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THE TRANSATLANTIC CABLE I

At the beginning of the nineteenth century a new industrial Europe was taking shape. Its capitalists knew that time is money and its politicians that time is power. During the Napoleonic wars the French and then the English set up systems of semaphores for transmitting military information but with this exception messages could travel no faster than a horse or ship. The invention of the electric telegraph in the 1830s changed all this and within ten years a network of telegraph wires covered England, western Europe and the more settled part of the USA. (Telegraphs were particularly important for the efficient and safe control of the new railways.)

It was thus inevitable that attempts would be made to provide underwater links between the various separate systems. The first cable between Britain and France was laid in 1850. The operators found the greatest difficulty in transmitting even a few words. After 12 hours the enterprise was brought to an abrupt conclusion when a trawler accidentally caught and cut the cable. Undeterred the railway engineer Crampton put up money for a new attempt with a heavier armoured cable of his own design.

Crampton's cable was a complete success and a spurt of submarine cable laying began. On the whole, the short lines worked, but their operators found that signals could not be transmitted along submarine cables as fast as along land lines without becoming confused. (It was the attempt to transmit at normal speed which had led to the jumbled messages along the first Anglo French cable.) The practical men just noted this fact as an annoyance while the scientific men observed that Faraday had predicted some retardation on account of the increased capacitance of undersea cables.

The record of the longer lines was, at best, mixed. Inspite of this an American called Cyrus J. Fields proposed a telegraph line linking Europe and America. Oceanographic surveys showed that the bottom of the Atlantic was suitable for cable laying and by connecting circuits of the existing land telegraph lines people had produced a telegraph line of the length of the proposed cable through which signals had been passed extremely rapidly. The British government offered a subsidy and money was rapidly raised. Contracts were placed and the business of spinning 2500 miles of cable put in hand.

The mechanical problems of laying such a cable were considerable. Airy, the Astronomer Royal stated that 'it was a mathematical impossibility to submerge the cable successfully at so great a depth'. (Airy had a bad track record – he failed to look for Neptune when it was predicted by Adams, he disbelieved Hamilton's prediction of double refraction, he predicted that the Crystal Palace would be destroyed by hail and he advised the designer of the Tay Bridge about wind speeds without taking into account gusting.) However, the laying was in the hands of an engineering genius – Charles Bright – and it was the electrical side which was to cause the worst problems.

Faraday had indeed predicted signal retardation but he and others like Morse had in mind a model of a submarine cable as a hosepipe which took longer to fill with water (signal) as it got longer. The remedy was thus to use a thin wire (so that less electricity was needed to charge it) and high voltages to push the signal through. Faraday's opinion was shared by Morse and by the electrical adviser Dr Whitehouse.

Thomson's researches had given him a clearer mathematical picture of the problem. The current flow in a telegraph wire in air is governed (approximately) by the wave equation

$$c^2\frac{\partial^2\phi}{\partial x^2}=\frac{\partial^2\phi}{\partial t^2}.$$

As we saw in Chapter 64 a pulse $\phi(x,t)=f(t-c^{-1}x)$ travels at a well defined speed c with no change of shape or magnitude with time. Thus signals can be sent as close together as our transmitter can make them and our receiver distinguish them. (Trained operators could manage up to 40 words a minute in Morse code.)

However in undersea cables (of the type proposed) capacitative effects dominate and current flow is governed (approximately) by the heat equation

$$K\frac{\partial^2\phi}{\partial x^2}=\frac{\partial\phi}{\partial t}.$$

We discussed this problem in Chapter 62 ending up with a series of remarks on the nature of the solution for a heat pulse. In particular, looking at statement (5) at the end of Chapter 62, we are led to the following prediction.

(5)′ For a very long submarine cable of length x the main effect of any sent electric pulse will last for a time T seconds proportional to x^2 (and inversely proportional to K).

If we try to transmit a further signal during this time T the two signals will be jumbled up when received. We are thus roughly limited to sending one signal every T seconds. The maximum rate of signalling is thus inversely proportional to the square of the length of the cable (and directly proportional to K). Thus in leaping from submarine cables of 30 miles length to cables of length 1500 miles retardation effects become not 50 times but 2500 times worse. Moreover, contrary to received opinion, increasing the voltage (i.e. increasing the pulse height) would, if anything, make things worse. Finally, since K turns out to be directly proportional to the conductivity, the wire should have as large a diameter as possible.

Whitehouse, whose professional reputation was now involved, denied these conclusions. The shareholders of Field's company were largely British and contained many Glaswegians who voted Thomson onto the board of directors. But even as a director Thomson had no authority over the technical advisers. Moreover the production of the cable was now underway on principles contrary to Thomson's own. Testing the completed cable, he was astonished to find some sections conducted only half as well as others. (This was not due to dishonesty or incompetence, the manufacturers were supplying copper to the then highest commercial standards of purity. The need for really high conductivity had not arisen before the Atlantic cable.) Orders were given for greater care to be taken in future.

Realising that the success of the enterprise would depend on a fast, sensitive detector, Thomson set about to invent one. The problem with an ordinary galvanometer is the high inertia of the needle (which thus requires a large kick to make it swing and a long time to stop swinging.) Thomson came up with the mirror galvanometer in which the pointer is replaced by a beam of light. This marvellous idea so impressed Maxwell as to inspire one of his verses (see Appendix D). The other directors who believed, or hoped, that Whitehouse was right, were polite but not enthusiastic about Thomson's activity on their behalf.

