W H Bragg & "Sound in War" from the RI Christmas Lectures, 1919.

(Prepared by R. W. Madsen November 30, 2018)

Introduction.

The 84th British Association Meeting was held in Australia in August 1914 with meetings in Adelaide, Melbourne, Sydney & Brisbane. Ernest Rutherford attended & in New Zealand as well, but it appears that W H Bragg (WHB) remained in England. JPVM (John Percival Vissing Madsen) attended meetings in Sydney & there was also the situation of German scientists attending as guests at the time WW1 began on July 28 of that year.

Shortly after the end of the War at the Christmas Lectures at the RI (Royal Insitution-London) in 1919, WHB delivered a series of 6 lectures on "The World of Sound" & published in 1920 including a lecture on "Sound in War"-Lecture VI, which was dedicated to all the juveniles including the grown up variety. The choice of this subject as a Lecture Series by WHB soon after the end of the War would, I believe, have typically represented his approach to let the public know the everyday applications of the principles of sound as well as those which had recently been used not only by himself on submarine detection but also by his son, William Lawrence Bragg (WLB) for sound ranging of artillery used on the Western Front.

With the anti-submarine detection work, WHB worked closely with ER (Ernest Rutherford) who used water tanks in the basement of Manchester University to especially develop improved hydrophones for the RN, & later in the War to work in close co-operation with Paul Langevin in France on Piezo-electric high frequency detection which was followed up by the transfer of technology to the US Navy by June 1917 after the US came into the War.

In July 1915 a Board of Invention & Research (BIR) was set up in London by Arthur Balfour (1st Sea Lord) which consisted of a Central Committee including Lord Fisher as President & J J Thomson which was supported by a Panel of 12 members including WHB, ER & Oliver Lodge: the subjects they considered were submarines, aeronautics, naval construction, marine engineering, internal combustion engines, oil fuel, anti-aircraft, noxious gases & ordnance & ammunition. Over the next 2 ½ years the BIR initiated many projects drawing on the extensive scientific talent in the UK, although the wastage of highly qualified scientists being lost in the trenches was keenly felt, such as Harry Mosely at Gallipoli.

The recognition of the danger to Britain of U-boats was quickly brought home when 3 older British Cruisers (Hogue, Cressy & Abukir-"Live Bait") were sunk on September 22, 1914 by U-9 at the Battle of Heligoland Bight, which was followed by a further cruiser (Hawke) being sunk by U-9 on October 15, 1914. The Lusitania was torpedoed by U-20 on May 7, 1915 demonstrating the extent of unrestricted warfare.

During the War Germany had 329 U-boats, of which 178 were destroyed but had been able to sink approximately 13 million tonnes of shipping (1914: 312,672 T, 1915:1,307,996 T, 1916: 2,327,326 T, 1917: 6,235,878 T, 1918: 2,666,942 T) representing a critical situation in 1917 for Britain & which was dealt with by the use of convoys, aircraft spotting & escorts, sailing at speed & zig-zagging & by the use of depth charges. The torpedoes used by the Germans typically had a range of up to 10,000 yards, a speed of less than 36 knots & carried 350-400 lbs of explosives using wet heater power.

The German U-boat losses increased as the war continued (1916: 48, 1917: 61, 1918: 69).

9. 'Advances in hydrophone technology during World War One were impressive'. Hydrophone drill aboard a drifter. (RUTHERFORD & W.H. BRAGG WORKED ON THIS)

"Sound in War."

Sound is the only suitable means of detecting submarine vibrations of a distance of more than a mile & our ears can be very efficient in recognising different sounds when a mechanical means is set up to collect the sound in water & transferred by a tube to the ear or by electrical means also which is much more flexible. The noise of the ship creates a great difficulty & if a submarine goes slowly the cavitations from the screws is less & through it all there is the beat of the engines. It is necessary to have an instrument which will indicate the direction from which the sound is coming & a "uni-directional" hydrophone was devised which had a baffle plate & air cavity on one side to remove the ambiguity of which side of the hydrophone the sound is coming from.

