lot longer to crack than existing systems. This small selection of his many notes on the subject shows him constantly experimenting with different ways to code and encipher telegraph messages. These including an interesting piece where he seems to be demonstrating to somebody how the Playfair cipher works, using 'Victoria' as the encryption key. It is often hard to discern the exact purpose of Wheatstone's coding the notes as – unsurprisingly – they are encrypted.

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1. B. Bowers, *Sir Charles Wheatstone FRS*, 1802-1875, IEE History of Technology Series, Vol. 29 (London: The Science Museum, 2001).

CATALOGUE ENTRY S3 | SIGNALS

BATTERY OF TEN DANIELL CELLS

KING'S COLLEGE LONDON ARCHIVES

In 1836 the floodgates to the future opened. It was the year in which John Frederic Daniell invented his Daniell cell. The rapid economic growth and unbridled wealth creation of the Regency had left provincial society chock-full of the well-educated sons of artisans and professionals. They came of age and were drawn to London to take up the professorships in chemistry and natural philosophy being created at the new London universities. Well-financed labs were built, patrons found, scientific societies established. Funding, excitement and a great deal of scientific brain-power were applied to the project of probing the mysteries of the universe. There was one thing limiting the breakthroughs into the unknown: power.

Daniell began his career as the first Professor of Chemistry at King's College, London. His brand-new lab included the best equipment for power generation at the time: Volta's voltaic pile, a stack of alternating zinc and copper discs, separated by discs of cardboard or felt soaked in an electrolyte (brine). Daniell was using it for his experiments in electrolysis (breaking down water into oxygen and hydrogen) and noted that the pile lost voltage because a film of hydrogen bubbles formed on the surface of the coper cathode and reduced its conductivity. It was also impossible to turn off and so ran down when not in use. Daniell designed his cell to solve these two problems. He added a second electrolyte to consume the troublesome hydrogen bubbles and kept the two electrolyte solutions separate so his cell wouldn't run down between uses.

Daniell took a zinc anode (like the negative terminal in a battery) and suspended it in a porous earthenware jar full of zinc sulphate. He initially used an ox-gullet but the earthenware jar proved nearly as good and a lot less smelly![1] The earthenware jar was then placed in a copper pot filled with a copper sulphate solution. The copper pot became the positive terminal or cathode. The porous earthenware jar kept the two solutions separate but allowed charged ions to move between them. Like in a modern battery, when the negative anode was connected to the positive cathode (the copper pot) a current flowed. When the connection was broken the porous jar kept the solutions separate so the cell did not lose charge.

The Daniell cell was a massive improvement and the first really practical power source. Several cells could be connected together to form a battery and provide any required voltage. The cells were robust, portable and sufficiently simple to be assembled onsite by engineers. It was an immediate success, not only for lab experiments but also a myriad of industrial applications. Technologies, which had been limited for decades by a lack of power suddenly had access to the reliable, long-lasting, cheap and scalable Daniell cell. The greatest among these new technologies and the most transformative was Charles Wheatstone's telegraph through which - with now ample power - 'dense flocks of ideas… [started] to fly, like starlings, across the globe'.[2]

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1. Andrea Sella, 'Daniell's cell', *Chemistry World*, Royal Society of Chemistry (2012), http://tinyurl.com/zuu67c4 (consulted 5 September 2016).

2. Ibid..