In a first attempt in 1857 the cable snapped after 335 miles had been laid. In 1858 new attempts were foiled by storm and breakages but the company went doggedly on and on 5 August 1858, Europe and America were linked by cable. On 16 August it carried a 99-word message of greeting from Queen Victoria to President Buchanan. But that 99-word message took $16\frac{1}{2}$ hours to get through. In vain Whitehouse tried to get his receiver to work – only Thomson's galvanometer was sensitive enough to interpret the minute and blurred messages coming through. In vain Whitehouse used his two thousand volt induction coils to try to push messages through faster – after four weeks of this treatment the cable gave up the ghost; 2500 tons of cable and £350 000 of capital lay useless on the ocean floor.

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THE TRANSATLANTIC CABLE II

In 1859 you could buy £1000 of stock in Field's company for £30. The submarine cable to India guaranteed by the British Government failed, costing the taxpayer £800 000. Worldwide eleven thousand miles of undersea cable had been laid and only three thousand miles were operating. And in 1861 civil war broke out in the United States.

Yet Field still continued to try and raise interest in his project travelling back and forth across the Atlantic over 30 times (and being sea sick each time). By 1864 things were moving again. Because of the Civil War most of the capital was raised in Britain, half being put up by the firm which was to make the cable. The cable was redesigned in accordance with Thomson's theories. Even more important, strict quality control was exercised: the copper used was so pure that for the next 50 years 'telegraphist's copper' was the purest available.

Once again the British Government supported the project – the importance of quick communications in controlling an empire was evident to everybody. (Before it failed the old cable had carried an order countermanding troop movements which had saved a seventh of the cost of the cable.) Public interest was intense: when Thomson was delayed at his laboratory, the Glasgow London train would be held until he arrived. (Only Thoreau in America and Arnold in England felt that rapid communication was not needed until people had something worthwhile to communicate.)

The new cable was mechanically much stronger but also heavier. Only one ship was large enough to handle it and that was Brunel's *Great Eastern*. Five times larger than any other existing ship she had been built to steam to Australia without refuelling but bad luck and the opening of the Suez Canal had prevented her profitable use and ruined a succession of owners. A separate company was set up to buy her at a knockdown price and lease her to the cable company in return for a shareholding.

But this time there was a competitor. The Western Union Company had decided to build a cable along the overland route across America, Alaska, the Bering Straits, Siberia and Russia to reach Europe the long way round. The Western Union's views on competition were simple. 'The public has been slow to learn how disastrous opposition to the Western Union Telegraph Company has been. Competitive lines cannot make a go of it and they might as well quit trying' (quoted in A.F. Harlow *Old Wires and New Waves*, Appleton Century 1936).

The commercial success of the cable would thus depend on the rate at which messages could be transmitted. Thomson had predicted the problems of the first cable by mathematics. On the basis of the same mathematics he now promised the company a rate of eight or even 12 words a minute. Half a million pounds was being staked on the correctness of the solution of a partial differential equation.

On 23 July, 1865 the *Great Eastern* set sail. All went well for nine days and then, when 1250 miles had been laid, the cable parted. For a fortnight the expedition fished for the cable in two miles of water. Three times they caught and lifted it but each time the lifting gear failed. Leaving a buoy to mark the spot the expedition sailed for home.

Thomson and the other engineers were now confident that the cable would do all that was required, since communication with the home base had been perfect until the final break. They also felt sure that they could recover the old cable. The company decided to build and lay a new cable and then go back and complete the old one. By now Field had tried three times to lay his cable and failed each time, yet the public subscribed half of the £600 000 required within two weeks.

This time all went well. Cable laying started on 12 July 1866 and the cable was landed on the morning of the 27th. On the 28th the cable was open for business and earned £1000. A director's meeting of the Western Union ordered all work on their projected line to be stopped. Their crews had laid 300 miles of cable in Alaska, 350 miles in Siberia, 400 miles in the Canadian waste but all this was abandoned at a loss of $3 000 000.

On 1 September after three weeks of effort the old cable was recovered and on 8 September a second perfect cable linked America and Europe. A wave of knighthoods swept over the engineers and directors. Investors who had seen their shares drop to almost nothing now received a return of 16% (in an age when government stock paid $2\frac{1}{2}$%). Even more importantly the cable manufacturers had established a commanding technical lead – in the next 80 years no less than 90% of all undersea cables were supplied by that one company.

Thomson's knowledge and instruments had contributed greatly to the success of the new industry. In turn the patents which he held made him a wealthy man. He could now indulge his love of the sea from his own yacht. (Though even here he and his friend Helmholtz studied the theory of water waves, '"which", [said] Helmholtz, "he loved to treat as a kind of race between us". When Thomson had to go ashore at Inverary for some hours, as he left he said: "Now, mind, Helmholtz, you're not to work at waves while I'm away" (quoted in S.P. Thompson, p. 614).')

Thomson enjoyed the wealth and fame that his work brought him. (His elevation to the Peerage in 1892 was to leave future generations with the vague impression that there had been three great Victorian scientists called, Thomson, Sir William

Thomson and Lord Kelvin.) But he delighted in technological progress itself and in that fact that '... science has tended very much to accelerate the results, and to give the world the benefit of those results earlier than it could have had them, if left to struggle for them and try for them by repeated efforts and repeated failures unguided by such principles as can be evolved from the abstract investigations of science (speech, on being made a freeman of Glasgow in S.P. Thompson, p. 405).'