Apart from submarine detection there was a need to locate enemy guns & the sound of the gun being fired & also the sound of the passing of a high velocity shell were considered. The V shape of a high speed shell travelling at greater than the speed of sound is called by the French an "onde du choc" & the shape of the V changes as the shell slows down & becomes blunted. The simple & highly efficient method finally adopted by the British Army was based on observations of the sound of the explosion due to the gun itself. In practice 6 microphones to give great accuracy & allowing for 1 or more being out of order, were connected by wires to a central station where each was joined up to its own recorder which operated by throwing a fine point upon a kinematograph film. When no disturbance came in from

any microphone, 6 straight lines were drawn side by side on the film, but if the explosive wave of the gun reached a microphone, the corresponding line was broken.

Fig. 91 the record of an enemy howitzer is shown: we observe the successive breaks as the wave reaches the microphones in turn. Very great

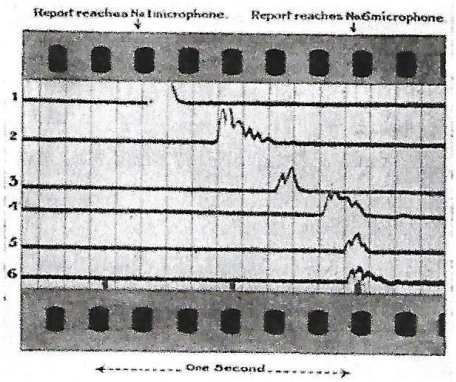


FIG. 91.—A piece of kinematograph film showing the effect of a 15 cm. German howitzer. The horizontal lines are the records made by the recorders, and are unbroken straight lines until the gun-wave arrives. The vertical lines show the time, there being 100 to the second.
(By courtesy of *Nature*.)

accuracy was required in the observations of the time: the film moved rapidly, as we can see by the time scale shown in the figure. In fact, observation could be made to two or three thousandths of a second.

The 6 microphones were spaced along a base about 9,000 yards long & 4,000 yards behind the front line. The central station was placed in a cellar or dug-out some 5,000 or 6,000 yards from the front line & in front of the base were 2 advanced posts at which an observer was stationed & when he heard a hostile gun fired & considered that its record was wanted he pressed a key which set all the apparatus going at the central station & when all the microphones had registered on the film it was developed, fixed, measured & read & in a very few minutes a telephone message would be on its way to our own batteries giving them the enemy position accurate to within 50 yards at a range of 10,000 yards. The sound rangers could work in any weather except when westerly winds blowing towards the guns lifted the sound waves over their heads. Photographic observations from aeroplanes were also responsible for gun location.

A further application of sound on the Western Front was in the use of the binaural technique in tunnelling to determine what activity the Germans were doing with their tunnel building by listening from Allied tunnels.

Ernest Rutherford & Submarine Detection: 1915-1917.

In January 1915 Rutherford was back in England after his trip to Australia & New Zealand during which time WW1 had broken out & unlikely to end soon & by which time his staff & students had been affected by enlistments. On July 19, 1915 the BIR was formed & ER became involved with the committee dealing with submarines & various other subjects of interest to physicists. In September 1915 ER visited Hawkcraig, Fife & observed a hydrophone demonstration & recommended extra support was required & with 2 physicists to be engaged. On September 30, 1915 ER prepared a report for the BIR on "Methods of Collection of Sound from Water & the Direction of Sound" & identified 7 lines of investigation for detecting submarines including: 1).Improve existing methods of detecting submarine sound. 2). Examine the best ways of transmitting external sounds in water. 3). Minimise sound noises from the motion of ships & engines. 4). Look at ship's motion to see how far off a submarine can be detected. 5). Develop methods to determine the direction of ships from their sound. 6). Investigate the nature of vibrations emitted by submarines.

On January 20, 1916 ER wrote another report on "Detection of Enemy Submarines by Acoustical Methods" in which he stated that detection ranges greater than 100-200 feet should be based on sound emitted by the submarine. ER carried out experiments (presumably in the water tanks at Manchester University & at Hawkcraig) on the diaphragm & microphone in hydrophones but both objects' natural resonances made it impossible to analyse the frequencies of submarine propellers & machinery.

ER made a new diaphragm 10 times more sensitive than the Navy diaphragms & then added a baffle to one side so that direction of sound could be determined with one rotatable device. In March 1916 scientists at Hawkcraig wrote a report on the Hervey-Gardner & Sir Ernest Rutherford diaphragms & also one other direction finder designed by ER. In August 1916, WHB wrote to ER: "Apparatus to be attached to your diaphragms on board battleships" & on August 2, 1916 a Patent Office application by ER & WHB was made for an " Improved Apparatus for detecting the direction of sound in water". 1500 special sets of hydrophones were issued to drifters & motor launches.

AMENDED SPECIFICATION.

Reprinted as amended in accordance with the decision of the Law Officer, dated the 30th day of July, 1920.

PATENT SPECIFICATION

Application Date: Aug. 2, 1916. No. 10,887/16. **125,446**

Complete Left: Mar. 1, 1917.

Complete Accepted: Apr. 24, 1919.

PROVISIONAL SPECIFICATION.

Improvements in Apparatus for Detecting the Direction of Sound in Water.

We, WILLIAM HENRY BRAGG, M.A., D.Sc., F.R.S., Resident Director of Research, Hawkcraig Experimental Station, Aberdour, Fife, and Sir ERNEST RUTHERFORD, M.A., D.Sc., F.R.S., Professor, 17, Wilmslow Road, Withington, Manchester, do hereby declare the nature of this invention to be as follows:—

or forming part of the diaphragm, and placed at its centre. One terminal of the microphone is preferably earthed to the ring, the other may be led from the microphone chamber into the iron tube hereinafter described by means of any suitable form of water-tight joint, either on the microphone chamber, or preferably at the end of a thin metal tube forming an

At the end of 1916 WHB's group moved from Hawkcraig , Fife to Harwich where the RN had its submarine & destroyer base, although according to J J Thomson the move had been delayed in the Admiralty who were not keen on Lord Fisher's possible involvement.

By November 1916 co-operative work with the French, in particular Paul Langevin (a former student of JJT & also known to ER from Cavendish days) was started dealing with the "Quartz-piezo electric effect". Robert Boyle, a former student of ER's who ER had brought across from Edmonton to help with submarine detection & acoustics met with Langevin & brought back from France Langevin's 1916 experiments in which he generated high frequency (100 kHz) sound waves using the piezo electric effect in quartz crystals.

By November 1916 ER had told WHB he had " pretty well cleaned up a study of diaphragms & that the quartz piezo effect works like a charm giving a sound that anyone could hear at once in a moderately quiet room" & also that :"It is astonishing how sensitive the ear is, for it is able to detect a movement of the molecules of about 1/1,000 th of a diameter of a molecule".

Boyle was appointed in 1917 to lead the sound-echo team at the Admiralty Experiment Station & the work was top secret & quartz was not to be mentioned- the work eventually became practical but only after they got hold of good quality French electronic valves that could amplify the weak return signals.

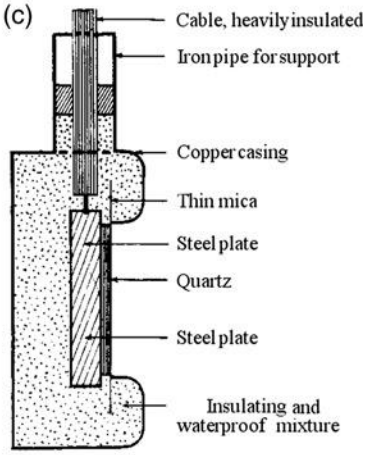
(a)

Paul Langevin
(1872–1946)

(b)

Robert W. Boyle
(1883–1955)

(c)



In April 1917 the US joined the War on the Allies side & promptly a joint Franco-British Mission including Rutherford crossed the Atlantic to acquaint the Americans with all their discoveries in anti-submarine work so as to avoid wasted effort. Rutherford& his group advised the Americans to set up an Experimental Station at the New London submarine base & to bring 10 of the most competent scientists in the country to develop Allied detection devices. Rutherford advised BIR to transfer further information to the US.

W H Bragg.

The Admiralty Experimental Establishment Station (June 1915-1918) was located at Hawkcraig Point in the Firth of Forth village of Aberdour, Fife (HMS Tarlair) & was the Navy's main hydrophone research & training base. The Navy work at Hawkcraig was under the command of Capt. C P Ryan RN who worked jointly with the BIR experiment station at Hawkcraig headed for a time by WHB from May 1916. Separate to the hydrophone work, Bragg was able to provide leadership in having a number of anti-submarine indicator loops installed (these indicator loops had been designed by Alexander C Mitchell with the help from HMS Tarlair-these loops are also sometimes referred to as "Bragg Loops"). In these loops tiny induced voltages from passing vessels were amplified by vacuum tubes but even with this assistance installing a long loop to monitor traffic in the English Channel proved impractical. A notable operational use of the loop was on October 18, 1918 when UB-116 was detected by hydrophones entering Hoxa Sound, Scapa Flow & was sunk in a remotely controlled minefield.

Late in 1916 Bragg's group moved to Harwich so that scientists & sailors could be in close contact & it appears they soon became acutely aware of the noise from a ship when in motion & this entailed further experimentation to deal with the problem. In 1917 & 1918 Bragg was assisted by Alexander Rankine working at Aberdour & then at Harwich & also Arthur Eve who worked at Harwich in 1917-18. In January 1918 WHB moved into the Admiralty as head of scientific research in the anti-submarine division & by War's end British vessels were being equipped with sonar using quartz mosaics.

W L Bragg (1890-1971).

Lawrence's younger brother Robert, died at Gallipoli on September 2, 1915.

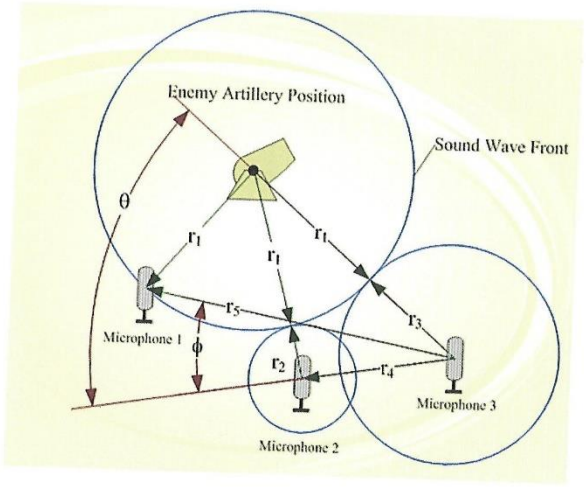
WLB enlisted early in the War with the Royal Horse Artillery & then was seconded in 1915 into the Royal Engineers to help develop a method to localise enemy artillery from the boom of their firing. The apparatus devised became known as the "hot wire air wave detector" & was developed with other scientists, William S Tucker, Charles G Darwin & Harold R Robinson.

WLB was in command of the Experimental Sound Ranging Station at Kemmel Hill in Belgium (On April 25, 1918 Kemmel Hill became the site of ferocious fighting in the Fourth Battle of Ypres as the Germans tried to force their way to the North Sea. It was recaptured by the Allies in late September, 1918).

William Tucker (1877-1955) invented a "hot wire" microphone capable of identifying the shell sound wave & the following report of the gun that fired it. A break through had come from WLB who found that the W.C (Water Closet!) at the farmhouse where he was billeted allowed him, once seated inside, to detect sound & pressure differences of shell waves & gun waves as they passed overhead. Tucker researched how to cool platinum wire with air currents caused by the sound waves they were detecting & he also noticed something unusual in that in his billet there were 2 mouse holes by his bed & he noticed a draught of cool air whenever the gun –wave arrived. Tucker devised a microphone consisting of a thin, electrically heated wire, stretched over a small hole in a container (he used rum jars) & recorded by a galvanometer the decrease in the electrical resistance of the wire as the gun wave struck. The rapid oscillations of the shell waves had almost no effect on the wire, whilst the gun reports resulted in well defined "breaks" on the cine film used as a detector. By September 1916 Tucker's new microphones had been supplied to all sound ranging sections & further improvements were made in 1917 to allow for poor weather conditions.

Hot wire ranging was used in WW2 & WLB acted as a civilian adviser.

During WW2 in London 1941, JPVM was in close contact with WHB (daily at the RI) & WLB at Cambridge.


Enemy Artillery Position
Sound Wave Front
θ
r1
r1
r1
r5
r3
Microphone 1
ϕ
r2
r4
Microphone 3
Microphone 2